AN EVALUATION OF THE SHELTER POTENTIAL IN MINES, CAVES AND TUNNELS

By

Robert A. Krupka

HI-507-RR June 11, 1965

Prepared under Contract Number OCD-PS-64-116, Subtask Number 4211-B, for the Office of Civil Defense, Department of the Army, Washington 25, D.C.

OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

Qualified requestors may obtain copies of this report from Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

The DDC will make copies of this report available to the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, Department of Commerce, for sale to the general public.

HUDSON INSTITUTE, INC.
Quaker Ridge Road
Harmon-on-Hudson
New York

ACKNOWLEDGMENTS

The author wishes to thank the following people for their advice and assistance.

Mr. Ronald D. Doremus, Vice President, National Limestone Institute, Inc.

Mr. Robert H. Rose, National Speleological Society.

Mr. C.M. Kasparian, Office of Civil Defense, Office of the Secretary of the Army.

At Hudson Institute, helpful advice was received from Frederick C. Rockett and William M. Brown, and assistance from Roberta Siegel and Michael Feilding.

SUMMARY

Some of the current interest in the active-passive defense field involves the design of high-performance damage-limiting systems. This study examines the availability and the potential of using mine space (and to a much lesser extent, cave and tunnel space) in future civil defense programs.

The study gives some background information concerning the previous research on the use of mines for shelter and suggests that the available survey information was inadequate to allow reasonable estimates to be made of potential. New estimates of usable space and yearly space increases are given, based on a sample survey of a few mines. The paper also discusses the possibilities and costs of developing new mine space and adapting mines to shelter use.

Information on caves and tunnels is also given. The study estimates cave potential at about 4 million spaces and railroad and vehicular tunnels at about 2 to 3 million spaces. Although this potential is very small compared to that available in mines, caves and tunnels may prove to be important assets in particular locations.

The study concludes that:

1. The use of mine space deserves renewed interest because previous estimates of the potential were probably grossly underestimated. Our estimate of current high-quality mine space potential is about one billion square feet augmented by a minimum growth rate of 55 to 70 million square feet per year. This space is available as follows:

Limestone Mines: 600-700 million square feet in more than 200 underground workings. Estimated increase is 43 to 57 million square feet per year.

Salt Mines: 200-300 million square feet located 600 to 1,200 feet below ground level accessible only by small shafts. The space is dry and regular in shape. Increase is estimated at 8 million square feet per year.

Gypsum and Sandstone Mines: About 50 million square feet located in a few large mines and increasing at 2 to 3 million square feet per year.

Our total estimates do not include space available in the lead-zinc mines, high-priced ore mines or in coal mines which could be considered in some programs. Coal mines, which had previously been considered too hazardous for use as shelters, are included (substantially) in the NFSS. As of June, 1964, the NFSS contained about 1,000 mines totaling 5.4 million spaces. Of these, approximately 370,000 spaces are located in about 80 coal mines, mostly in Kentucky.

2. Presuming willingness to have shelter space further than the 25-mile limit currently used in the NFSS,* mine space might prove important in making up non-city deficits and for possible use by some of the urban population.

3. Mines offer the possibility of superior protection which could save many lives as compared to home basements and many NFSS shelters.

4. It appears possible to create new shelter space in selected areas by encouraging operators of limestone quarries to convert to

*Facilities which lie outside a Standard Metropolitan Statistical Area boundary and which are between 25 and 50 miles from the center of a populated area can be considered for use in the NFSS upon request of local, state or regional CD directors.

underground operations or to develop new mines. This mine space would become available at about one-tenth the cost of constructed fallout shelter space.

5. The cost of adapting mines to shelter use will vary from zero to about $100 per space, depending on existing facilities, access, location and geological factors. In a national program using mines to a large extent, we believe it possible to develop 100 million high-quality spaces for under $5 billion.

6. Developing undergroung space might prove an attractive alternative to building shelters in accelerated programs (1-4 years), since the construction force is in place and structural material requirements would be reduced.

The following recommendations are made:

1. An underground assets survey should be undertaken to increase the knowledge of existing and potential mine space and to determine feasibility of its use in nation-wide programs. A survey of this kind should include a study of the relationship between the location of space and population centers and the amount of space which could be planned for use.

