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ANALYSIS OF ENERGY RESOURCES AND PROGRAMS OF THE SOVIET UNION AND EASTERN EUROPE. APPENDIX E: OTHER HYDROCARBONS AND ENERGY SOURCES

George D. Hopkins, et al

Stanford Research Institute

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ANALYSIS OF ENERGY RESOURCES AND PROGRAMS OF THE SOVIET UNION AND EASTERN EUROPE

Appendix E: Other Hydrocarbons and Energy Sources

Stanford Research Institute

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The objective of this study was to conduct an analysis of the energy resources and programs of the Soviet Union and Eastern Europe and their relationship to the rest of the world. A survey was made of energy development technology which included exploration, development, production, distribution, storage and utilization of energy and new forms of energy. Also, an appraisal was made of recent resource recovery and research and development of energy conversion technology, distribution, and utilization (Over)

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efficiency. The economic aspects of energy developments and use were discussed as related to patterns of consumption, trade, and the Gross National Product of the Soviet Union and Eastern European countries. The overall energy supply and demands of these countries were projected to the 1980 and 1990 time frames. Finally an analysis was made of the Soviet political/military/energy strategy policies relative to the economic impact on Eastern and Western Europe.

This appendix discusses oil shale, peat, geothermal and uranium resources of energy in the Soviet Union and Eastern Europe.

ANALYSIS OF ENERGY RESOURCES AND PROGRAMS OF THE SOVIET UNION AND EASTERN EUROPE

Appendix E: Other Hydrocarbons and Energy Sources

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I OIL SHALE

A. Geology of Eastern European Oil Shale

Oil shale is actually not shale, and does not contain oil. It is, instead, a fine-grained, compact, laminated sedimentary rock that contains kerogen, an organic high-molecular weight mineraloid of indefinite composition. Although oil shale has some properties common to both petroleum and coal, it is distinct, representing an intermediate or transitional stage in hydrocarbon accumulation and evolution.

The general geological consensus is that oil shale was deposited largely at the bottoms of quiet lakes and lagoons containing large quantities of nearly fresh water. However, oil shales were formed in many different geological times and in a range of geographic and physiographic environments.[1] As a result, the degree and effectiveness of complex geochemical processes varied, and consequently the chemical composition of kerogen in oil shales varies greatly. Particularly variable are the contents of nitrogen and sulfur. Most of the sulfur is in the form of iron sulfides and gypsum, although some sulfur is combined with the organic matter.

Organic material is common in almost all types of sedimentary rocks.[2] With increasing amounts of organic matter, some sedimentary rocks grade into oil shales, and others grade into coal seams. Oil shales show that organic material is collected and preserved at much different rates in succeeding strata or sections of strata. Oil shales are generally thin-bedded, occurring intercalated with other sedimentary horizons. Although they represent sharp changes in deposition character, oil shales must be originated through long term rhythmic changes in the deposition; in this respect, they appear to be the result of processes similar to that which resulted in coal seam formation.

The organic portion of oil shale ranges from 10 to 40 percent, and the oil yield ranges from 2 to 24 percent. The geochemistry of oil shales differs from coals in that organic matter is closely associated with the mineral mass. Oil shale quality is closely dependent on the source organic matter as well as on the conditions of its diagenesis and interaction with the sediments. The character of oil shales is also influenced by the successive alterations experienced subsequent to deposition; since the deposits cover a range of ages, this also contributes to the variability in quality.

Generally speaking, older oil shales have higher yields of oil than more recent deposits. However, lesser oil yields are found in metamorphosed deposits, owing to escape of the parts of the hydrocarbon fractions. For this reason, oil shales seem to be of little importance in much of Eastern Europe, especially in countries that have experienced severe Alpine folding. Although oil shale deposits occur in Bulgaria and Czechoslovakia, these resources are small in comparison to those of the USSR. The deposits are not well-known, and therefore it is difficult to arrive at an independent assessment of resources or recoverable reserves. Table E-1 summarizes available data for these countries.

Bulgaria has moderate-sized deposits near Bresnik, where about 125 million barrels of shale oil are inferred. Other deposits that are less well-known occur in the vicinity of Sofia, Kustindil, Radomir, Vratca, Stdra Zagora, Kazanlik, and Gorna Djoumaya; no resource estimates are available for these deposits. Probably, however, Bulgarian oil shale will be limited to relatively small scale, local uses.

Table E-1

OIL SHALE RESOURCES
OF EASTERN EUROPE

	Bulgaria	Czechoslovakia
Geological age		Permian
Thickness (feet)	9-150	<1
Grade (gallons/ton)	34	50
Inferred resources (million barrels)	125	*
Association deposits	Coal	Coal

---

* Unknown

Source: Jaffe, Colorado School of Mines.

Czechoslovakia has small oil shale deposits in the Kladno Basin associated with coal deposits, as well as in the western Bohemian region. These deposits, however, are quite small and unlikely to be developed, other than to meet local needs.

B. Geology of Oil Shale in the USSR

A brief description of the geology of oil shale in the USSR is given below.

1. Siberia

The oldest platform-type oil shale deposits of the USSR are in Siberia. This area covers about 150,000 square kilometers. The oil shale sequence is of Lower Cambrian age and is about 25 to 90 meters thick. The producing formation is mainly marine limestones and shales, with varying contents of organic matter. Most oil shales have thicknesses of about 1 to 2 meters.

2. Baltic Basin

The most important oil shale resources occur in this area. There are two shale formations, both of Ordovician age. The Baltic oil shale area covers about 4,000 square kilometers. The rocks of this area are mainly carbonate rocks, with oil shale deposits interbedded with marl and limestone. Structures associated with oil shale occurrences are complex, associated with fractures and karst topography, which complicate mining operations.

3. Russian Platform and Urals

In this region the oil shale comprises a horizon in the Devonian sedimentary sequence. However, the oil shale is not of good quality, although the total resources appear to be large.

4. Kazakhstan

Oil shales occur in clastic sediments in Kazakhstan. In this area, the oil shale is about 1.5 meters thick and is included in a sequence of folded sediments. Younger deposits of Upper Paleozoic age also occur in this region.

5. Kuznetsk Basin

Oil shale beds of Devonian age occur in the Kuznetsk Basin. In this basin the oil shale is interbedded with shale, and the beds are persistent over large areas. The oil shale occurs in fairly thick beds (5 to 17 meters) that are sufficiently close to the surface to permit surface mining.

Oil shale deposits of more recent geological ages occur in Central Asia and elsewhere in Siberia. For the most part, these deposits are relatively small and low grade, although they are not well-known. While the resources in these deposits may appear to be great, their small size, lower quality, and remoteness from centers of industry will probably relegate them to lesser positions compared to the oil shale deposits of the European USSR.

C. Oil Shale Resources of the USSR

The oil shale of the USSR is significant not because of its quality or quantity, but because of the locations of major deposits in areas lacking other fuels. Oil shale represents an important local fuel in the Baltic area and in the Middle Volga region.

Table E-2 presents estimates of the oil shale resources of the USSR. There are five principal oil shale regions; Baltic, northern and eastern Russian platform, Kazakhstan, Kuznetsk Basin, and eastern Siberia. Estimated "geological reserves" (remaining resources in place) as determined in 1955 and 1968 are shown. In nearly every case (except for Siberia), the amount of estimated resources has declined in the most recent estimate, with the total tonnage of Soviet oil shale being "only" 140 billion metric tons.

Still, these resources remain ill-defined. Only about 5 percent are proven, with another 15 percent considered probable; four-fifths of the total estimated resources are classed as possible, and their actual magnitude remains uncertain. Furthermore, nearly three-quarters of the possible resources are located in the remote regions of Siberia (Figure E-1). Even if these resources were better known and could be developed, it seems likely that they would be of lesser importance than the more sizable deposits of oil, gas, and coal that occur in Siberia. The best known

Table E-2

OIL SHALE RESOURCES OF THE USSR
(Million Tons)

Region	(1) "Geological Reserves"* 1/1/55	(2) "Geological Reserves" 1/1/68	(3) "Minable Reserves"† 1/1/55	(4) SRI Estimate Resources in Thick Beds @ 20% x (2)	(5) SRI Estimate Recoverable Reserves @ 50% x (4)
Baltic					
Estonia	14,477	8,400	10,463	1,680	840
Gudov	5,242	2,900	3,551	580	290
Chudov	711	-	206	-	-
Total	20,430	11,300	14,220	2,260	1,130
N and E Russian Platform					
Izhem	6,800		6,350		
Sysolsk	5,401	10,000 (est)	5,401	2,000	1,000
Kostroma	48		42		
Volga Region					
Kirov	354		-		
Chuvash	15	1,500	-	300	150
Murdov	1		-		
Tatar-Ulyanovsk	1,036		1,029		
Kuibyshev-Saratov	4,551	2,800	3,972	560	280
Total	18,206	14,300	16,794	2,860	1,430
Kazakhstan					
Kenderal	4,000	3,600	698	720	360
Baikhozhin	17	-	7	-	-
Total	4,017	3,600	705	720	360
Kuznetsk Basin					
Barzasski	1,500	238	500	48	24
NE Siberian Platform	111,000	111,000	22,000	22,200	11,100
Total	156,000	140,200	55,000	28,088	14,014

* J. A. Hodgkins, Soviet Power, (Prentice-Hall, Inc., Englewood Cliffs, N.J., 1961).

† V. A. Kutlukov, Geology and Prospects of Studies of Oil Shales in the USSR, UN Symposium on the Development and Utilization of Oil Shale Resources, Tallinn 1968.

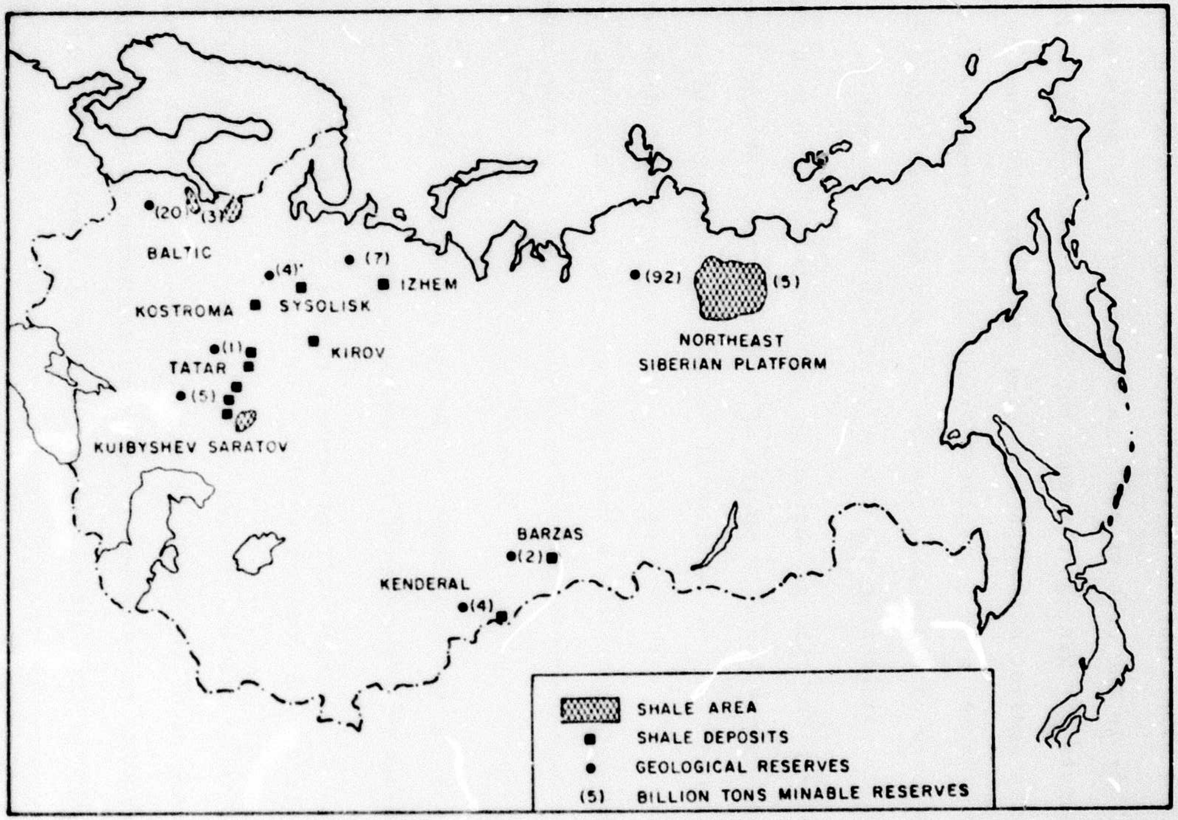

Figure E- I

GEOLOGICAL RESERVES OF OIL SHALE AND ENERGY POTENTIAL OF MINABLE SHALE IN THE USSR and highest quality oil shale resources are those of the European part of the USSR. The Baltic and Middle Volga regions, deficient in other fuels, are fortunate to have the highest quality oil shale deposits.

Table E-2 also shows Soviet-estimated "minable reserves" of oil shale as of 1955. As in the case of coal, this term refers to deposits that might be targets for mining, and does not imply a recoverability factor. Because of the smaller estimated remaining resources determined in 1968, the minable reserves must be revised accordingly.* Attempting to arrive at a new estimate of oil shale reserves, we have employed recent data for the deposits in calculating the amount likely to be recoverable.

In constructing this new estimate, we have relied upon USSR oil shale data that were presented in a series of papers at the 1968 U.N. Symposium on the Development and Utilization of Oil Shale Resources held in Tallinn, Estonian SSR. Data were derived from a number of papers by different authors representing different institutes and agencies, and this variety may have introduced errors of unknown amount into the analysis; however, any such errors are believed to be small.

In discussing the development of Baltic oil shales, Gazizov[3] noted that the balance of resources of the operating pits and mines

> ". . . comprise only 14 percent of the total balance resources of the categories $A+B+C_1$, of the basin."

Gazizov goes on to discuss changes in oil shale thickness and quality toward the margins of the basin. Shale deposits ". . . which have been earlier considered to be rather prospective are found to be non-standard in accordance with the data of the preliminary prospecting." That is,

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* Note that for the Baltic region, the latest estimated remaining resources are less than the earlier minable reserves.

they are not suitable for development. Allowing for the fact that exploration may have been incomplete and that further work may lead to discovery of more promising oil shales, it is assumed that up to 20 percent of the resources in place may be of sufficient thickness and quality to permit efficient operations. Applying this factor to the 1968 estimated remaining resources, we found that about 28 billion tons of oil shale occur in thick beds suitable for development (Table E-2, column 4). However, nearly four-fifths of this resource is in Siberia, and the most likely developments of the near term will occur only in the European sector.

Not all the remaining resources will be recovered. Gazizov states that "mining losses" range from about 50 percent in underground mining to about 30 percent in surface operations. In the Baltic shales, fracturing and karst conditions greatly complicate mining, and influence the recovery of mined shale. In this analysis, we assume that only about 50 percent recovery will be achieved; in certain areas where surface mining can be practiced, this assumption may be over-conservative. Applying this factor to the remaining resources in thick beds, we estimate that about 14 billion tons of recoverable oil shale occur in the USSR. Only about 2.5 billion tons occur in the European sector, and only about 1 billion in the Baltic region, where previous developments have been concentrated. Therefore, it seems unlikely that oil shale would become other than a local fuel that is used to supplement energy supplies.

The above estimate of recoverable oil shale reserves may be checked against a more complete estimate according to reserve categories (Table E-3). This table shows that the total estimated resources in Categories $A + B + C_1 + C_2$ is about 16 billion tons. However, this estimate excludes the deposits of the northeast Siberian platform that represent the bulk of the oil shale resources of the USSR, and therefore these

Table E-3

OIL SHALE RESOURCES OF THE USSR BY RESERVE CATEGORIES - JANUARY 1, 1964
(Million Tons)

	A+B	C_1	C_2	Total
RSFSR	1,316	1,251	5,131	7,698
Leningrad	422	698	1,956	3,076
Kostromsk	1	5	36	42
Kuybyshev	403	326	1,895	2,624
Ulyanousk	33	15	112	161
Saratov	108	36	2	146
Orenburg	309	67	457	833
Kemerovsk	34	8	90	132
Irkutsk	-	91	-	91
Baskor SSR	5	6	32	43
Komi SSR	-	2	550	552
Estonia	1,963	1,969	4,667	8,599
Kazakhstan	8	46	164	218
Kirgiz	2	20	43	65
Taozik	1	3	26	30
TOTAL	3,290	3,289	10,031	16,610

data are not comparable with the SRI estimated total recoverable reserves presented in Table E-2. In order to compare these data, the Siberian resources must be excluded, and the data are as follows:

SRI estimated recoverable oil shale reserves exclusive of Siberia	2.9 billion tons
Soviet estimated resources in Categories A + B	3.3 billion tons

The difference in these estimates is small (less than 10 percent). Thus, it seems reasonable to expect that the oil shale reserves of the USSR will be about 3 billion tons, most of which are in the European sector.

D. Oil Shale Production and Use in the USSR

Although the mining of oil shale is of lesser importance relative to the overall fuels economy of the USSR, the unique nature of its use warrants a brief look at this resource. Oil shale accounted for approximately 0.7 percent (on equivalent fuel basis) of the total fuels production in the USSR in 1970.[4] It is, however, of major importance as local fuel in Estonian SSR and in the region of Leningrad. In 1970 it accounted for 60 percent in the fuels balance of Estonia.[5]

The major production of oil shale occurs in the Estonian SSR and the Leningrad and Volga regions of RSFSR. The Leningrad deposits (Gdov) are essentially the continuation of the Estonian (Baltic) deposits, having the same hydrocarbon composition and varying only in the amounts and type of mineral content.[6] Production at other known deposits has not begun or has been terminated on economic grounds. Table E-4 covers the historical production trends.

The production in 1970 amounted to 24 million metric tons, with approximately 18.9 million tons produced in Estonian SSR. The Soviet plans call for production to increase to 32.7 million tons by 1975,[7] of which 26 million tons are to be accounted for by production in Estonia.[8]

The shale deposits of Estonia and the Leningrad region lie in horizontal seams about 3 meters (approximately 10 feet) thick, at depths of 6 to 90 meters (20 to 300 feet) and have been mined by traditional methods employed by the coal industry. Both deep shaft mining and open seam mining are used. The open seam mining methods are currently favored, on economic grounds, with most of the planned production growth to be

Table E-4

OIL SHALE PRODUCTION IN THE USSR FROM 1940 to 1970
(Thousand Metric Tons)

		RSFSR					
Year	Total	Total	Leningrad	Volga	Kuybyshev	Estonia	Kazakh SSR
1940	1,683	734	404	330	201	947	2
1945	1,384	512	--	512	250	860	12
1950	4,716	1,156	347	809	412	3,543	17
1955	10,793	3,782	2,068	1,715	1,170	7,010	-
1960	14,147	4,901	3,480	1,421	1,422	9,246	-
1965	21,259	5,425	4,145	1,280	1,280	15,834	-
1966	21,374	5,342	4,171	1,141	1,141	16,062	-
1967	21,601	5,478	4,259	1,219	1,219	16,123	-
1968	21,868	5,420	4,276	1,144	-	16,448	-
1969	23,020	5,515	4,343	1,172	-	17,505	-
1970	24,319	5,417	n.a.	n.a.	-	18,902	-

n.a. - not available.

accounted for by this method. Open pit mining is practiced in the Baltic region only (Estonian SSR), as is evident from the reported regional production and mining methods statistics in Table E-5.

Table E-5

MINING METHODS FOR OIL SHALE IN THE USSR
(Millions Tons per Year*)

Mining Region and Method	1965	1971	1975 (Plan)
USSR - total	21.2	25.3	32.7
Open pit mining	3.3	8.0	13.0
Deep shaft mining	17.9	17.3	19.7
RSFSR - total	5.4	5.3	6.7
Open pit mining	-	-	-
Deep shaft mining	5.4	5.3	6.7
Estonian SSR - total	15.8	20.0	26.0
Open pit mining	3.3	8.0	13.0
Deep shaft mining	12.5	12.0	13.0

* Compiled from statements and statistics in:

1. N. V. Melnikov, Mineralnoe toplivo, "Nedra," Moscow 1971.
2. Ugol, No. 12, p. 28, 1972.
3. A. P. Petrov, "Prospects of Development of the USSR Oil Shale Industry," Tallinn 1968.

The reported costs and productivity of oil shale mining have been improved because of expansion and modernization of deep shaft mining and wider introduction of open pit mining methods. The reported monthly productivity of a worker in the Estonian shale industry is 160 tons for deep mines and 500 tons for open pit mines,[9] while his counterpart's productivity in the coal industry is 50 and 329 tons, respectively.[10] The reported production cost of one ton of Estonian shale is 2.5 rubles, which is justification enough for using it as local fuel rather than relying on coal, gas, and oil, which have to be delivered from other regions. The reported cost of hard coal delivered in Estonia is 18 to 20 rubles per ton.[11] The reported cost of mining oil shale is the same as for coal, if referred to the same calorific value.[12] The growth in productivity in the oil shale industry can be seen below in Table E-6.

Table E-6

AVERAGE MONTHLY PRODUCTIVITY OF A WORKER IN THE USSR OIL SHALE INDUSTRY
(Metric Tons)

Producing Region	1950	1955	1958	1965	1968	1969
USSR - total	34.8	55.7	71.4	116.8	128.0	137.0
Leningrad region	26.8	47.2	58.5	89.0	89.9	93.0
Volga region	25.9	43.8	54.8	66.3	71.6	78.3
Estonian SSR	41.0	67.0	80.6	133.7	153.3	164.6

Source: N. V. Melnikov, Mineralnoe toplivo, Pub. "Nedra," p. 142 (Moscow 1971).

The estimated capital investment required to expand production of oil shale by 1 ton was reported to be 14 rubles in 1970.[13] This would imply that to expand production to the planned 32.7 million tons per year by the end of 1975 would require a total investment of 118 million rubles for this current five-year plan (1971-1975).

The uniqueness of oil shale use in the USSR is that it is used directly as fuel in the boilers of electric stations. Approximately two-thirds of all oil shale produced in the USSR in 1970 was burned in electric stations. Table E-7 shows the growth in usage of oil shale in electric stations of the USSR.

Table E-7

USE OF OIL SHALE IN THE USSR AS FUEL FOR ELECTRIC STATIONS (Million Tons per Year)*

	1960	1965	1970	1975 (Plan)
Total production	14.1	21.2	24.3	32.7
Used in electric stations	4.7	10.3	16.0	24.4
Percent of total	33%	49%	66%	75%†

---

* Calculations based on reported consumption and production data: Narodnoie khoziaistvo SSSR v 1970 g. Pub. "Statistika," p. 183 (Moscow 1971); Energetika SSR v 1971-1975 godakh, Pub. "Energia," p. 171 (Moscow 1972).

† Assuming all new shale is to be used in electric stations.

The mined shale contains 30 to 40 percent of organic matter, with a heat of combustion averaging 2,150 to 3,600 kilocalories per kilogram (Kcal/kg). These characteristics make the shale somewhat analogous to low grades of brown coal. However, unlike coal, it contains appreciable quantities of hydrogen and oxygen, and on burning, causes formation of compounds leading to equipment corrosion. The high ash content, if burned directly in boilers as is done in the USSR, causes extreme wear of equipment and high particulate emissions. This problem has apparently been solved in the Soviet electric stations through lengthy experimentation in boiler, dust collector, and filter design. At present most of the power stations in Estonian SSR and some in the Leningrad region are working exclusively on oil shale. The recently completed "pre-Baltic" station, which has an installed capacity of 1,624 megawatts (MW), is designed to burn shale with a calorific value of 2,000 Kcal/kg. Another station, the "Estonian," designed for shale, is being built now with an ultimate capacity of 1,600 MW.

Although the burning of oil shale in electric stations is less efficient and equipment replacement is more costly than in similar plants working on coal, the production costs of electricity are lower. It is reported[11] that the cost of production at the "pre-Baltic" station is 0.0071 rubles per kilowatt-hour (kWh). This is lower than for similar regional stations working on coal that has to be delivered from other regions.

The balance of the oil shale is being used for production of town gas and liquid products. This sector is unlikely to grow in the future unless use is made of the reported new methods developed for multiple use of shale. In this method, shale is processed in a fluidized bed at high temperature with a heat carrier. A high calorific gas is produced simultaneously with liquid product and clinker, which is usable in the construction industry. The gas and liquid product, after cleanup and refining, could be used as relatively clean fuel in electric stations or as petrochemical feedstocks. This development is worth watching, as it may supply answers to use of the oil shales in the United States. It appears, however, that the development is still in a highly experimental stage and is unlikely to be commercialized in the near future.

Processed shale from which hydrocarbons have been removed is used for production of building materials.

As already mentioned, direct use of shale as a fuel is made difficult because of the high ash content, sulfur content, and corrosion and scaling on boilers. A further difficulty is that the maximum capacity of power plants using Baltic oil shales is limited by the need to control emissions of particulates and sulfur oxides.[14] In addition to emissions from plants (which may be up to 20 times the maximum permissible normal--0.5 mg/ milligrams per cubic meters SO_2), shale stored in stockpiles is subject to spontaneous combustion and this leads to further air pollution. Burning dumps ". . . evolve into the atmosphere great amounts of smoke containing dust as well as toxic gases. . ." Attempts to control this situation have included changing dump practices and changing procedures to reduce the content of shale fines.

II PEAT

Peat consists of partly decayed vegetable matter, inorganic materials, and water in varying proportions. It is often considered to represent an initial stage in the process of coal formation; under favorable geological conditions, peat may be ultimately transformed into coal. There is considerable variation in the characteristics of peat deposits, and especially in the physical properties of the peat itself. Differences are related to varieties of plants from which peat is formed; climate; water-land regime; and quantity of sediment deposited in the locality of peat occurrence. These differences in peat character are reflected in its quality and consequently in its prospective use.

All known peat bogs of the USSR are post-glacial in age, or about 13,000 years old. Clearly, the process of alteration of vegetable matter has barely begun. Still, there are important deposits in the USSR that are used extensively.

By Soviet standards, only bogs meeting the following criteria are considered commercial:

- Thickness of at least 1 meter.
- Less than 2 percent of peat volume comprised of undecomposed stumps.
- At least 20 percent decomposition for all vegetal matter.
- Less than 23 percent ash.
- Non-permafrost soil conditions.

Estimated peat resources of the USSR are presented in Table E-8 and in Figure E-2. A total in-place resource ($A + B + C, + C_2$) of 124 billion

Table E-8

ESTIMATED PEAT RESOURCES OF THE USSR - JANUARY 1, 1966
(Billion tons)

Republic	A+B	C_1	C_2	Total
RSFSR	7.2	10.9	93.6	111.7
Belorussia SSR	1.5	1.9	2.0	5.4
Ukraine SSR	0.4	0.7	1.2	2.3
Estonian SSR	0.1	0.7	1.1	1.9
Latvian SSR	0.3	0.9	0.4	1.6
Lithuanian SSR	0.2	0.4	0.4	1.0
Others	0.05	0.05	-	0.1
Total	9.75	15.55	98.7	124.0

Source: "Energy Resources of the USSR."

tons is estimated to be present. Almost all of this resource occurs in the Russian Soviet Federated Socialist Republic (the largest administrative subdivision); Table E-9 presents a more detailed breakdown of estimated resources for the RSFSR.

Although the total resources are quite large, the estimated recoverable reserves are more modest. Assuming that the A + B categories reported by Soviet sources are roughly equivalent to recoverable reserves, only about 8 percent of the total peat deposits of the USSR may be expected to support development. The predominant peat developments of the past have been in the European part of the USSR, and this pattern is likely to persist in the future. The largest proved reserves are in the Leningrad region, closely followed by the Moscow region. Other important deposits occur at Upper Volga, Middle Urals, and the Volga-Viatskiy regions.

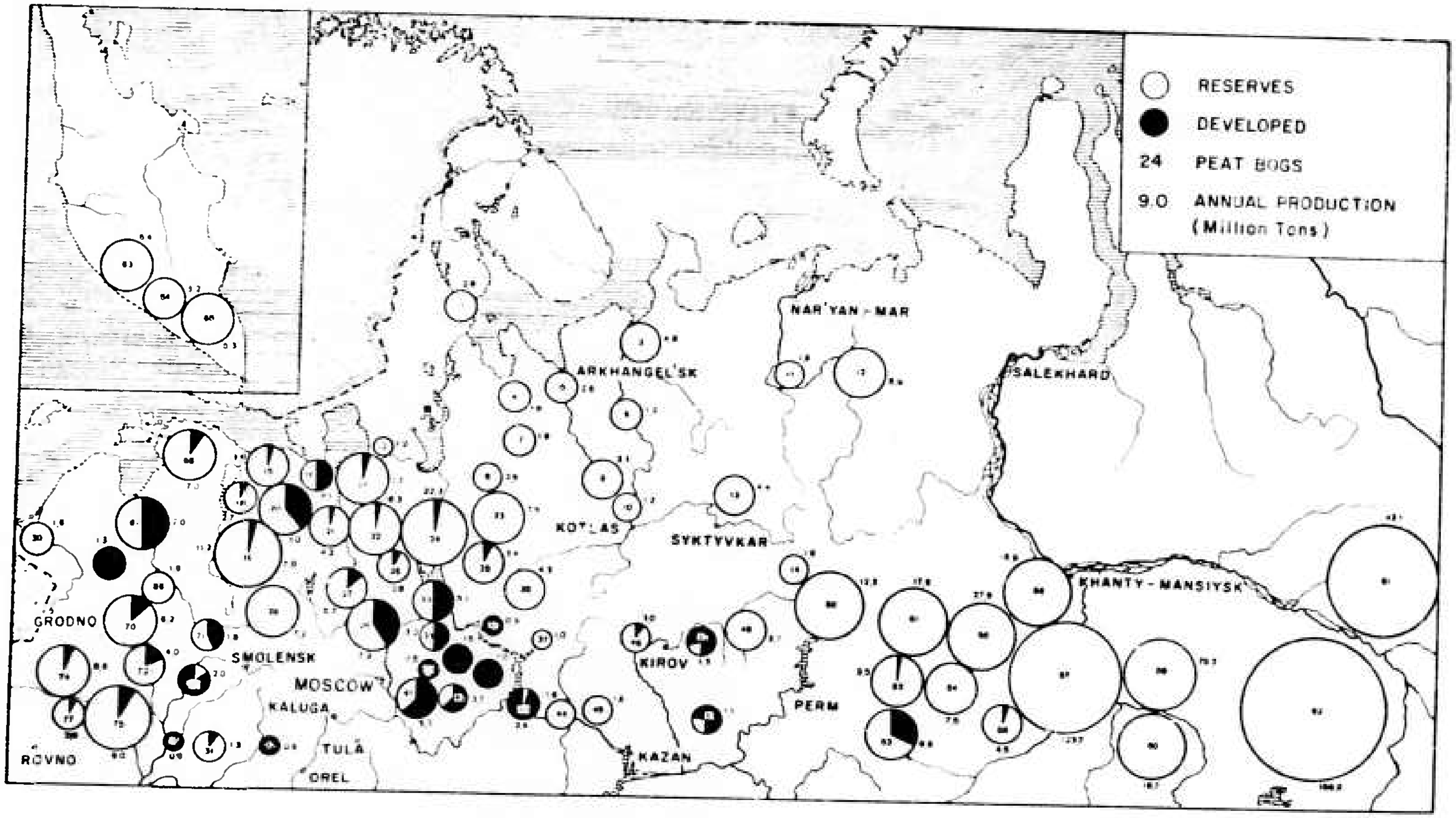

Figure E-2
DISTRIBUTION OF PEAT BOGS IN THE USSR

Table E-9

EXPLORED AND CURRENTLY DEVELOPED PEAT RESOURCES OF RSFSR, BY ECONOMIC REGION (as of January 1, 1963)
(Million Tons)