2. A study of the feasibility of underground shelter systems using existing and new mine space should be undertaken and might be part of the "5 City Study."

3. Further investigation should be made to determine alternative means of acquiring and encouraging the development of suitable mine space at specific locations.

4. Alternative implementation plans and preparations should be considered for using mines in various kinds of Increased Readiness Programs.

A separately bound volume containing three appendices is included as part of this report. It contains detailed listings of NFSS mines and caves and detailed listings and locations of railroad and vehicular tunnels. This data is intended for possible use by those researchers desiring to undertake more specific studies of shelter potential in mines, caves and tunnels.

TABLE OF CONTENTS

INTRODUCTION

This study examines the availability and some costs of mines and, to a lesser extent, caves and tunnels for possible use as shelter in future civil defense programs. The importance of these potential resources is now considered by us to be greater than it was in the past owing to the apparent usefulness and practicality of civil defense programs aspiring to levels of protection heretofore thought to have excessive cost. Very effective civil defense programs seem to have a procurement cost that is comparable to the figure assumed for the fallout shelter program in DOD damage-limiting studies. The extensive use of mines could constitute an important element in these programs not only because they meet such basic life-saving criteria as often being located outside expected blast areas and always providing at least minimum fallout protection for survival, but because they also offer considerable hardness at low cost and protection of health from radiation effects, and they tend to avoid or reduce domestic debate and unfavorable international responses.

The development of highly effective, low-cost civil defense programs is possible for situations in which (1) there would be a period of two or more days during which preparations and operations could take place; (2) plans and preparations had been made which took advantage of time available; and in which (3) survival measures do not stop with the first detonation, but continue during and after attack. A more complete discussion of these points is contained in a report by William M. Brown[1] and will not be repeated here. This study of mines, caves, and tunnels is intended to explore tentatively a potential source of shelter which may be more important when these assumptions are made. In particular, these resources are made more practical by population movement from expected target areas--a passible primary protective measure against blast and thermal effects in low-cost "zero-casualty" civil defense programs.

If high-quality blast shelters were not available and urban evacuation was employed, it is only reasonable to utilize the best available fallout protection. In many possible contexts and locations, mines offer an attractive option. They have a PF which approaches infinity, thus insuring survival from radiation even in areas having extremely high radiation fields. Also, mines offer some blast and a high degree of thermal protection. These qualities suggest that mines have advantages in predicted attacks that raise the confidence for survival, and they have more effectiveness than non-city basements and NFSS shelters in unexpected attacks.

One of the most important advantages of space in mines, caves and tunnels is its low cost compared to developed shelter. Many mines offer space at about the cost of NFSS shelter in existing buildings. Few mines would require expenditures equal to the cost of developed shelter. Thus, from a cost standpoint alone, mines are attractive.

The cost and effectiveness of mines are significant in DOD procurement planning for damage-limiting capability. Recent studies reported to the Armed Services Committee have assumed about $5 billion for a fallout shelter program. For the same budget extensive use of mines would radically change the characteristics and total effectiveness of an optimum damage-limiting program.* For low to moderate procurement budgets ($1-3 billion per annum) civil defense appears to have greater marginal utility than

---

*Some calculations bearing on this matter are presented in a report by William M. Brown.[2]

more bomber defense or BMD. Mines could contribute to this favorable cost/effectiveness estimate.

Another but possibly lesser advantage of mines as shelter is their low domestic and international visibility. The acquisition and development of mines would probably be less noticeable to the public and to allies and potential enemies.* Low visibility contributes to reduced possibility of arousing domestic controversy and strategic responses.

This paper represents the results of a limited study of the shelter potential in existing mines and the possibilities of developing new space. The study examines some of the available data on mines and estimates the current and the yearly increase of potential space in suitable mines.

Some information is given on adapting mines for use as shelters, including site and cost examples. Data on caves and tunnels is also included.

*Less noticeable than, say, an urban blast shelter building program or the deployment of an ABM system.