Economic Region*	Total	A + B million tons	A + B percent	C_1 million tons	C_1 percent	C_2 million tons	C_2 percent	Developed million tons	Developed percent
RSFSR Including:									
Upper Volga	1,273.0	905.8	71.0	312.4	24.5	54.8	4.5	490.0	39.0
Volga Viatskiy	1,390.0	703.4	50.6	457.4	32.8	230.0	16.6	262.0	19.0
Eastern Siberia	132.1	0.9	1.0	-	-	131.2	99.0	-	-
Far East	1,488.7	26.0	2.0	806.4	54.0	656.3	44.0	-	-
Western Siberia	36,057.6	53.8	0.1	1,852.2	5.2	34,151.6	94.7	-	-
Western Urals	1,258.4	231.2	18.5	124.6	10.0	902.6	71.5	0.1	-
Kami ASSR	1,611.5	19.1	1.0	229.4	14.0	1,363.0	85.0	31.0	3.0
Krasnoyarsk	3,725.0	9.3	0.3	218.4	5.7	3,497.4	94.0	-	-
Kuznetsk	181.3	35.7	20.0	90.4	50.0	55.2	30.0	-	-
Leningrad	9,311.9	2,023.5	22.0	4,222.6	45.0	3,068.2	33.0	-	-
Moscow	2,676.8	1,612.5	60.0	678.8	26.0	385.5	14.0	710.0	7.7
Murmansk	654.3	5.0	1.0	33.3	5.0	616.0	94.0	770.0	29.0
Lower Volga	4.0	2.5	62.5	1.0	25.0	0.5	12.5	-	-
Privolzhskiy	40.7	33.6	82.5	4.4	11.0	2.7	6.5	0.8	20.0
Priokskiy	283.5	188.7	66.5	36.1	12.7	58.7	20.8	8.1	20.0
North Eastern	13.4	3.3	25.0	4.2	31.0	5.9	44.0	88.8	31.0
North Western	4,680.6	194.0	4.0	472.9	10.0	4,013.7	86.0	-	-
Middle Volga	151.5	75.1	50.0	36.1	24.0	40.3	26.0	-	-
Middle Urals	45,295.1	898.9	2.0	3,067.2	7.0	41,329.0	91.0	2.7	2.0
Khabarovsk	707.7	7.8	1.0	81.4	11.5	618.6	87.5	152.6	0.3
Central Chernozlemnii	102.6	87.0	85.0	9.4	9.0	6.2	6.0	-	-
South Urals	137.8	28.5	20.0	70.2	51.0	39.1	29.0	42.7	42.0
								8.2	6.0
Total	111,181.5	7,145.6	6.4	12,808.7	11.6	91,227.2	82.0	2,567.0	2.5

* Economic region boundaries have changed since 1963 and are at present consolidated into 19 regions for all of USSR.

Peat from these deposits is used locally to supplement fuel supplies for home heating and other domestic purposes. Peat production for fuel use from 1940 to 1970 is presented in Table E-10.

Table E-10

SUMMARY OF PEAT PRODUCTION IN THE USSR FOR FUEL USE ONLY (Thousand Metric Tons)

Year	Total (thousand metric tons)
1940	33.2
1945	22.4
1950	36.0
1955	50.8
1960	53.6
1965	n.a.
1970	57.3

n.a. - not available.

III GEOTHERMAL RESOURCES

A. Introduction

Geothermal resources may be considered as being the natural heat of the earth; the energy that may be extracted from such natural heat; and all minerals or other products obtained from naturally heated fluids, but excluding oil, hydrocarbon gas, or other hydrocarbon substances. In a technical sense, geothermal resources are porous rocks containing water (or steam) at elevated temperatures. The heat energy stored in these rocks may be conveyed to the surface by extraction of the associated fluids. Thus, there are two basic components to a geothermal system: (a) a source of heat (high regional heat flow, or local igneous intrusion, or high temperatures and pressures in thick sedimentary deposits), and (b) circulating water.

Geothermal resources represent an emerging source of energy that may in the future contribute to overall energy supplies. For the most part, however, such contributions are likely to be relatively small in comparison to the more conventional fuels, at least for the foreseeable future.

Rocks constituting geothermal reservoirs may be practically of any age or type so long as they are relatively porous and permeable (or sufficiently brittle to sustain open fractures at elevated temperatures). Four types of geothermal resources have been recognized:[15]

1. Normal geothermal gradient and heat flow, such as occur on continental masses and in most ocean basins. The geopressured resources of thick, recent sedimentary accumulations are of

this type. The apparent resources of the Western Siberian basin would be an example.

2. Higher than normal geothermal gradient and conductive heat flow, such as along the world rift zone. The geothermal fields of Iceland would exemplify this type, as would those of the Transcaucasus.

3. Hot spring areas with convective transfer of most of the total heat flow in shallow depths by circulating water and dry steam. Some thermal springs of the circum-Pacific region and the Kamchatka, USSR, area would be examples of this type.

4. Composite hydrothermal systems with both convective and conductive heat transfer, representing a combination of (or intermediate stage between) types 3 and 4, emphasizing hot water. Heat flow to the surface is appreciably lower from these systems than from hot springs. The thermal springs of Czechoslovakia, Poland, and Bulgaria appear to be examples of this type.

Although the thermal waters of Europe have long been employed for recreational or medicinal purposes, only recently has attention been directed toward their possible use as a source of energy. In view of this fact, much basic data on the resources need to be re-evaluated (and in many cases, acquired) so as to achieve an understanding of the actual energy potential from this prospective source. Thus, it is probably premature to attempt to prepare a comprehensive, detailed assessment of geothermal energy potentials, especially for Eastern Europe. However, there is sufficient information on hand to establish the likely framework in which further work will be performed. This practice is regarded as justifiable because it serves to place some limits on the likely locations and dimensions of geothermal resources as an energy source.

Accordingly, the remainder of this section will serve to describe the geothermal situation in the USSR and the COMECON countries as it appears from present information.

B. Geothermal Resources of the USSR

1. Considerations of Geothermal Potential

There have been a number of recent studies of geothermal phenomena and resources in the USSR. Several have been compiled into a useful bibliography.[16] More recent works are given in the references cited, and listed at the end of this report. Examples are references 17, 18, and 19, the latter being a recent review of the characteristics of Soviet geothermal resources and their projected development. Table E-11 presents some of these data.

Considerable activity in geothermal exploration is underway in Dagestan, Chechen-Ingush SSR, Georgian SSR, Kabardino-Balkar, northern Osetya, Stavropol, Krasnodarskiy Kray, Kazakhstan, Kamchatka, Caucasus, Kuriles, and Sakhalin. It has been estimated that the geothermal resources of the USSR have a daily capacity of 22 million cubic meters of hot water and 430,000 tons of steam. This is equivalent to 40 million tons of standard conventional fuels. The 1975 plan is to produce about 15 million cubic meters of hot water and 170,000 tons of steam.[19] Of the total, the geothermal resources at depths of 1,000 to 3,500 meters at temperatures between $50^{o}C$ and $130^{o}C$ have an estimated output of about 8 million cubic meters daily; nearly three-quarters of these resources are at shallow depths (1,000 to 1,500 meters).

Soviet sources state that the heat capacity of currently developed geothermal resources are in the range from 130 Kcal/kg to 170 Kcal/kg; for purposes of this analysis, an average value of 150 Kcal/kg

Table E-11

USSR GEOTHERMAL RESOURCES

Area of Economy	Temperature (Degrees C)	Discharge M^3/DAY	Pressure (atm)	Depth to Water Table (M)	Suspended Impurities (mg/1)	Mineral-ization (g/l)	(pH)	(O_2)	(CO_2)	H_2S (mg/l)	Period of Exploitation Yrs
Thermal Energy											
Electric Power	> 100	10,000	2.5	5,000	5	3(9)	5.5-9.5	0.1(0.5)	10(250)	1(10)	25-30
Cooling	60-90	2,500	1.0	2,500	5	9	5.5-9.5	0.5	50	10	25-30
Town-Building											
Heating	70-90	1,000	1.5	2,500	5	3(9)	5.5-9.5	0.1(0.5)	10(250)	1(10)	25-30
Boiling Water Supply	40-60	1,000	1.5	1,500	5	3(9)	5.5-9.5	0.1(0.5)	10(250)	1(10)	25-30
Air Conditioning	25-50	500	1.0	1,500	5	9	5.5-9.5	0.1(0.5)	0	10	25-30
Reservoirs, Spas	25-40	250	1.0	1,000	10	9(12)	5.5-9.5	-	50(500)	1(10)	25-30
Agriculture											
Hot Houses, Greenhouses, Conservatories	40-70	500	1.0	1,500	5	5(12)	5.5-9.5	0.5(0.5)	50(550)	1(10)	25-30
Heating Soil	25-50	500	1.0	1,000	5	5	5.5-9.5	(0.5)	50	1	25-30
Heated Irrigation	25-50	250	2.0	1,000	10	5	5.5-9.5	-	50	1	25-30

Source: V. A. Stevovich, "Soviet Geothermal Electric Power Engineering -- Report 2", December 1972, NTIS Accession Number AD 754-947.

is used. The heating value of a ton of standard coal equivalent is 7,000 Kcal/kg; therefore, the unit heat capacity of geothermal resources is only about two-hundredths of that of coal.

At present, there are 11 geothermal facilities in operation in the USSR, with a total amount of consumed heat at $1{,}400 \times 10^9$ Kcal/year.* The efficiency of conversion of geothermal energy into electricity or some other usable form is not great, usually of the order of 10 to 15 percent of the total amount of consumed heat.† Therefore, the total amount of usable energy would be of the order of about 140×10^9 Kcal/year. To allow comparison with other energy forms considered in this study, this amount of usable heat may be compared with the heating value of standard fuel or coal equivalent. A kilogram of standard coal is taken in this report to represent 7,000 Kcal, a ton of standard fuel is therefore 7 million Kcal. The usable geothermal heat is thus equivalent to the standard fuel as follows:

$$140\times10^9 \ \frac{\text{Kcal}}{\text{year}} \times \frac{\text{ton}}{7\times10^6\ \text{Kcal}} = 20\times10^3 \ \frac{\text{ton}}{\text{year}}$$

This result suggests that the existing geothermal facilities of the USSR are not of exceptional importance to its overall energy balance. A greatly improved efficiency of heat extraction would be required to increase the amount of equivalent fuel significantly. Although Soviet

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* From reference 19. Original values were given as 200 Gcal/hr. These were converted to annual values assuming 7,000 hours of annual operation.

† See, for example, P. Kruger and C. Otte, "Geothermal Energy," Stanford University Press, 1973.

sources* indicate that geothermal resources represent an equivalent of 125,000 tons of conventional fuel, this figure is regarded as unrealistically high; it would imply a thermal conversion efficiency of roughly 60 percent, which does not appear consistent with the state of the art of geothermal systems.

2. Prospects for Use of Geothermal Resources in the USSR

The USSR has recognized the energy potentials of geothermal resources for some time.[20] In 1964, the Soviet Academy of Sciences estimated that at least 94 million barrels per day of hot water and steam (ranging in temperature from 130° F to 356° F) could ultimately be produced. Attention to the possible use of geothermal resources has increased in recent years, and a number of individual sites have been investigated.[18] The prospective uses of these resources vary from space heating, spas, agricultural purposes, and power generation.

Figure E-3, a map prepared by the Soviet Academy of Sciences, shows areas regarded as promising for thermal water utilization. This map deserves comment:

- Areas shown as "promising for thermal water prospecting" cover a wide range of geological characteristics. In view of the relatively low heat flow and geothermal gradients, it does not seem likely that the northwest area adjacent to Finland would have much promise, and it might be found that the Urals may not be exceptionally favorable. The most promising areas appear to lie in the remote regions along the southern border and in the basins of the European platform.

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* Cited in reference 19.

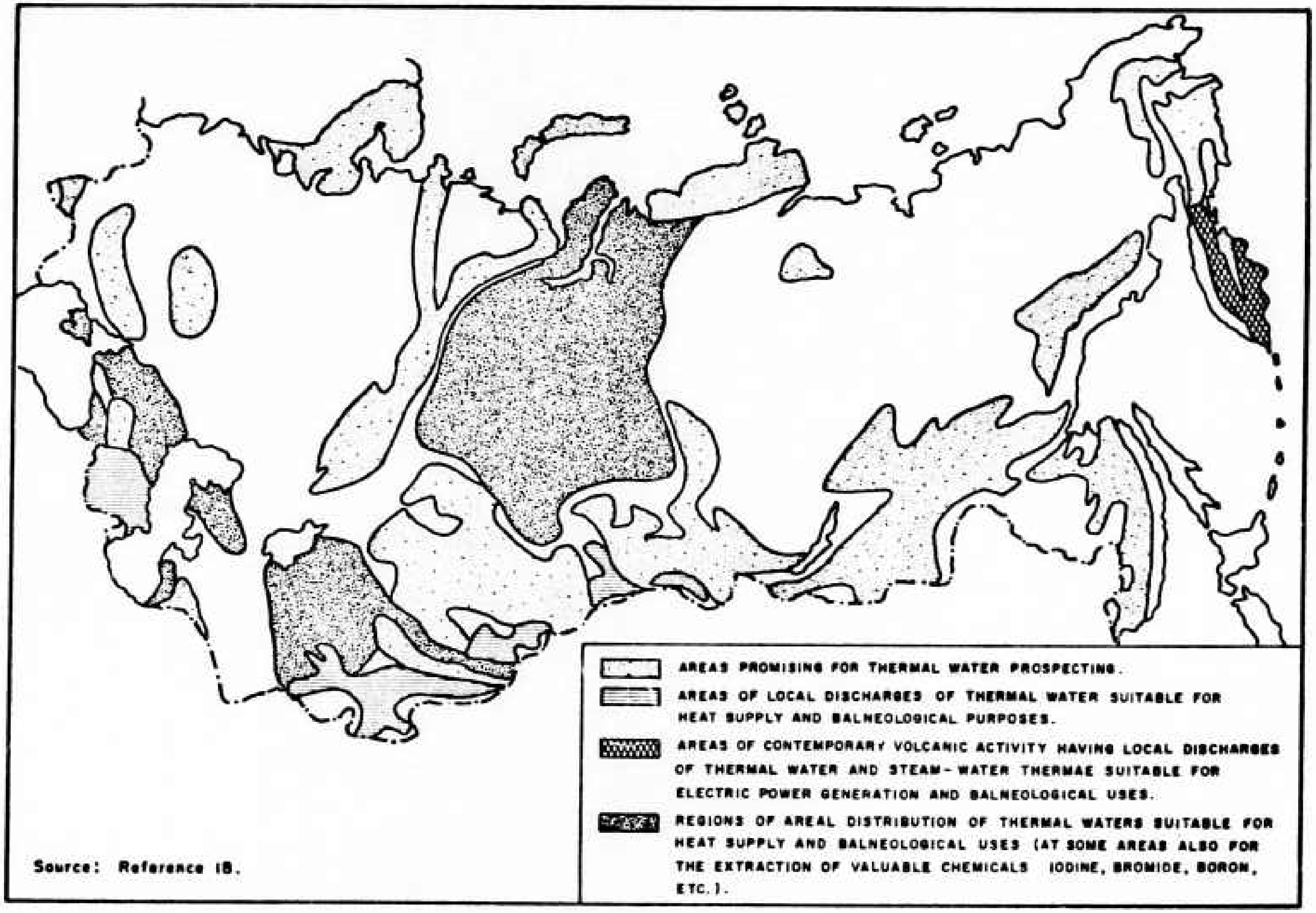


Figure E-3

PROSPECTIVE USE OF THERMAL WATER IN THE USSR

- Areas shown as having local discharges of thermal water are found in the Transcaucasus, where exploration and development are being undertaken. Other areas in this category are in rugged and remote regions of the southern mountains, and are unlikely to experience development in the near future.