GENERAL CHARACTERISTICS

The mining industry consists basically of two types of operations. The first is quarrying or open-pit mining and the second is tunneling. We are primarily interested in the tunneling operations, although it is possible that with proper incentives* some open-pit operations might possibly be converted to tunnel operations.

Mining is generally carried out in a single-ore vein. The operator is interested in removing as much of the vein as possible and in doing it as cheaply as possible. In mining high-priced ores** (gold, silver, platinum etc.) the vein will be followed in any direction and the operation continued even if it is required to support the entire length of the excavation.

Due to the interest in removing all of the vein, the operator will shave any remaining supporting pillars and will usually excavate a complete formation between two others representing the floor and the ceiling. These residual pillars are often calculated as part of the value of the diggings and their removal assumed when the main operation is completed. Miners call this "robbing the pillars." This often results (especially in coal mines) in collapse of the ceiling or in severe instability of the cavity.

With regard to such mines, it is known that the space which might be available for use as underground installations is generally irregular in chamber size, floor elevation and ceiling height. We can therefore conclude that spaces resulting from mining high-priced ores may not be considered

---

*Especially for limestone operations.

**The price is high enough to justify mining the entire vein, seam or bed, or even much adjacent country rock as well as in the case of rich gold veins.

highly habitable and safe shelter space. This does not mean that the use of such space is a last-order alternative.* For example, some large lead and zinc mines in Oklahoma and Kansas could possibly be used with little loss of habitability compared to other mines and with little expense in safety measures.

Generally, the more suitable space for shelter results from mining low-priced ores such as limestone, halite (rocksalt) and gypsum which are found sufficiently below the surface to require a tunneling operation for removal.

The operator of the low-grade ore mine has different interests from the operator of the high-priced ore mine. He is interested in rapid advances and extracting large volumes of rock from a limited number of access portals or shaft heads. He will therefore not be concerned with robbing pillars but will be very interested in maintaining the structural integrity of the space between the working faces and the exits.

The operator is also interested in minimum excavation cost and uses heavy equipment such as shovels, heavy dump trucks and large mucking machines. This results in minimum ceiling heights of about 14 feet, a limit set by the type of equipment employed. Maximum ceiling heights used depend on the thickness of the vein, structural considerations and the economics involved in heightening the cavity versus lengthening the tunnels. Some mines have ceiling heights of up to 100 feet (see Figure 1). This, then, results in space consisting of rooms or chambers, laid out (more or less) in a regular pattern with level floors and ceilings, completely self-supporting and, in most places, dry (see Figures 2, 3, and 4).

---

*In fact, several coal mines are included in the current NFSS listings (see Appendix I). This represents a change in thinking, since previous studies categorically dismissed coal mines as being too hazardous.