- Areas of recent volcanic activity are limited to the Kamchatka Peninsula, where efforts to develop geothermal steam for electric energy generation are in progress.

- Areas of thermal waters suitable for heat supplies are found in the Ukraine, Kazakhstan, and the Western Siberian Basin. These resources seem to be of the geopressured type, although they are quite imperfectly known at present and are essentially undeveloped.

The amounts of thermal water "reserves" of the USSR are given in Table E-12. More than half the total occurs in the western Siberian Basin. As noted elsewhere in this report, the western Siberian Basin has important resources of oil, gas, and coal as well as geothermal waters. The fact that such a variety of energy resources are located together in this area suggests that there may be a genetic relationship among them. The hydrocarbon resources represent each physical state (solid, liquid, and gas), and each is believed to require the application of heat in arriving at their common states. Further, each has experienced a common geological regime. It is intriguing to speculate that the individual fossil fuels may represent products of parts of the same general process, and that this process was intimately involved with the geothermal resources occurring in the area. However, this possibility requires further research.

Table E-12

THERMAL WATER RESERVES IN THE USSR

Province	Estimated reserves (in thousands of cubic meters per 24 hours)	Exploitation reserves (in thousands of cubic meters per 24 hours)	Percentage of total reserves
European part of the USSR	3,025	1,210	15.4
Caucasus and Cis-Caucasus	1,950	780	
Crimea and Cis-Karpatyan region	575	230	
Other regions of the European part of the USSR	500	200	
Soviet Central Asia	1,375	500	7.0
Kazakhstan	1,200	480	6.1
Western Siberia	10,750	4,300	54.1
Eastern Siberia and the Soviet Far East:	3,400	1,360	17.2
Southern part of Eastern Siberia	750	300	
North-Eastern region, Yukutskaya ASSR, The Magadan region (including the national county of Chukotka) and the Khabarovski Krai	900	360	
Kamchatka and the Kuriles*	1,500	600	
The island of Sakhalin	250	100	
Total	19,750	7,900	100

* The Kamchatka Peninaula and the Kuriles Islands, in contrast to the rest of the country, are in the zone of contemporary volcanic activity where in iaolated areas and at shallow depths the thermal waters have the temperature ranging from 80 to 200 C and above.

Source: Tichonov, et al.

a. European Area

The European area of the USSR is characterized primarily by relatively low temperatures at 1 kilometer depth, with large areas of the great plain being from $10^{\circ}C$ to $30^{\circ}C$. These lower temperature regions extend from the Polish border to the Urals over the northern two-thirds of the European part of the country. This large region lacks apparent surface geothermal manifestations such as thermal springs, and the potentials for development do not appear promising, with the possible exception of the suspected presence of geopressured resources in this area.

The southern third of European USSR is a different geothermal situation. Temperatures at 1 kilometer depth in this region are everywhere greater than $30^{\circ}C$. There are extensive areas where the temperatures are greater than $40^{\circ}C$; these are narrow, east-west zones along the northern part of the Black Sea, traversing the Caucasus and broadening into substantial areas east of the Caspian Sea. Smaller (but still substantial) areas have temperatures greater than $50^{\circ}C$; these occur within the general zone of higher temperatures. It is probably significant that so many of the thermal springs noted in Figure E-3 occur in this general region of greater temperature at 1 kilometer depth, implying that there is a genetic relationship. The geothermal resources of this region would therefore appear to be largely of the hot water/dry steam types associated with the intensive tectonic activity of the area that continues to the present day. This assumption does not preclude the possible occurrence of geopressured resources in this area, but does suggest that their occurrence may be less widespread than the other types.

There are many thermal springs in the general region of the oilfields of the Caucasus. Indeed, the subsurface thermal characteristics have been used to guide the search for oil in this area.[21] It was found that geoisotherms clearly define the main anticlinal folds that are the producing structures, and thus can be used in exploring for buried structures that may not be apparent from other information.

Important hot water deposits of Krasnodar, Stavropol, and Mahachkala of the Caucasus occur in porous sediments. These sediments are situated over the areas of highest 1 kilometer temperatures (>50°C).

b. Eastern Regions

The regions of the USSR east of the Urals display a different geothermal regime than the European sector.[22] In the European region, the temperature at 1 kilometer depth increases southward. Most of the region is characterized by low temperatures (less than 30°C). In the Black Sea area and in the Caucasus, temperatures are mainly between 30° and 50°C, with a few smaller regions reaching up to 100°C. (See Figure E-3.)

Most of the western Siberian Basin has temperatures at 1 kilometer that are between 30° and 50°C, generally similar to the temperatures of the Transcaucasus region but in marked contrast to those in most of European USSR. The Ural mountains represent a sharp demarcation between these temperature regions. Higher temperatures at 1 kilometer depths in the western Siberian Basin are also evident at 2 kilometer depths, concentrated in the same areas. It is potentially significant that the area of western Siberia where high temperatures are found at 1 kilometer depth coincides with the area of sizable deposits of oil and gas.

Little is known about the temperature regime at depths of several kilometers in much of central Asia or the far eastern regions of Siberia.

3. Geothermal Production and Use

At present, 11 geothermal facilities are in operation in the USSR. Data on these facilities are currently incomplete but important characteristics of selected geothermal facilities are shown in Tables E-13 and E-14.

Apart from generating electricity, geothermal energy is used in several other areas of the Soviet economy. These are in four main areas: domestic and industrial applications, agriculture, medical and health applications, and geothermal byproducts.

a. Domestic and Industrial Applications

Domestic and industrial applications of geothermal energy include heating, hot water supply, permafrost (mining and construction), refrigeration and air conditioning, and swimming pools and baths.

- Heating is the largest domestic use of geothermal energy in the USSR. Low temperature waters from thermal springs or drill holes represent an annual saving of at least 15 million tons of standard conventional fuels, and increased use of geothermal resources is projected for the future. It has been estimated, for example, that the total geothermal heat value is comparable to the total coal, oil, and peat resources of the country. This, however, is apart from geothermal resources used in electricity generation as described above.

- Hot water supply from geothermal sources is extensively used for domestic and industrial purposes. Many hot water supply systems are constructed to function also as heating systems.

Table E-13

CHARACTERISTICS OF REPRESENTATIVE CURRENTLY OPERATING GEOTHERMAL STATIONS IN THE USSR

	Paratunka	Pauzhetka
Installed Capacity (MW)	0.75	5* 20†
Number of wells	8	22
Temperature (°C)	82	170
Surface pressure (atm.)	n.a.	2.2-6.7
Geothermal water consumption (cubic meters)	289	n.a.
Well depth (meters)	302-604	100-400
Heat capacity (kilocalories/kilogram)	n.a.	170

n.a. not available.

* Present.

† Projected.

Table E-14

CHARACTERISTICS OF PROJECTED GEOTHERMAL PLANTS IN THE USSR

	Bolshe-Bannaya	Makhachkala	Yuzhvo-Kurilsk	Zhirovskiy	Sevsro Kambalny
Installed capacity (MW)	8 initial 24 final	12	5-6	36	4
Temperature (°C)	100	120	130	100	n.a.
Number of wells	20	n.a.	n.a.	n.a.	n.a.
Heat capacity (Kcal/Kg)	150	160	130	n.a.	n.a.

n.a. - not available.

- Possible use of geothermal resources to melt permafrost and facilitate mining and mineral recovery is projected; however, these uses have yet to be achieved.

- Geothermal waters may also be used for refrigeration and air conditioning, as a further part of an overall heating/water supply system.

- Outdoor swimming pools are heated by geothermal waters, either directly or as the outflow from a generating plant or heating system.

b. Agricultural Applications

Agricultural applications of geothermal energy are primarily for hot house cultivation of vegetables and other plants. Several geothermally heated hot houses have been developed in Siberia and the Far East.

c. Medical and Health Applications

Medical and health applications of geothermal waters are common at numerous spas and sanatoriums, so as to take advantage of the reputed healing influence of mineralized waters.

d. Geothermal Byproducts

Geothermal byproducts include recovered salts extracted as a result of processing for other uses, principally power generation.

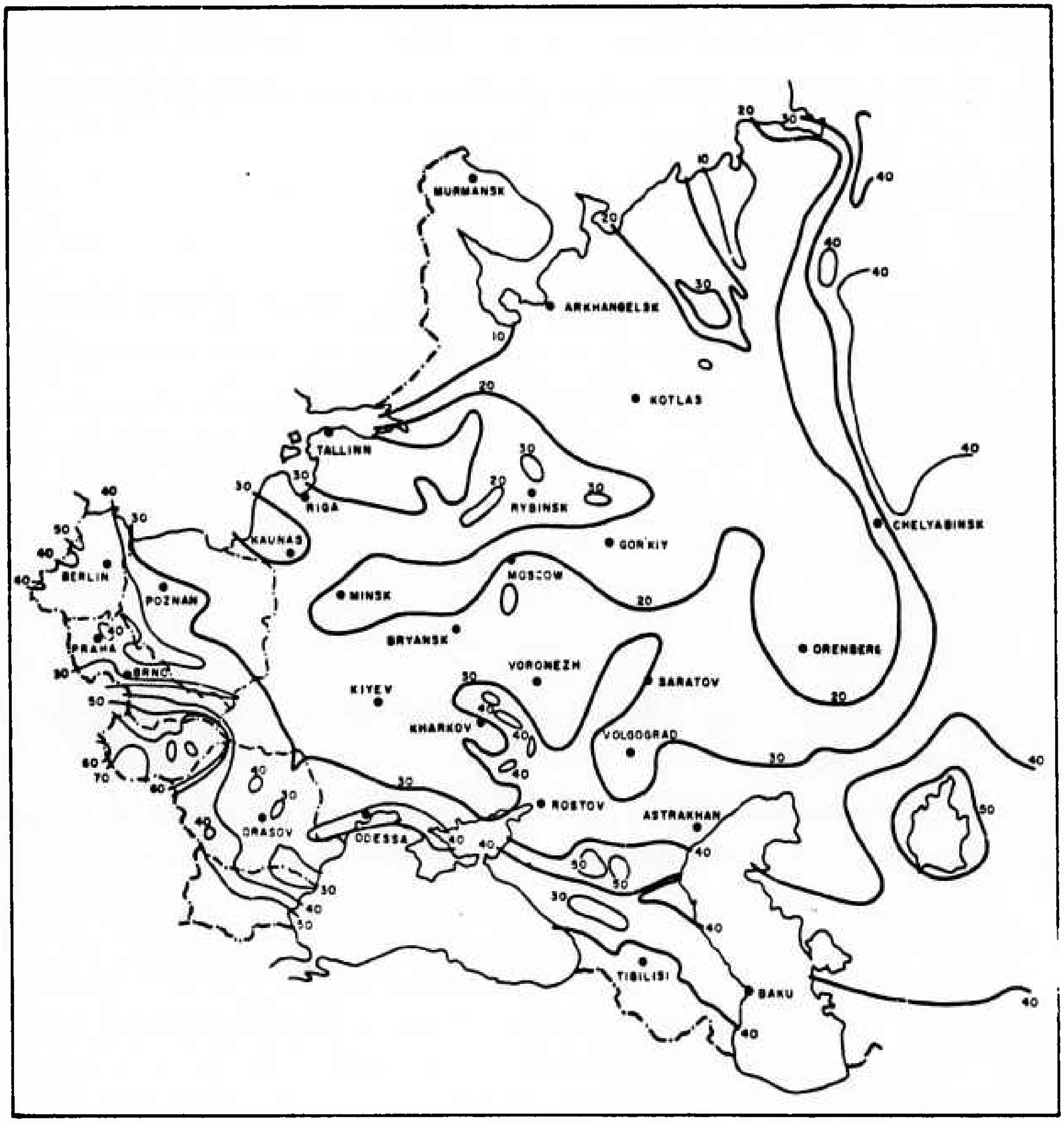
C. Geothermal Resources of CMEA Countries

1. Summary

Figure E-4 shows regional geothermal data for Eastern Europe, in the form of a map of isotherms at 1 kilometer depth.[23] The map shows that most of the area from the borders with Western Europe to the Urals (the great plains and lowlands regions) is characterized by modest geothermal conditions of between 20°C and 30°C at this depth. These conditions are consistent with the relatively undisturbed character of the sediments and the absence of intrusive activity in this region. Owing to the low temperatures, it seems unlikely that geothermal resources of the more familiar types will be present in this region. However, the possibility that geopressured resources may exist needs to be examined through further work.

The uplands that extend through the German Democratic Republic, southern Poland, northeastern Czechoslovakia, and into Romania and Bulgaria are characterized by 1 kilometer temperatures of 30°C to about 50°C. This zone also extends along the northern border of the Black Sea and through the Caucasus into Kazakhstan and Central Asia. The Donets Basin and Volga-Urals provinces are northerly offshoots to the main trend. The area where these higher temperatures occur is noted, in Eastern Europe at least, for the occurrence of numerous thermal springs and other surface geothermal manifestations. Thermal springs also occur along this same trend in the USSR and the Caucasus, but these have been less developed for recreational and medicinal purposes than the springs further to the west.

Localized regions where the 1 kilometer temperature is greater than 50°C are found in the German Democratic Republic, Hungary, along the Caucasus trend, and in the Aral Sea region. These geothermal highs are



Source: L. Stegeno, 'Geothermal Map of Eastern Europe" GEOTHERMICS, Vol. I, No. 4, p. 140, December 1972.

Figure E-4

GEOISOTHERMS AT I KILOMETER DEPTH, °C

clearly associated with recent tectonic activity. It is perhaps significant that geothermal highs coincide with structural lows (the Hungarian Basin, the Aral Sea Basin, the local basins of the Transcaucasus, and the western Bulgarian basin). These temperature-structural relationships need to be investigated in greater detail.

2. Geothermal Resources of Bulgaria

Located in a region of relatively high geothermal anomalies (Figure E-4, generally 30°C to 50°C or greater at 1 kilometer depth), Bulgaria appears to be favorably situated for geothermal resources. However, as Figure E-4 shows, data are lacking for the southern half of the country. Unfortunately, this is the region where most of the thermal springs of Bulgaria occur and where additional data are obviously required. There is insufficient information at present with which to evaluate the energy potential for these resources.

The U.S. Geological Survey reported on some 97 thermal springs in Bulgaria as of 1965. These springs included those with a wide range of surface temperature; the lowest temperature was reported as 56°F, with the highest being 187°F. More commonly, water temperatures were in the somewhat narrower range from about 75°F to 120°F.

In view of the relatively low temperatures and the sparse technical data about the deposits, it does not seem likely that geothermal resources would represent an important factor in the Bulgarian energy scene in the coming years.