FIGURE 1

Vertical Mining at Morton Salt Company Mine,
Grand Saline, Texas

FIGURE 2

Limestone Mine 2,200 Feet Underground, Barberton, Ohio

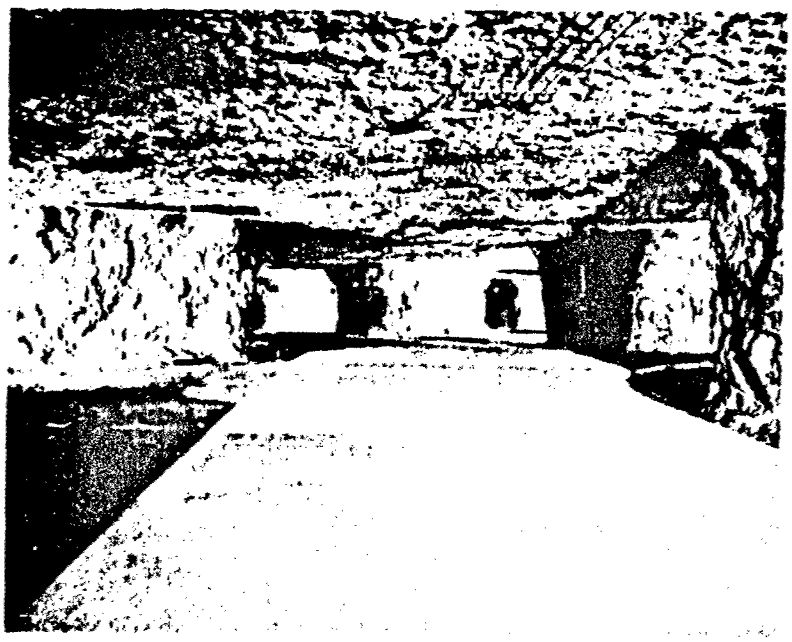


FIGURE 3

Roadway in Atchison, Kansas, Limestone Mine

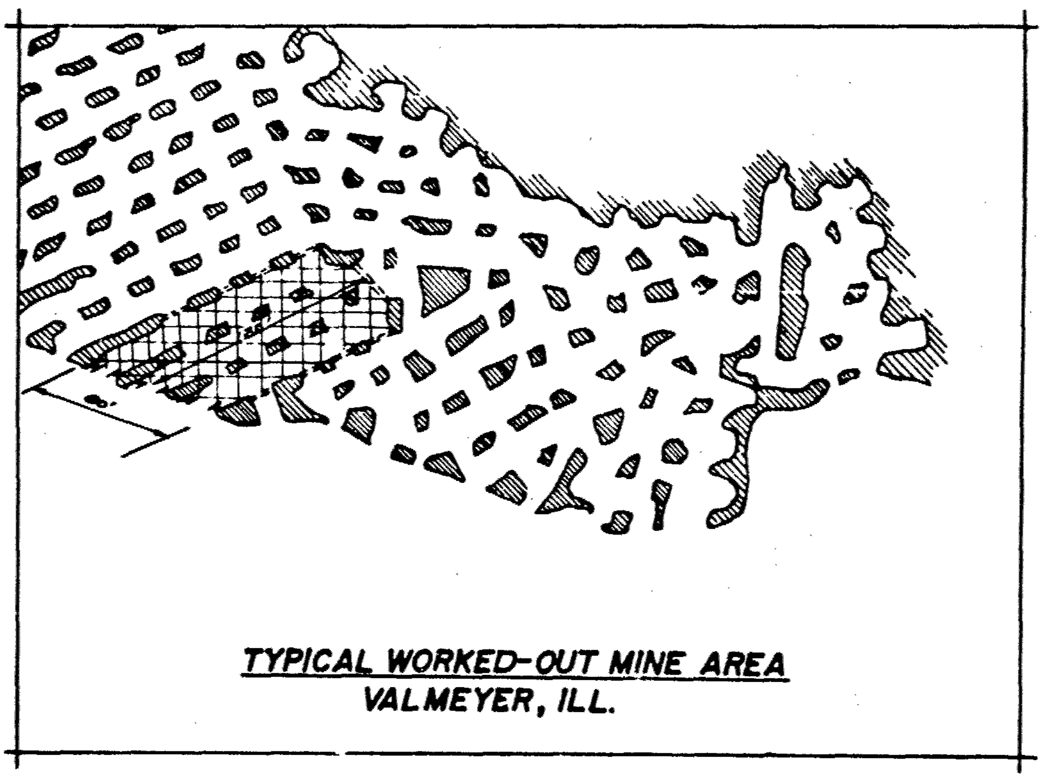


FIGURE 4

Limestone Diggin's in Valmeyer, Missouri,
20 Miles South of St. Louis

BACKGROUND INFORMATION ON MINE STUDIES

About 20 years ago, the Corps of Engineers awarded a contract to an engineering firm to "determine the feasibility and cost of constructing and operating strategic defense plants underground." This resulted in a series of nine confidential reports and three appendices (since declassified).[3]

Part of this effort was concerned with the adaptation of existing mines to industrial use. The civilian firm and the U.S. Army Corps of Engineers investigated 147 existing mining areas which met the following requirements:

1. Cover of not less than 50 feet
2. Area of not less than 25,000 square feet
3. Minimum room sizes of 20-foot widths and 10-foot heights
4. A floor grade not in excess of three per cent.

The total area was found to be 327 million square feet. Of this total, approximately one-third was found accessible by horizontal drift entrances. Ninety-five per cent of the drift mine space was in units of over 500,000 square feet per mine. Eighty-five per cent of the remaining space, accessible by shaft entrances, was in units of over a million square feet, the majority being located in mines less than 500 feet deep.