3. Geothermal Resources of Czechoslovakia

Czechoslovakia occurs in a region of recent intense folding and tectonic activity. Figure E-4 shows that the temperatures at 1 kilometer depth are usually greater than 30°C (with the exception of a narrow east-west zone through the center of the country). Highest temperatures are found in the southeast (greater than 50°C), and, to a lesser extent, in the north central and northwest parts of the country (30°C to 40°C).

Terrestrial heat flow measurements were made in Czechoslovakia beginning in 1964, using specially drilled bore holes.[24] The average heat flow is 1.70 $\mu cal/cm^2 sec$, higher than the mean world value of 1.58 $\mu cal/cm^2 sec$, but in good agreement with the average value for central Europe (1.67 $\mu cal/cm^2 sec$). Geologically older units have lower heat flow values than younger formations. This means, generally, that heat flow values will increase from west to east in Czechoslovakia. For example, the older Bohemian Massif in the west has an average heat flow of 1.61 $\mu cal/cm^2 sec$ while the younger Carpathians in the east have an average heat flow of 2.13 $\mu cal/cm^2 sec$. The geothermal field in the Ostrava-Karvina coal basin has an average heat flow of 1.81 $\mu cal/cm^2 sec$. These data are consistent with surface geothermal manifestations in thermal and mineral springs, as they suggest greatest potential in the eastern and western limits of the country, with little apparent potential recognized in the center.

Czechoslovakia has many thermal and mineral springs, and at least 1,600 sites have been recognized, with others likely to be identified through further investigation. Mineral waters in Czechoslovakia refer to "ground water which exceeds in value one of the following criteria:

1 g/ℓ dissolved solids

1 g/ℓ dissolved CO_2

1 mg/ℓ H_2S

1 mg/ℓ titrated sulfur.

or $5\ mg/\ell\ I^-$

$10\ mg/\ell\ Fe^{+2}$

$0.7\ mg/\ell$ As

or higher concentrations of

F^-, Zn^{+2}, Li^+, Sr^+, etc.

Thermal waters are waters with the temperature above $25^{\circ}C$ (until recently the boundary was $20^{\circ}C$)."[25]

In Czechoslovakia, mineral waters recognized as having medicinal properties are protected by law. Thermal waters are not yet applied to the generation of power; also, there are fewer thermal springs than mineral springs.

The hydrogeology of Western and Eastern Czechoslovakia is important in the context of geothermal resources. In the west (Bohemian Massif), ground water is stored principally in thick and extensive layers of pervious sandstones. The deeper aquifers are confined, and are marked by a series of artesian springs. In the east (Carpathian mountain region), a greater variety of hydrologic zones is present. The variety is attributed to the stratigraphic and structural relationships of the area. The most important hydrologic zone is in the sediments occurring in the central part of Slovakia, where tectonic structure plays an important role in determining water circulation patterns.

The thermal springs are located relatively coincident with regions of high temperatures at 1 kilometer depth or high geothermal gradient, or both. This suggests that the thermal springs are related to a more deep-seated phenomenon and therefore may represent potential sources of energy.

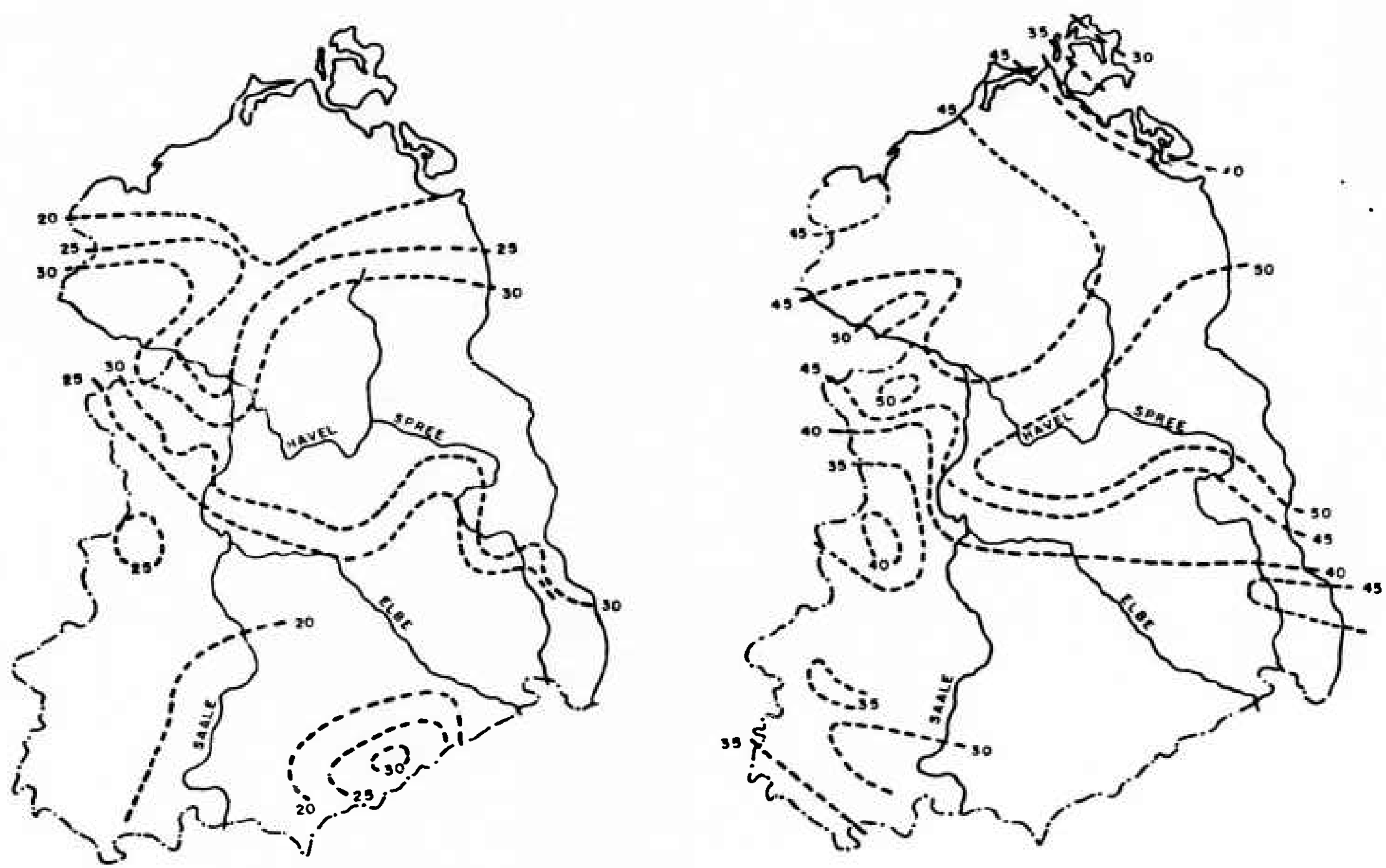
Most thermal springs in Czechoslovakia are rather tepid; the U.S. Geological Survey in 1965 reported the highest temperature thermal spring in Czechoslovakia to be only about $72^{\circ}F$.[26] More recent Czech data indicate that there are several springs having temperatures of "more than 45°C (99°F). Hotter springs are concentrated in the eastern part of the country, in the general area of greater temperatures at 1 kilometer depth. This is still rather discouraging in terms of potential geothermal resource development. It is possible, however, that further exploration or drilling may discover waters of higher temperature at greater depth; this possibility, however, remains unproven and the potential use of geothermal resources in Czechoslovakia must be regarded as speculative.

4. Geothermal Resources of the German Democratic Republic

The German Democratic Republic occurs in a region where temperatures at 1 kilometer depth are generally between 30°C and 40°C (see Figure E-4). Highest temperatures (40°C to 50°C) are found in the northern two-thirds of the country, where no known thermal springs were noted by the U.S. Geological Survey.[26] This is a region where relatively thick sedimentary strata occur, and it is conceivable that the higher temperatures may represent the presence of geopressured zones that may ultimately become developed.

A few thermal springs occur in the southernmost part of the GDR, near the Czech border. These are in a region of recent tectonic disturbance, as are those across the frontier in Czechoslovakia. However, these springs are only 20°C to 31°C and their likelihood as a potential power source appears to be slight.

Temperatures at 0.5 and 1 kilometer depths in the German Democratic Republic are shown in Figure E-5. These temperatures are relatively modest (mostly around 30°C) and hence, important geothermal potentials appear unlikely in the GDR.



A. Temperatures at 0.5 Km, °C

B. Temperatures at 1 Km, °C

Figure E-5

TEMPERATURES AT 0.5 AND 1 KILOMETER DEPTH

5. Geothermal Resources of Hungary

Hungary has the highest temperatures at 1 kilometer depth of all the countries of Eastern Europe (see Figure E-1). All temperatures reported are greater than 50°C, ranging up to 75°C in the south central part of the country.

The Hungarian basin is part of the Alpine tectonic system; it has a maximum depth of 5 kilometers below sea level and an average depth of about 2 kilometers. Very high heat flow measurements have been recorded in Hungary, ranging from a high of 3.035 $\mu cal/cm^2 sec$ to more "moderate" values of 1.9 to 2.0 $\mu cal/cm^2 sec$. Many other heat flow measurements occur in the average magnitude of about 2.4 to 2.6 $\mu cal/cm^2 sec$. The average value of the geothermal gradient in Hungary is 54.2°C per kilometer, but over large areas it is more than 70°C per kilometer. The highest measured temperature gradient is 225°C per kilometer at Lakitelek, more than four times the average value. The Lakitelek area appears to be generally similar to **Larderello,** Italy, where electricity has been produced from geothermal resources for many years.

It was estimated[27] that 20,000 square kilometers of rocks having porosity greater than 10 percent occur in Hungary. More than 4,000 cubic kilometers of hot water at 60°C to 200°C occurs at less than 1 kilometer depth, making these resources attractive targets for development.

It was found that higher geothermal gradients than average (>70°C/kilometer) occur at places where the depth to basement is shallow, while lower gradients (<45°C/kilometer) are found where the sediments are thickest.[28] Apparently, the thicker sedimentary sequence blankets the deeper heat sources and lowers their surface heat flow.

The geological aspects of geothermal waters in Hungary were examined by Korim.[29] No active volcanic belts or apparent near-surface igneous activity was noted. Bottomhole temperatures at 2.5 to 4.5 kilometers are in the range of 150°C to 250°C; however, these deeper formations do not appear to be related to the surface water occurrences.

Geophysical data indicate that the earth's crust is 24-26 kilometers thick under Hungary; this is 8-10 kilometers thinner than the average for Europe. The geothermal anomalies are thus attributed to processes taking place within the upper mantle, which in turn influence the hydrogeology of nearer-surface rocks and their structures.

Two basic geological units are regionally important as surface thermal water occurrences: the Mesozoic carbonate basement rocks and the Cenozoic clastic sediments. These units appear to occur in separate parts of the country; basement rocks occur in a northeast trending belt through the center of the country, while the sediments occur in the extreme northwest and southeast. About 20 percent of the total thermal wells occur in the older rocks, where the water storage and yield are largely controlled by fractures. Thus, the reservoirs in this unit are of variable character and are ill-defined as to capacity.

The remaining thermal waters occur in the more recent sedimentary deposits, largely alternating sand, sandstone, and clays in individual beds from 5-25 meters thick, which occur as multi-unit reservoir systems. The most favorable area is in southeast Hungary, where an aquifer occurs at 800 to 2,400 meters depth.

Highest heat flow values are found in the southcentral part of the country, diminishing toward the northwest and northeast. These data indicate that Hungary is an "island" of high geothermal values surrounded by areas that are relatively "normal" from the thermal standpoint. Accordingly, a more detailed discussion of Hungarian geothermal characteristics is presented.

The Hungarian Basin has several hydrologic systems of importance to geothermal resources; these will be described briefly from the oldest to the youngest.

- The deepest (oldest) system is made up of fractured Paleozoic and Mesozoic sediments. Limestones comprise much of the sequence, and contain large amounts of water in karst topography. These can represent important sources of heated water, although the reservoirs are located only with difficulty.
- The basal conglomerates, lying on the basement rocks, also may represent additional sources of heated water.
- High porosity sandstones of high permeability deposited in lower Pliocene times are the most extensive and important formation from the standpoint of geothermal resources. More than half the geothermal potential of Hungary is represented in these strata.

The porous rocks containing the geothermal water are under the lithostatic load of the overlying strata at depths of about 1 to 3 kilometers. Only a small part of the lithostatic pressure is borne by the interstitial waters, which are under essentially hydrostatic pressure only.

There are several surface geothermal manifestations in Hungary, in the form of thermal springs and wells, as catalogued by the Geological Survey.[26] Most of these are low temperature, with the greatest measured temperature being only about 80°C. These wells are scattered throughout the country.

Deeper reservoirs are reached through drilling to depths of about 2 kilometers using standard oil-field exploration equipment. Most hot waters in the Hungarian Basin are alkali-hydrocarbonate type, with about 2,500 ppm soluble salts.

It was noted recently that deep drilling (5-6 kilometers) for oil exploration in Hungary has been hampered by technical difficulties. These are the result of "abnormally high geothermal gradients and high formation pressures"[30] in lower strata. This could be of importance for potential development of geopressured resources. Temperatures are generally in the range from 400°F to 600°F and pressures frequently exceed simple hydrostatic pressures. It was noted that "effective pore pressures measured in wells in Hungary exceed those of the U.S. Gulf Coast, and temperatures exceed those measured in Kansas, California, or the Rocky Mountains." Formation pressure gradients increase with depth, and values exceeding 0.866 psi/ft must be expected. These anomalous pressures were explained by compaction and uplift.

It seems clear from these data that there is an important potential for development of geopressured resources in Hungary, and that future work is required to test this potential to determine its energy contribution.

There were 80 geothermal wells in Hungary as of 1970 (Figure E-6). The average production of hot water at 85-90°C is about 80 to 90 cubic meters/hour, with an average energy content of about 4 to 5 million kcal/hour. The total output is about 6,800 cubic meters/hour, with about 0.44 MW considered as the ultimate capacity. The optimum useful production capacity of geothermal energy at present is about one-third the ultimate capacity or about 0.15 MW. Geothermal energy has been used in Hungary for heating and for control of soil temperatures to aid in agriculture.