Limestone mines accounted for most of the space, with salt mines next. The rest was made up of lead-zinc, sandstone, gypsum, slate, potash, and mines exploiting other minerals. Potash accounted for almost 10 per cent of the total; the space was located in two Carlsbad, New Mexico, shaft mines of 15,000,000 square feet each.

Discounting the New Mexico sites and other "disproportionate" sites,* states with large amounts of space distributed in many mines included Pennsylvania, Missouri, New York, Kansas, and Illinois.

This, then, comprised the basic data for estimating existing underground space. Around 1952, an attempt was made to update the original information. The results of the updating (along with some of the original data) were prepared in unclassified form by the Office of the Chief of Engineers.[4] This document contains a composite listing of some 310 mines totaling about 470 million square feet of space. The updating procedures, as will be discussed later, are somewhat hazy and misleading and the final listing contains some significant errors.

The last known updating of this information was done in 1957 and is contained in a study prepared first for the RAND Corporation[5] and then for the Federal Civil Defense Administration. It attempted not only to estimate the increase in suitable space but also to use and adapt the original 1948 information for civil defense (shelter) purposes.

This effort, insofar as estimating existing mine space was concerned, was very limited. The updating procedure consisted basically of telephone spot-checks of 20 mines listed in the original data** and applying the apparent percentage increase on a nation-wide basis. In addition, some new mines were identified in 1957 and included in the listings. The 20 mines comprising about one-third of the total original area of 327 million square feet are listed in Table 1. The percentage increase was determined as shown and applied to the 1948 listings.

---

*55 million square feet of lead-zinc space around Picher, Oklahoma.

**The data published in 1948 (Ref. 3), not the Corps data as published in 1956 (Ref. 4).

TABLE 1

1957 INVESTIGATION OF USABLE EXISTING MINES[6]

	1948 List Mines Investigated	Area in M.S.F. 1948	 1957	
1.	West Winfield Mine, W. Winfield, Pennsylvania	0.500	4.050	
2.	Dunbar Mine, Dunbar, Pennsylvania	0.500	0.600	
3.	Buffalo Creek, Worthington, Pennsylvania	11.832	13.000	
4.	Vang, Casparis, Pennsylvania	0.500	0.500	
5.	Medusa, Wampum, Pennsylvania	4.000	4.000	
6.	Cambria, Wampum, Pennsylvania	0.450	0.450	
7.	Annandale, Boyers, Pennsylvania	24.000	48.250	
8.	Les Buchannon, Forestville, Pennsylvania	0.435	0.435	
9.	Kaylor Mine, Kaylor, Pennsylvania	14.390	26.500	
10.	Sugar Creek, Independence, Missouri	5.000	10.500	
11.	Pixley, Independence, Missouri	2.610	6.000	
12.	Kansas City Quarries, Kansas City, Missouri	0.435	1.500	
13.	Thompson Limestone Mine, Kansas City, Kansas	1.500	12.400	
14.	International Salt Co., Detroit, Michigan	1.250	14.780	
15.	Retsof Salt Mine, Retsof, New York	25.000	45.700	
16.	Independent Salt Mine, Kanopolis, Kansas	3.000	0.700	(?)
17.	Centropolis, Kansas City, Missouri	1.500	8.500	
18.	Natural Cooler, Atchison, Kansas	0.501	2.000	
19.	Kerford, Atchison, Kansas	0.500	1.000	
20.	Morton Salt, Kanopolis, Kansas	11.590	0.000	(?)
	TOTALS:	109.493	200.865	

Difference = 91.372 M.S.F.

% Increase in area = 83%

$$\left(\frac{91.372}{109.493} \times 100 = 83\% \right)$$

Now, although this should have resulted in an estimate of about 600 million square feet, the published estimate was more than 750 million square feet (Table 2). The difference presumably represented the additional space found during the study. In checking the data, our investigation indicated that an additional 150 million square feet of limestone and lead-zinc space was located in Missouri and about 20 million square feet of additional lead-zinc space in Oklahoma. We have not been able to corroborate these estimates.

Qualification to the Data

For several years this background information has been considered "best-source" research information by the Office of Civil Defense and some of its contractors. Specific estimates of available shelter in mines have been made using this data, particularly in the 1961 Technical Operations report entitled, "Shelter from Fallout."[7] This report used the original Corps data directly and concluded that under some conditions (mines close to people, drift entries, proper habitability provisions, etc.)...

> ...2,000,000 to 4,000,000 people of the continental United States might realistically take advantage of the theoretical 47,000,000** shelter spaces in mines....[8]

Because such estimates are made, we are inclined to comment on the validity of the source information.

First, the original 1948, 1952 Corps compilation of mine space was never intended to be taken as a comprehensive list of available underground

---

*From 470,000,000 square feet at 10 square feet per space.

TABLE 2

SUMMARY OF ESTIMATED PRESENT
TOTAL USABLE AREA OF MINES (1957)[9]

State	Number of Sites	Area in 10^6 Sq.Ft.
Alabama	1	0.408
Arizona	1	0.110
Arkansas	1	0.320
California	6	3.536
Colorado	1	0.174
Illinois	13	12.104
Indiana	3	2.610
Iowa	3	2.760
Kansas	19	75.240
Kentucky	9	7.360
Louisiana	4	11.700
Maine	1	0.055
Michigan	2	20.740
Minnesota	2	0.366
Missouri	26	208.900
Nebraska	2	1.190
Nevada	3	0.992
New Mexico	2	54.170
New York	11	119.610
North Carolina	1	0.183
Ohio	7	10.330
Oklahoma	57	123.060
Pennsylvania	17	106.000
Tennessee	7	3.640
Texas	1	1.100
Vermont	2	1.230
Virginia	4	0.680
West Virginia	5	10.720
Wisconsin	7	8.400

TOTAL STATES: 29

TOTAL MINES: 218

TOTAL AREA: 787,688,000 Sq. Ft.

space. It was only supposed to be "taken as indicative of the types of mines existing for possible utilization by industry." That means the investigators were interested only in big areas--near railroads, in industrial area complexes, and deep (i.e., 50 feet--very deep for fallout protection). Less than 10 per cent of the sites were under 75,000 square feet (big shelter).

The 1948 study had these particular caveats:

> The sites listed do not include all existing mines, but only those which appear reasonably adaptable in case of emergency. Many mines were eliminated as being small, dangerous or otherwise impractical to adapt to industrial use. No coal mines are included, due to dangerous nature of their roofs, the low headroom, and the extreme gas and water conditions.[10]

So far as the usefulness of the data for our purposes is concerned, these caveats have interesting implications. The first statement seems to convey the feeling that all underground space was located and that the list was trimmed to fit the application. The second sentence implies that these were investigated (or at least the plans or descriptions pre-used) to eliminate sites which did not meet the criteria. The third is obvious. For industrial use, most coal mines would not be attractive.

Although attempts were made to cover the country in the 1948 study, it was not possible to gather all of the mine data. The study was very selective. It concentrated on industrial areas only, using data as it was readily available through large mineral producers or through those state geological departments which were able to make such information available. Only 28 states were noted as having suitable space.

In our limited investigations, we were not able to determine the extent of the 1948 survey nor to obtain an estimate of the number or total space failing to meet the industrial criteria used in the study. Presumably, since current criteria for adequate fallout shelter space is less stringent, more than 327 million square feet of usable mine space existed in 1948. In addition, we do not categorically exclude all space in coal mines. Although many sites may not be usable for industrial or shelter use (due to gas hazards, instability, low headrooms, etc.), a significant number of shelter spaces may be considered usable at selected sites or in the portals of others. (NFSS shelter location efforts have included many coal mines.)

A second set of comments concerns the data published in 1956 containing the list of 310 mines totaling some 470 million square feet. In spot-checking the list, we found some errors. Some are significant, some are not. Among these are the following:

1. The New Mexico listing shows three potash mines at Carlsbad, each at about 14 million square feet. Two of these mines (one under the name "Union" and the other under the name "Union International Corp.") are the same mine. This changes the apparent total New Mexico space from 43,600,000 square feet to 28,000,000 square feet.
2. The Pennsylvania listing shows a 24,500,000 square foot limestone mine under the name "West Pennsylvania Cement Company, West Winfield." A check of the area failed to verify the existence of this facility.