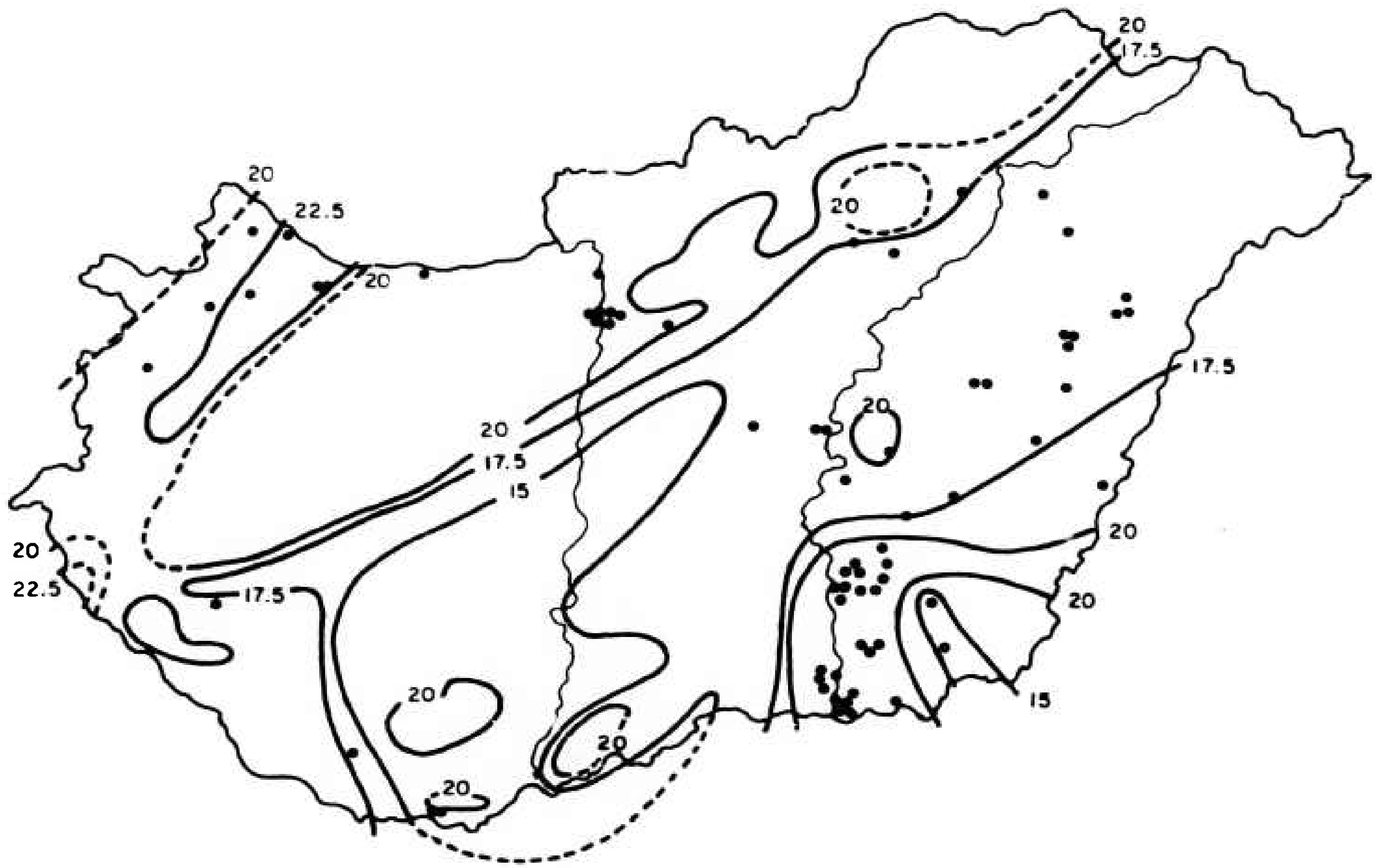


Figure E-6

LOCATION OF GEOTHERMAL WELLS IN HUNGARY AND GEOTHERMAL DEGREE CONTOURS IN Meters/°C

The development and utilization of geothermal resources in Hungary was described by Belteky.[31] Detailed data on the number of wells, output, characteristics, and utilization are shown in Tables E-15, E-16, and E-17. The tables show that most wells (70 percent of the total) have temperatures less than 60°C, and that the principal use of these thermal waters is for heating or recreational/medicinal purposes (spas).

Despite long-standing use of the geothermal resources of Hungary, the average geothermal characteristics have changed only slightly over time. Increasing attention is being given to "multipurpose utilization" of geothermal wells, especially those from which associated natural gas can be recovered for industrial use.

6. Geothermal Resources of Poland

Poland is in an area marked by relatively modest temperatures at 1 kilometer depth (see Figure E-4). In the northeastern third of the country, temperatures range from 20° to 30°C at 1 kilometer, while in a northwestern trending belt across the center of the country, temperatures are generally from 30° to 40°C. In a small area in the southwestern part of Poland, 1 kilometer temperatures are greater than 40°C. The surface heat flow in Poland is about 0.8 $\mu cal/cm^2 sec$ in the shallow crystalline formations of the Eastern European shield area of the northeast, and about twice as much (or 1.7 $\mu cal/cm^2 sec$) in the Czechoslovakian frontier at the southern part of the country.

Important amounts of thermal waters under high pressures occur in thick sedimentary sequences of the Polish lowlands. The temperatures of these waters are low, rarely exceeding 40°C. However, the water is relatively pure (low dissolved solids content) and in high volume.[32] This description suggests that these waters may actually represent geopressured resources of the type occurring in the U.S. Gulf

Table E-15

THERMAL WATER WELLS IN HUNGARY - JANUARY 1, 1972

Degrees Centigrade	No. of Wells	Percentage of Total	Output (cubic meters per minute)	Output (Percent)
35-44	194	41.5%	109.90	28%
45-59	133	28.6	106.40	27.2
60-69	50	10.8	50.30	12.8
70-79	34	7.3	42.20	10.7
80-	55	11.8	83.40	21.3
Total	466	100.0	392.20	100.0

Table E-16

NUMBER, OUTPUT, AND USE OF THERMAL WELLS - JANUARY 1, 1972

Use	No. of Wells	Percentage of Total	(cubic meters per minute)	(Percent)
Baths	195	41.8	167.19	42.6%
Agricultural heating	77	16.5	115.73	29.6
Apartment heating	6	1.3	9.45	2.4
Drinking	110	23.6	56.41	14.3
Industrial and domestic use	11	2.4	10.63	2.7
Water-injection and water-level observation	11	2.4	12.42	3.2
Shut-down	56	12.0	20.36	5.2
Total	466	100.0	392.20	100.0

Table E-17

WATER TEMPERATURE, NUMBER, AND OUTPUT OF WELLS SUPPLYING SPAS

Temperature Range (degrees C)	No. of Wells	Percentage of Total	(liters/ minute)	(Percent)
35–14	67	34.5%	54,978	33.0%
45–59	76	38.8	52,813	31.6
60–69	28	14.4	31,540	18.8
70–79	20	10.2	24,369	14.5
80–	4	2.1	3,490	2.1
Total	195	100.0	167,190	100.0

Coast province and elsewhere. Present developments in Ciechocinek and Koszuty achieve flows of 400 cubic meters/hour and 40 cubic meters/hour, respectively, with the dissolved solids content being low. This suggests that the waters are under high pressure, as are those for typical geopressured systems. It would appear, therefore, that the Polish lowland may represent a region with some promise for geopressured resource development. However, this possibility remains to be tested by further exploration and drilling.

Thermal waters in the southern part of Poland are associated with recent tectonic activity, a different type of geothermal resources than those described above. These latter resources are more likely to be associated with thermal springs and other surface manifestations of geothermal occurrences. However, the temperatures of these manifestations are rather low ($\sim 30^{\circ}C$) and their potential for further development does not appear promising.

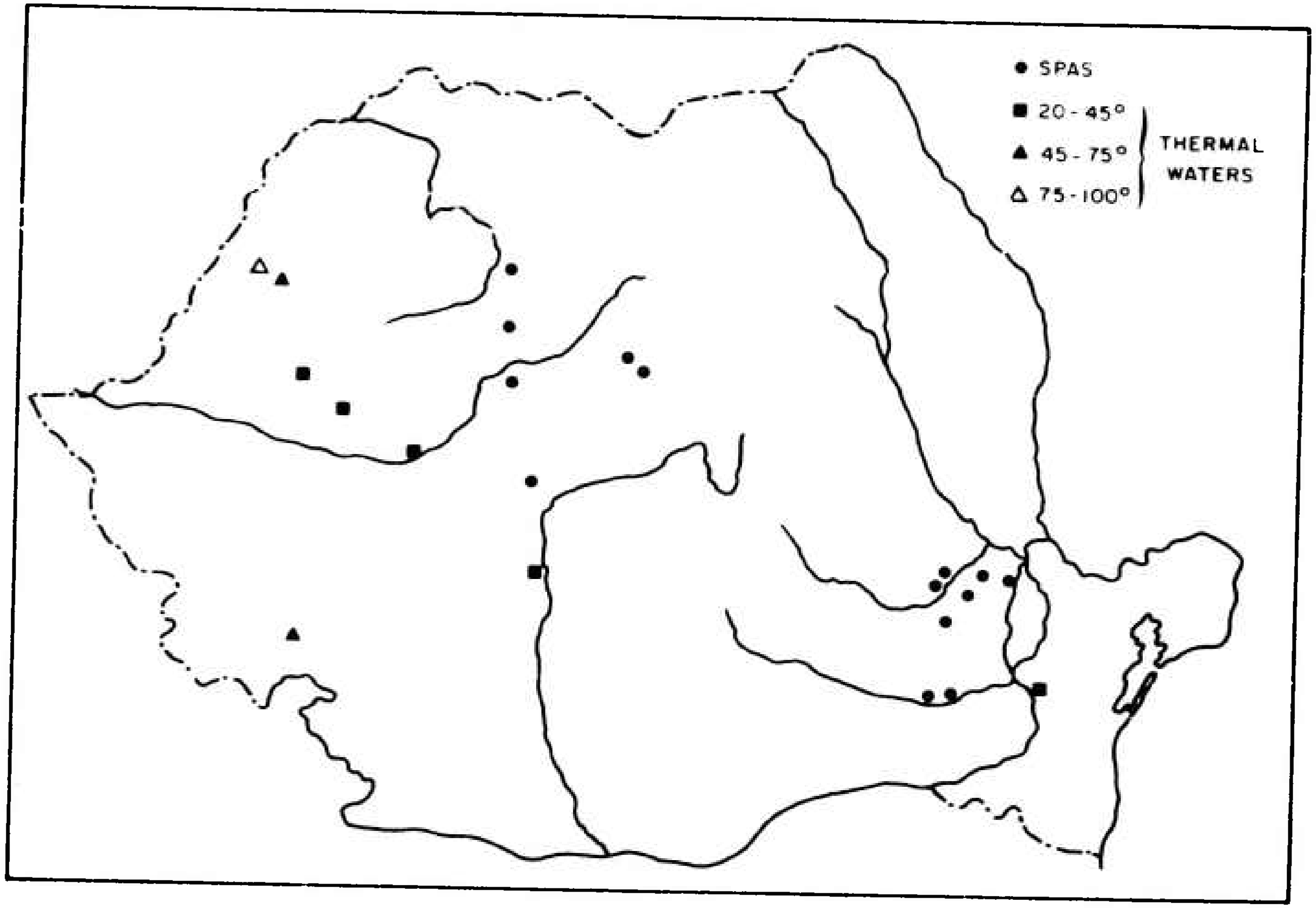
The chemical character of brines in northwest Poland was recently examined.[33] Brines occur at depths greater than 2,000 meters. Most authors attribute the origin of brines to leaching of soluble salts from the salt-bearing sedimentary sequence occurring in this region. A similar origin has been suggested for the brines of the Imperial Valley, California. However, this recent work in Poland has been interpreted to suggest the presence of fossil saline water, which has been later diluted by recent meteoric water. It was further suggested that the water of the most concentrated brines resulted from in-place filtration through semi-permeable clay membranes separating more permeable strata. Additional exploration work is necessary to determine with precision the nature and origin of these brines.

7. Geothermal Resources of Romania

Romania is situated in a region where temperatures at 1 kilometer depth are mainly between 30°C and 40°C (see Figure E-4). Higher temperatures (greater than 40°C) are found at depth along the western frontier of the country. The lowest temperatures (less than 30°C) are found in the southeastern region and in a small area of the central part.

A number of low temperature thermal springs were noted in Romania by Waring.[26] Temperatures of these springs ranged from about 20°C to nearly 50°C. More recently, the mineral and thermal waters of Romania were reported upon by Ghenea and Nicolescu.[34] Figure E-7, adapted from their work, shows the locations of principal hot springs and mineral waters. The figure shows that most springs have low temperatures, as reported by the U.S. Geological Survey.

There is a possibility that higher temperatures and/or geopressured resources may occur in the extreme northwest part of Romania--part of the Tectonic basin that comprises Hungary. However, this possibility remains to be tested by further exploration.



Source: Reference 34.

Figure E-7

GEOTHERMAL RESOURCES OF ROMANIA

IV URANIUM IN THE USSR AND EASTERN EUROPE

A. Geology of Uranium Resources

There are few published data on the uranium resources of the USSR and the Eastern European countries. Indeed, most published estimates of uranium resources rather pointedly exclude this region: ". . . 'world' in the present report excludes the USSR, Eastern Europe and the People's Republic of China."[35] At the very least, this omission represents an incomplete and hence misleading accounting of the world uranium resources, and greatly complicates the process of estimating the magnitude of potential peacetime nuclear uses, such as in generation of electricity. A further and related problem is the uncertainty that imperfect knowledge about this important (and projected high growth) sector introduces into the overall energy balance of these nations. Finally, similar uncertainty extends to these nations' roles in international trade in energy or fuels.

Still, this situation is not surprising. It is a logical consequence of the importance of uranium as an essential portion of nuclear weapons systems, and the array of security requirements that are attendant to such systems and their components. There seems little likelihood that such security requirements will be relaxed substantially in the future: thus, information on uranium resources may continue to be obscured.

The absence of information about uranium resources probably also reflects incomplete knowledge about the occurrence and characteristics of uranium in particular deposits. Although this problem is most pronounced for the remote and imperfectly explored regions of the USSR, it is doubtless true for portions of the Eastern European countries as well.

In view of this situation, analysis of the uranium resource potentials of Eastern Europe and the USSR must rely upon basic geological principles. Accordingly, this discussion will first present regional exploration criteria for uranium, as a basis for evaluating the remaining uranium resources and calculating recoverable reserves for each country.

Uranium deposits occur in a variety of geological regions, representing a range of depositional processes.[36] These are summarized below:

Deposit Type	Percent of Known Reserves
1. Conglomerates	65%
2. Other sedimentary rocks	25
3. Vein or vein type deposits in igneous or metamorphic rocks	10
	100%

Nearly two-thirds of total known reserves occur in Precambrian conglomerates, with another one-quarter of known reserves occurring in other sedimentary rocks, mainly sandstones. Thus, the clastic sedimentary rocks thus account for about 90 percent of known resources. The remaining 10 percent of the known resources occur in vein or vein-type deposits in igneous or metamorphic terrain; formerly, these represented most of the known resources. Unlike the conglomerates or sandstone deposits whereby product minerals may also be recovered, vein deposits often have uranium as the only extractable mineral, adversely affecting the overall economic aspects of operations.

In addition to these three basic classes of deposit, uranium also occurs as low grade deposits in shale, phosphorite, or granite. Present in great abundance, these latter deposits would provide virtually inexhaustible uranium supplies if cost of recovery were no obstacle. As a practical matter, however, their contribution to uranium reserves in the near future seems likely to be small.

The average uranium content of common rock types is as follows:[37]

Rock Type	Average Uranium Content (ppm)
Igneous	3.5 ± 0.5
Shale	3.7 ± 0.5
Limestone	2.2 ± 0.1
Sandstones	4.1 ± 1.5

This tabulation further illustrates the point that clastic sediments (e.g., sandstones and conglomerates) are richest in uranium content and are therefore the most promising targets for exploration. The tabulation, however, is for uranium content in ppm; when percent uranium oxide (U_3O_8) is the measure (Table E-18), sandstones still rank highest among typical rocks, with the exception of metasediments.

There are a number of provinces that contain favorable geologic features for uranium occurrence, but in which deposits have yet to be discovered. The preceding data indicate that the most promising areas for future discoveries will probably be characterized by sedimentary features associated with deposits covering a range in geologic age. An analysis of regional or generalized geological criteria for uranium occurrence[38] describes the characteristics of the three principal areas:

- Precambrian areas contain about 70 percent of the total world uranium resources; this total is comprised of conglomerates (65 percent) and vein deposits (5 percent). Known Precambrian deposits are largely confined to shield areas: stable terrain comprised of igneous and metamorphic rocks that contain various amounts of in-mixed sediments. There is a wide variety of uranium mineralogy, host rock, and structural control in these areas. There are three main classes of uranium deposits in Precambrian areas:

    1. Silicic host rocks associated with metamorphosed sediments.
    2. Metamorphosed sedimentary host rocks associated with younger intrusive bodies.
    3. Metamorphosed sedimentary host rocks with minor intrusions of varying age.