3. The Detroit, Michigan, listing shows two salt mines, one under the heading "Detroit Salt Mine" having 7,405,000 square feet and the other listed as "International Salt Company" having 1,250,000 square feet. These are the same mine.

Other listings which appeared in this data but not in the 1948 report also appear suspect. However, we were not able to uncover other significant errors. These examples are given as a caution to those using such information in estimating shelter potential in mines.

In conclusion, we suggest that the mine information needs "gathering" and updating. Mine space potential is a dynamic parameter. Total space is changing. It is the sum of the area increases in working mines and the potential in new diggings. The characteristics of mines as shelters have not been studied closely. This too requires additional effort to make sound developments of civil defense plans.

CURRENT ESTIMATES OF MINE SPACE POTENTIAL

In this section we will make some estimates concerning the current potential space and possible increases. These estimates are made without benefit of any survey work or extensive sampling.* The information used came from the following sources:

1. Existing Corps of Engineer data
2. National Limestone Institute
3. Some large producers (i.e., International Salt, National Gypsum)
4. Some independent operators
5. NFSS data as of June, 1964.

Salt Mines

A summary of information obtained on salt mine space is shown in Table 3. This is a fairly comprehensive listing of existing mines, although much of the data on area is lacking. Using a sample of mines in existence in 1946 and the data gathered by Hudson Institute in 1964, the over-all space has apparently increased by a factor of about 3.5. Assuming all salt mines increased by the same factor, one would judge the existing space to be around 300 million square feet.

However, because it is possible that some of the mines not included in the sample may have ceased operations, or did not increase at the same rate, this figure might be high. Using only the 1961 data and rocksalt production figures,[11] we estimate the potential to be not less than 200 million square feet.

---

*We did not contact official agencies (i.e., Bureau of Mines, state geologists, etc.) outside of the Office of Civil Defense, and did not systematically contact mine operators. Such detailed work is beyond the scope of this report.

Rocksalt production is now about 8 million tons per year and over a ten-year period showed a rate increase of about one-third million tons per year. All of this production comes from the deep mines. Solid halite weighs about 1.8 tons per cubic yard. The expected increase in mine volume is then:

$$\frac{8 \times 10^6}{1.8} = 4.4 \times 10^6 \text{ cubic yards or}$$
$$120 \times 10^6 \text{ cubic feet}$$

Most of this space has a ceiling height between 10 and 20 feet. Assuming an over-all average of 15 feet, the annual increase in area would be about 8 million square feet. This seems about right, judging from information supplied by large producers.

The distribution of salt complexes is shown in Figure 5. All of the space is deep underground (600-1,200 feet) and has very limited shaft access. The Retsof, New York, complex encompasses about 2,700 acres of salt vein and is perhaps the largest salt mine in the world.[12] Locations of other large mines include Detroit, Cleveland, Hutchinson (near Wichita) and central and southern Louisiana.

The excavated areas are typically flat, regular in shape, and would require very minor trimming and cleanup to permit installation of shelter facilities. The mines are very dry. Ambient temperature is between 50° and 60° F.

Although much of this space is available and convertible to use as shelter, performance problems arise in terms of distribution with respect to the population, access rates and habitability (especially ventilation). In these respects salt mines are less suitable than, say, the multiple-drift entry limestone mines.