    Although there are important exceptions, uranium generally favors the sediments deposited apart from volcanic activity (miogeosyncline environment). The metamorphic derivations of these sediments are also important host rocks. Finally, uranium deposits have also been found in the sedimentary vein that covers Precambrian shield areas.

    Figure E-8 shows the locations of major geological features important for uranium occurrence. Shield areas are exposed in the Kola Penisula area of the USSR, as well as in the Ukraine and along the southern margin of Siberia. There are also extensive areas that are covered by younger sediments.

- Sedimentary Basins contain about 20 percent of the world uranium resources. These basins vary in shape, amount of sediments, and degree of development. Considered most favorable for uranium deposition are closed depressions characterized by relatively thin accumulations of terrestrial sediments on a rigid but sinking block around which intense deformation has taken place. These basins are typified by the Colorado Plateau region of the United States, the Fergana Basin of the USSR (located in Central Asia), and the Pannonian Basin of Hungary and Romania (see Figure E-8).

- Folded Mountain Belts contain the remaining 10 percent of the world's uranium resources. Numerous uranium occurrences have been noted in such terrain. In Europe, certain granites intruded into the folded mountain chains contain commercially valuable uranium-bearing veins. These deposits are known to occur in Germany and Czechoslovakia. Additional deposits doubtless occur in other regions (see Figure E-8).

It is clear from the above that uranium occurs in a range of rather different geologic conditions, and that detailed knowledge of specific local features will be required to determine likely resources with precision. However, the requisite geologic work has not been performed in many areas (or, as in Eastern Europe and the USSR, if done was not reported). Consequently, in order to estimate resources for such areas, reliance has to be placed on general comparisons of size of area and distribution of deposits with features in better known areas. It was found by Butler[39] that the amount of uranium resources in sedimentary rocks can be approximated by (1) multiplying the area involved by the fraction of the outcrop length of the formation (or the fraction of thoroughly explored ground--i.e., ore-bearing) and (2) using the best data on thickness to compute volume and tonnage. For the Colorado Plateau deposits, the area thought to be underlain by ore is about 0.5 to 0.6 percent of the total area considered likely to be uranium-bearing. Ore-grade uranium deposits are considered to be 0.1 percent U_3O_8 or more. Larger amounts of lower grade deposits (60-150 ppm) occur, but these are marginal at best. The limits of such areas may be approximated for incompletely explored areas by general geologic information about the region.*

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* See, for example, W. S. Keys and P. H. Dodd, "Lithofacies of Continental Sedimentary Rocks Related to Significant Uranium Deposits in the Western United States," Second UN International Conference on Peaceful Uses of Atomic Energy, Vol. 2, pp. 367-378, 1958.

Table E-18

URANIUM CONTENTS OF TYPICAL ROCKS
(Weight Percent)

Rocks	Uranium content (% U_3O_8)
Sandstones	0.15 to 0.30, avg 0.22
Quartz-pebble conglomerates	0.12 to 0.16
Veins	0.10 to 1.0
Metasediments	0.23
Granite	0.0015
Phosphates	0.012 to 0.024
Black shales	0.007 (U.S.) 0.3 (Scandanavia)

Source: U.S. Geological Survey, Professional Paper 820.

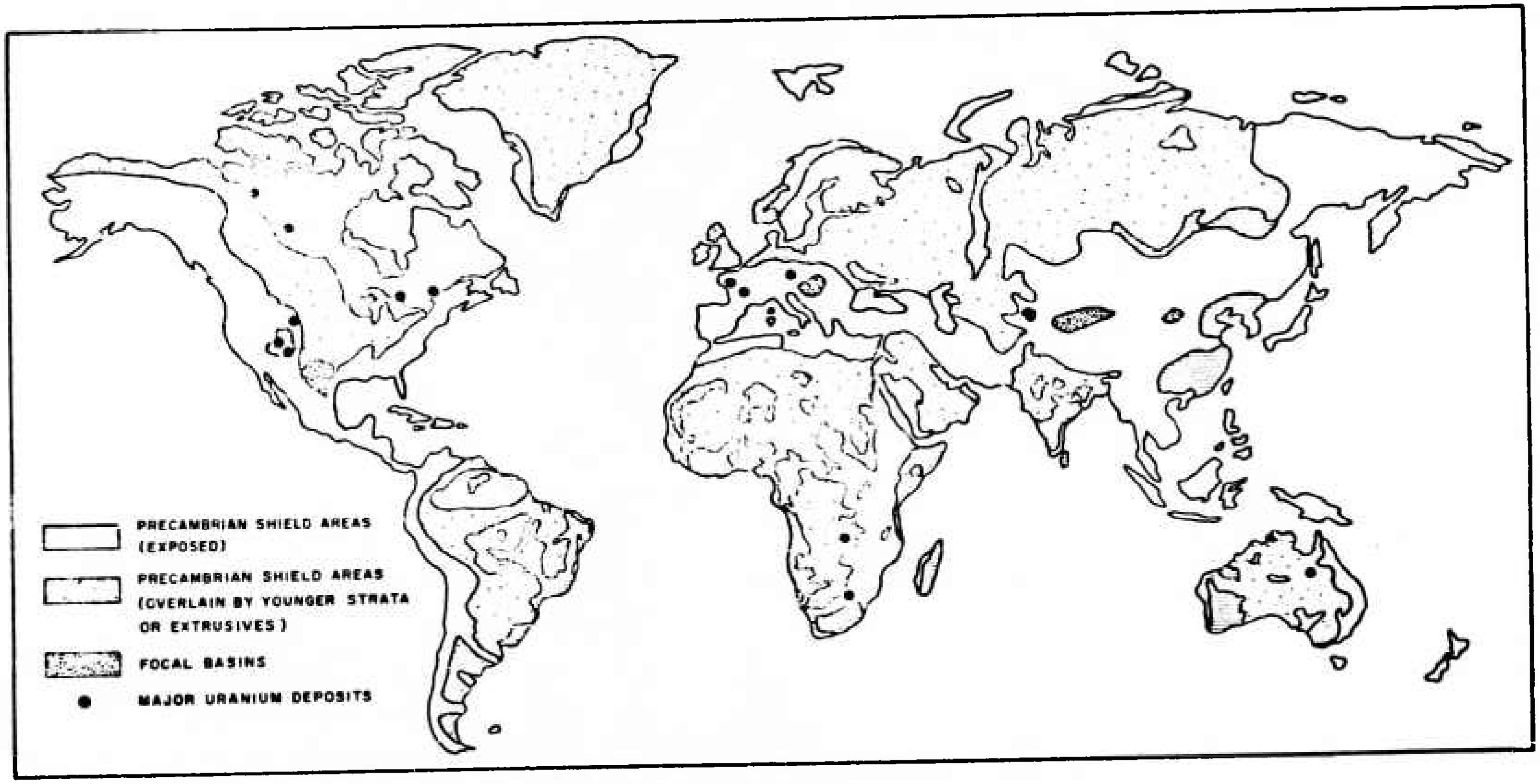


Figure E-8

RELATIONSHIP OF SELECTED URANIUM DEPOSITS TO MAJOR TECTONIC FEATURES OF THE WORLD

B. Uranium Deposits of the USSR

Currently available information indicates that uranium reserves of the USSR are known to occur in at least 16 different deposits (Table E-19). The table shows the estimated reserves of uranium metal and U_3O_8 for these deposits. Figure E-9 shows locations of some of the key deposits. The remainder of this section will summarize some salient features about these principal uranium deposits of the USSR.

1. Fergana Valley

There are several uranium deposits in the Fergana Valley of Central Asia. The principal ore body is an oxide replacement in a highly fractured and soluble limestone. The uranium content was estimated to be about 1 percent U_3O_8. Additional deposits, representing a variety of geological types, also appear to be present in this area.

2. Kara Tau Mountains

The most important uranium deposits in this area appear to be rather low-grade uranium-bearing shales. The uranium is scattered in irregular pockets.

3. Urals

A number of small and scattered uranium occurrences have been suggested in the Ural Mountains. At present, these appear to be poorly known.

4. Krivoy Rog Area (Ukraine)

Uranium ores occur in lenslike and disseminated bodies. These deposits were being worked in the early 1960's and production may be continuing at present.

5. Estonia

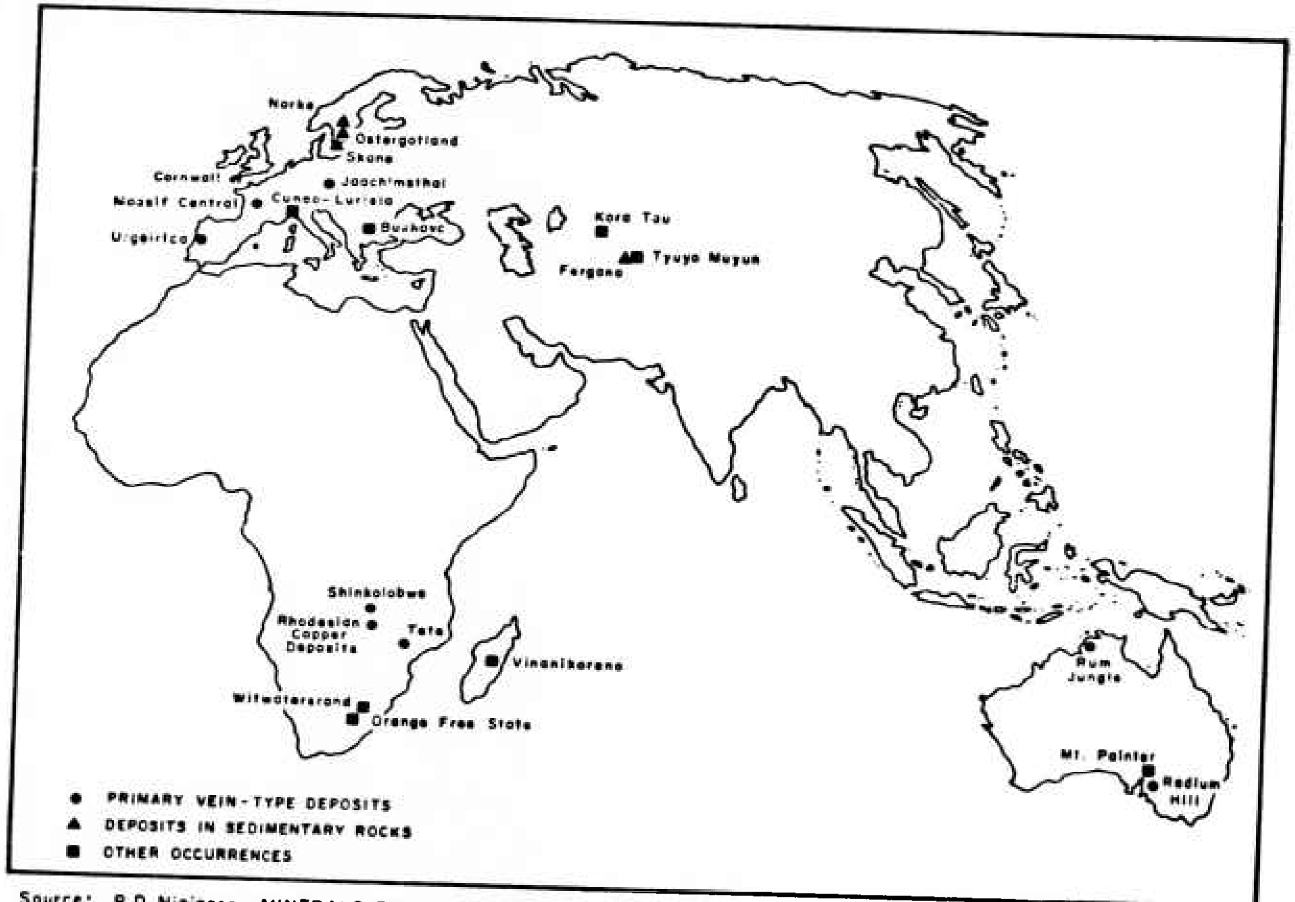
Uranium occurs in shales similar to those found in Sweden. However, the uranium is widely dispersed, and large volume of rock would have to be processed to realize its recovery.

Table E-19

ESTIMATED URANIUM RESERVES IN THE USSR
(Metric Tons)

Deposit	Uranium Metal
Fergana Valley	10,000 to 30,000
Kara-Tau Mountains	500 to 2,000
Urals	100 to 4,000
Krivoy Rog (Ukraine)	15,000 to 50,000
Estonia	~50,000 to 100,000
Kola Peninsula/Karelia	100 to 2,000
Ukrainian Shield	100 to 2,000
Northern Caucasus/ Caspian/Aral Seas	1,000 to 10,000
Lake Issyk-Kul	1,000 to 10,000
Altai-Zapadnvy Sayan Mountains	1,000 to 10,000
Transbaikal	500 to 5,000
Aldan	500 to 5,000
Far East	500 to 5,000
Jurassic Sub-bituminous Coal	5,000 to 40,000
Northern Siberia	500 to 5,000
Permian Basin	500 to 5,000
Total	86,300 to 285,000

Source: Joint Committee on Atomic Energy, U.S. Congress, 1961.



Source: R.D. Nininger, MINERALS FOR ATOMIC ENERGY (Von Nostrand & Co., New York, N.Y., 1954)

Figure E-9

PRODUCTIVE AND OTHER SIGNIFICANT DEPOSITS OF URANIUM

6. Kola Peninsula and Karelia

Uranium occurs in small quantities in the igneous rocks that comprise this area, and may also be present as vein deposits.

7. Ukrainian Shield Area

Possible uranium mineralization may occur in the area adjacent to the Hungarian and Czechoslovakian borders.

8. Northern Caucasus

This area of extensive mineralization and tectonic activity may contain uranium deposits as well.

9. Lake Issyk-Kul' Area

This area borders the Fergana Valley region, and may also be uranium-bearing.

10. Altai-Zapadnyy Sayan Mountain Area

Uranium-bearing monazite deposits have been reported to be present in this area.

11. Trans-Baikal Area

Uranium-bearing monazite placers occur in this area. Also, there are probably minor deposits scattered throughout the area.

12. Aldan Area

This area is similar to the Trans-Baikal area.

13. Far East

The diverse geological conditions in this area suggest that any uranium deposits present would be small and scattered.

14. Jurassic Brown Coals

Uranium is known to occur as minor amounts in certain brown coal deposits. There are numerous small brown coal deposits of Jurossic Age in Southern Siberia and the Far East from which uranium might be extracted.

15. Permian Basis

The possibility of uranium-bearing sediments in this area has been suggested, and remains to be demonstrated.

C. Uranium Mining and Processing Technology

Information about mining and processing of uranium in the USSR and Eastern Europe is more readily available than information about ore reserves, but is fragmentary and incomplete at best. The foregoing discussion suggests that uranium deposits of the USSR and other CMEA countries are structurally complex, similar in some respects to those of the rare metals. This complexity necessitates extensive exploration drilling and sampling to define the limits and quality of the ore bodies and permit design of mining methods for ore recovery.

Both surface and underground mining methods appear to be used.[40] In surface mines, the ore bodies defined by exploratory drilling and sampling are drilled and blasted using granulated explosives that appear to be similar to the ammonium nitrate/fuel oil mixtures (ANFO) used so widely in the United States. The broken rock and ore are loaded by shovels or by "rotary excavators" (presumably equivalent to the bucket wheel excavators employed in surface coal mining in Germany and elsewhere, but smaller). Transportation of the mined ore is by truck and belt conveyor, again apparently similar in concept to those of the West.

In underground uranium mining, the Soviets discuss capabilities of an "entry-drive combine." In this context, however, the machines described are similar in appearance and apparent function to the continuous mining machines common to underground coal mines of the United States. This machine has an articulated cutting head which mechanically removes ore from the face of the mine, and also has mechanical crablike arms that collect the mined ore and feed it to an integral conveyor system that traverses the machine to supply the mined ore to a car or other haulage system for removal from the mine.

Considerable attention appears to have been given to chemical leaching of uranium ores in attempts to mine complex deposits as well as to improve overall recovery.[41] This method also appears to have promise for uranium recovery from ores with very low uranium content. The process entails the following steps:

1. Breaking and preparation of ores.
2. Equipment installation.
3. Capillary leaching by sulfuric acid solutions: collection of leachate.
4. Absorption extraction of uranium from solution.
5. Recovery and recycling of reagents.

Processing of recovered uranium ores in the USSR and Eastern Europe is little discussed in readily available literature. However, given the nature of the material and the likely uses for which it is intended, it seems reasonable to expect that the techniques employed will be generally similar to those used in the West.

D. Estimated Uranium Reserves, Production, and Trade of the USSR and CMEA Countries

It was pointed out earlier that there are no published estimates of uranium resources from Eastern European or Soviet sources. However, an estimate of uranium reserves in these countries was prepared in 1961 for the Joint Committee on Atomic Energy of the U.S. Congress.[42] Table E-20 summarizes this estimate. The table shows that the largest reserves are in the USSR, as might be expected. The second largest reserves are estimated to be in the German Democratic Republic; reserves of the other countries are individually small but clearly would be significant in the aggregate.

In an attempt to place the estimated resources and reserves in perspective, some brief remarks on estimated uranium production are offered. Again, it is emphasized that these data are estimates only, and not a result of published statistical information from original sources, and therefore may be subject to greater than normal uncertainty.

Table E-20

ESTIMATED URANIUM RESERVES IN
EASTERN EUROPE*
(Metric Tons)

Country	Uranium Metal*	Uranium Oxide U_3O_8
Bulgaria	15,000	17,689
Czechoslovakia	25,000	29,481
German Democratic Republic	100,000	117,925
Hungary	15,000	17,689
Poland	1,000	1,179
Romania	15,000	17,689
USSR	80,000 - 270,000	93,340 - 318,396

* Hearings, U.S. Joint Committee on Atomic Energy, U.S. Congress, 1961.

On the basis of available information, the annual output of the Soviet Union is on the order of 8,000 tons of oxide per year, and the annual output of the other Eastern European Countries is about 600 tons (Table E-21). Total production is about 11,600 tons. These figures are, at best, a broad estimate based on a search of the literature of the past 30 years. Production capability in future years would not appear to be limited by reserves.

Substantial uranium trade by and among the CMEA countries cannot be ruled out. Already European countries and Japan are trading heavily with the CMEA countries for a wide range of minerals and metals. Japan, in particular, is stepping up its trade with the East, and there is no reason to suppose that this will not include uranium in the future. In view of its considerable lack of success in exploring for uranium in Canada and in the United States over the past three years, Japan might well consider more promising areas such as eastern Siberia. However, if uranium prices remain at low levels for some years, it is rather doubtful that Japan will pursue such a course too vigorously.

The European countries are less likely than Japan to seek uranium supplies from the CMEA countries because most countries are developing sources in nations that have traditionally supplied Europe with minerals.

Table E-21

ESTIMATED URANIUM PRODUCTION CAPABILITY OF THE EASTERN EUROPEAN COUNTRIES
(Thousand Tons of U_3O_8 per Year)

Country	Thousand Tons of U_3O_8 per Year
USSR	8,000
German Democratic Republic	100
Poland	50
Czechoslovakia	250
Romania	50
Hungary	50
Bulgaria	100
Total	8,600

Apart from selective sales of uranium, it would appear difficult for the Soviets to affect Western markets very much. Multiple sources of supply are one of the factors that deter Soviet sales; another is that there is no apparent real shortage of uranium ores. Further, the demand for uranium 15 years hence and beyond will be so enormous that Soviet trade would have to be exceedingly large to have any effect. But it is always possible that individual governments will deal with the CMEA countries for their uranium supply; even modest CMEA sales will make it difficult for new and existing uranium producers, particularly those outside the United States, to compete. An added advantage of the Soviets is that the USSR imports U_3O_8 from the CMEA countries and offers uranium processing on a contract basis, in competition with the United States.

E. Uranium Deposits in Individual Countries

1. Uranium Deposits in Bulgaria

Bulgarian uranium deposits are distributed more or less throughout the country, but the largest concentration of uranium occurs at the Bukhovo deposit near Sofia. The rocks in this are described as follows:

Era	Period	Rock Type
Mesozoic	Cretaceous	Marly limestone
	Jurassic	Sandy shale and sandstone
	Triassic	Breccia and conglomerate
Paleozoic	Silurian	Schist

The uranium deposits occur as fillings of fractures in the Silurian schist. The deposit is not a true vein filling, and the uranium is presumed to have been formed either by oxidation of a pitch blende-bearing vein or by deposition from surface waters.

Bulgaria had four mines operating in 1952 in the Bukhovo and Kremikovzi-Seslavkzi areas. The Bukhovo Mine reportedly contained ore that ran 2 percent U_3O_8. In 1954 a large new mine was opened in the Rhodope Mountains between Mada and Zilatograd; the ore was shipped to the USSR without concentration. By 1955 Bulgaria had its own ore-processing plant built underground. This study encountered no additional information after 1955 on Bulgarian uranium mining.

2. Uranium Deposits of Czechoslovakia

Czechoslovakia's uranium resources have been developed and worked for over a hundred years, especially in the area of Joachimsthal near the German border. Most of the ore occurs as vein fillings into a series of fractures in Precambrian schists and slates that have been intruded by granites. Pitch blende occurs in thin-banded, fairly continuous stringers in veins of dolomite and quartz, either individually or in association with other minerals. It also occurs as streaks and isolated patches in veins or in the country rock.

The Bohemian Massif and the Carpathian Mountains also contain uranium deposits. In these areas the uranium deposits are principally veins intruded into Precambrian metamorphic and igneous rocks.

In 1954 Soviets were mining additional deposits located at Susice and Prackovice in central Prerov. Production at the Joachimsthal Mine was declining, and the largest producing mine in 1954 was at Pribram, which reportedly was much bigger than the Joachimsthal deposit and had reserves for 30 years. In 1957 Czechoslovakia's main export item to the USSR was uranium. Additional deposits are reported at Jihlava in Moravia.

In 1968 Czechoslovakia was believed to be producing 10,000 tons of uranium a year--all of which was sold to the USSR at a reported price of $7.50 a pound equivalent. (It is no wonder that the Soviets viewed seriously the recent attempt of Czechoslovakia toward liberalizing its political and economic institutions.)

3. Uranium Deposits of Poland

Poland has issued little information on its uranium development activities, and few data are available.

4. <u>Uranium Deposits of Romania</u>

Most of Romania's uranium deposits occur in the Transylvanian mountains of the east-central part of the country. These mountains are made up of folded and metamorphosed Paleozoic sedimentary rocks that have been intruded by Tertiary volcanic rocks. The uranium deposits occur as veins in which uranium minerals are present in association with deposits of other minerals.

Romania reportedly has small but adequate uranium resources to satisfy its own needs for reactor fuel. The head of the state electricity board has stated that heavy water reactors will be installed in Romania in order to use the native uranium and save on foreign exchange that would otherwise be required for imported uranium and enrichment service for the other types of reactors.

Deposits and mines in Romania are located near Capnic in the lead mining region of Baia Mare; at Beica in western Transylvania; and at Turnu Severin. The USSR sold back to Romania its one-half interest in mines in the Baita district of Transylvania.

REFERENCES

1. I. M. Ozerov and V. I. Polozov, "Principles of Oil Shale Commercial Classification," UN Symposium on the Development and Utilization of Oil Shale Resources, Tollinn, 1968.

2. D. R. Williamson, "Oil Shales: Part 3, The Nature and Origins of Kerogens," Mineral Industries Bulletin, Vol. 7, No. 5, Colorado School of Mines, Golden, Colorado, September 1964.

3. M. S. Gazizov, "Geological Conditions and Ways of Development of Baltic Oil Shale Deposits," UN Symposium on the Development and Utilization of Oil Shale Resources, Tallinn, 1968.

4. Narodnoie khoziaistvo SSSR v 1970 g, Pub. "Statistika," p. 183, (Moscow 1971).

5. Teploenergetika, No. 12, p. 16 (1972).

6. M. I. Podkletnov, "Main Methods and New Trends in Shale Processing in the USSR," UN Symposium on the Development and Utilization of Oil Shale Resources, Section III, Tollinn, 1968.

7. N. K. Baybakov, "State Five-Year Plan for the Development of the USSR National Economy for the Period 1971-1975," Part I, JPRS-56970-1, p. 111 (Joint Publications Research Service, Arlington, Va., September 1972).

8. Ugol, No. 12, p. 28, 1972.

9. Ugol, No. 12, p. 27, 1972.

10. Ugol, No. 4, p. 74, 1973.

11. Teploenergetika, No. 12, p. 17, 1972.

12. N. V. Melrikov, Mineralnoe toplivo, Pub. "Nedra," p. 172 (Moscow 1971).

13. Melnikov, op.cit. p. 145.

14. S. L. Epshtein, "Problems of Purification of Atmospheric Air in the Shale Basin," UN Symposium on the Development and Utilization of Oil Shale Resources, Tollinn, 1968.

15. L. T. Grose, "Geothermal Energy: Geology, Exploration, and Developments," Parts I and II, Mineral Industries Bulletin, Vol. 14, No. 6, November 1971, and Vol. 15, No. 1, January 1972, Colorado School of Mines, Golden, Colorado.

16. "Geothermal Bibliography of the USSR," prepared by Informatics, Inc., for the Defense Advanced Research Projects Agency (DARPA), Washington, D. C.

17. F. A. Makarenko, B. G. Polak, and J. B. Smirnov, "Geothermal Field on the USSR Territory," XXIII International Geological Congress, Vol. 5, pp. 67-73, 1969.

18. A. N. Tichonov, E. A. Lubimova, and I. M. Dvorov, "Utilization of Underground Heat in the USSR," Academy of Sciences of the USSR, Moscow.

19. V. A. Stevovich, "Soviet Geothermal Electric Power Engineering--Report 2," NTIS Accession No. AD 754-947, December 1972.

20. "Soviets Eye Geothermal Development, "Oil and Gas Journal, pp. 122-124 (July 27, 1964).

21. S. T. Ovantanov and G. P. Tamrazyan, "Thermal Studies in Subsurface Structural Investigations, Apsheron Peninsula, Azerbaijan, JSSR," Bulletin of American Association of Petroleum Geologists, Vol. 54, No. 9, pp. 1677-1685, September 1970.

22. G. P. Tamrazyan, "Fundamental Differences Between the Temperatures at Depth in the European USSR and Adjacent Asiatic Regions," Doklady, Akod. Nank SSSR, Vol. 157, pp. 11-14, July-August 1964.

23. L. Stegena, 'Geothermal Map of Eastern Europe," Geothermics, Vol. 1, No. 4, p. 140, December 1972.

24. V. Cermak, "Terrestrial Heat Flow in Czechoslovakia and Its Relation to Some Geological Features," XXIII International Geological Congress, Vol. 5, pp. 75-85, 1969.

25. G. A. Waring, et al., "Thermal Springs of the United States and Other Countries of the World--A Summary," Professional Paper 492, U.S. Geological Survey, 1965.

26. T. Boldizsar, "Terrestrial Heat and Geothermal Resources in Hungary," Presented at International Symposium on Volcenology, Auckland, New Zealand, November 22-December 3, 1965.

27. T. Boldizsar, "Geothermal Energy Production from Porous Sediments in Hungary," Geothermics, Vol. 2, Part 1, Special Issue No. 2, pp. 99-109 (1970).

28. K. Korim, "Geological Aspects of Thermal Water Occurrences in Hungary," Geothermics, Vol. 1, No. 3, pp. 96-102 (1972).

29. O. Alliquander, "High Pressures, Temperatures Plague Deep Drilling in Hungary," Oil and Gas Journal, pp. 97-100, May 21, 1973.

30. L. Belteky, "Development and Utilization of Thermal Waters in Hungary," Geothermics, Vol. 1, No. 3, pp. 103-112 (1972).

31. J. Dowgiallo, "Occurrence and Utilization of Thermal Waters in Poland," Geothermics, Vol. 2, Part 1, Special Issue No. 2, pp. 95-98 (1970).

32. J. Dowgiallo and E. Tongiorgi, "The Isotopic Composition of Oxygen and Hydrogen in Some Brines from the Mesozoic in Northwest Poland," Geothermics, Vol. 1, No. 2, pp. 67-69 (1972).

33. C. Ghenea and M. Nicolescu, "Apercu General Sur Les Eaux Minerales et Thermales de Roumanie," XXIII International Geological Congress, Vol. 18, pp. 99-112, Prague, 1969.

34. "Uranium: Resources, Production and Demand," A Joint Report by the European Nuclear Energy Agency and the International Atomic Energy Agency, September 1970.

35. R. D. Nininger, "Geologic Distribution of Nuclear Raw Materials," Proceedings, Second UN International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, pp. 7-10, 1968.

36. J. A. S. Adams and C. E. Weaver, "Thorium-to-Uranium Ratios as Indicators of Sedimentary Processes: Example of Concept of Geochemical Facies.

37. J. Kratchman, "Regional Exploration Criteria for Uranium," Proceedings, Second UN International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, pp. 325-329, 1958.

38. A. P. Butler, Jr., "Geologic Appraisal of Uranium Resources of the United States," Second UN International Conference on the Peaceful Uses of Atomic Energy, Vol. 2, pp. 11-16, 1958.

39. G. N. Popv and D. P. Lobanov, "Razrabotka Mestorozhdenii Radioaktivnykh Rud" (Mining of the Radioactive Ores), Moscow, 1970.

40. Symposium on Uranium Recovery, International Atomic Energy Agency, Sao Paulo, 1970; Vienna 1971.

41. U.S. Congress Joint Committee on Atomic Energy, 1961. Hearings on International Atomic Policies of the United States, pp. 1613-1618.

BIBLIOGRAPHY
(Geothermal Studies)

Alexandrov, A. L., E. A. Lubimova, and G. A. Tomara, "Heat Flow through the Bottom of the Inner Seas and Lakes in the USSR," Geothermics, Vol. 1, No. 2, 1972, pp. 73-80.

Arshavskayra, N. I., I. G. Berzina, and E. A. Lubimova, "Geochemical and Geothermal Parameters for the Pechenga and Ricolatva Regions, Baltic Shield," Geothermics, Vol. 1, No. 1, 1972, pp. 25-30.

Kutas, R. I., "Investigation of Heat Flow Anomalies in Some Regions of the Ukraine," Geothermics, Vol. 1, No. 1, 1972, pp. 35-39.

Lubimova, E. A., et al, "Terrestrial Heat Flow on Pre-Cambrian Shields in the USSR," Geothermics, Vol. 1, No. 2, 1972, pp. 81-89.

Lubimora, E. A., U. A. Zor'n, and S. V. Lysak, "Geothermal Anomaly in the Baikal Lake Region," Geothermics, Vol. 1, No. 1, 1972, pp. 31-34.

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