TABLE 3

SALT MINES

NAME OF MINE	TOWN	STATE	TYPE OF ACCESS	ROOM WIDTH & HEIGHT (FT.)	MIN. COVER (FT.)	AREAS - SQ.FT. x 10^{-3} 1946 (1)	1952 (2)	1957 (3)	1964 (4)	INCREASE PER YEAR (5)
AMERICAN SALT COMPANY										
Lyons	Lyons	Kansas	Shaft	50x10	1,010	4,140	-	-	-	-
CAREY MONSANTO COMPANY										
Cote Blanche	Cote Blanche	Louisiana	-----------------------New Mine-----------------------------------							
CAREY SALT COMPANY										
Winnfield	Winnfield Parish	Louisiana	1 shaft	50x20-60	600	619	-	-	2,000	-
Hutchinson	Operation #3	Kansas	1 shaft	50x10	600	2,668	-	-	12,000	218
Lyons	Operation #5	Kansas	1 shaft	50x12	1,012	2,175	-	-	-	-
CARGILL, INCORPORATED										
Belle Island	Belle Island	Louisiana	------------------New Mine----Shaft sunk to 1,250 feet in 1962--------							
CAYUGA ROCK SALT COMPANY										
Myers	Myers	New York	2 shafts	40-60x10-80	1,200	5,000	5,000	-	-	-
DIAMOND CRYSTAL SALT COMPANY										
Jefferson Is.	Jefferson Island	Louisiana	2 shafts	60x70	740	2,004	-	-	-	-
INDEPENDENT SALT COMPANY										
"	" Kanopolis	Kansas	Shaft	42x10	830	3,000	700?	-	-	-

KEY:

1. From "Report-Underground Installations-Sites and Geological Formations," October 31, 1948. Prepared for Chief of Engineers, U.S. Army, under Contract W-49-129-Eng.-59, Guy B. Panero, Engineers, New York, N.Y. (data gathered in 1946).
2. From "Underground Plants for Industry," DOD-DOA-OCD. January 1956 (material from (1) except data gathered in 1952).
3. From "Preliminary Report for the RAND Corporation, Santa Monica, California, on Usable Existing Mines and New Site Formations," Guy B. Panero, Engineers, New York, N.Y., December 1957.
4. Data gathered in 1964 by Hudson Institute.
5. Increase Per Year estimated by Mine Operator; data gathered by Hudson Institute.

TABLE 3 (Continued)

SALT MINES

NAME OF MINE	TOWN	STATE	TYPE OF ACCESS	ROOM WIDTH & HEIGHT (FT.)	MIN. COVER (FT.)	AREAS - SQ.FT. x 10^{-3} 1946 (1)	1952 (2)	1957 (3)	1964 (4)	INCREASE PER YEAR (5)
INTERNATIONAL SALT COMPANY										
Detroit	Detroit	Michigan	2 shafts	50-60x20-22	1,180	1,250	7,405*	14,780	25,000	1,000
Retsof	Retsof	New York	2 shafts	65-85x10	1,130	25,000	10,000**	45,000	60,000	3,000
Cuylerville+	Cuylerville	New York	2 shafts	40-50x8-12	1,100	6,000	-	-	-	-
Leicester+	Leicester	New York	2 shafts	40-50x8-10	1,100	22,000	22,000	-	-	-
Avery Island	Avery Island	Louisiana	2 shafts	70x80	500	1,367	-	-	-	-
Cleveland (Whiskey Is.)	Cleveland	Ohio	----------------New Mine----------------							
MORTON SALT COMPANY										
Weeks	Iberia Parish	Louisiana	2 shafts	50x70	700	-++	-	-++	1,413	152
Kanopolis	Kanopolis	Kansas	2 shafts	45x11-15	810	11,590	0‡	-	-	-
Kleer	Grand Saline	Texas	Shaft	50-70x20-80	700	602	-	-	-	-
Fairport	Grand River	Ohio	----------------New Mine----------------							
Other Mines Appearing in References (3),(4),or (5) but Not Currently Identified as to Ownership or Operational Status:										
UNITED SALT COMPANY										
" "	Hockley	Texas	Shaft	30x25	?	-	63	-	-	-

*Ref. (2) lists two Detroit Mines. One is the original Ref. (1) listing at 1,250,000 sq. ft. The other is under the name "Detroit Salt Mine" at 7,405,000 sq. ft. Apparently these are one and the same mine.

**Apparent error.

+Part of 2,700-acre Retsof complex.

++Reference (1) lists a mine at Weeks, Louisiana, to the Myles Salt Company, and Ref. (3) changed the name to the Morton Salt Company. Listing shows shaft, 62x65 feet room size, 500-foot minimum cover, 2,209,000 sq. ft. in 1948.

‡Reference (3) shows 0,000 sq. ft. area (?).

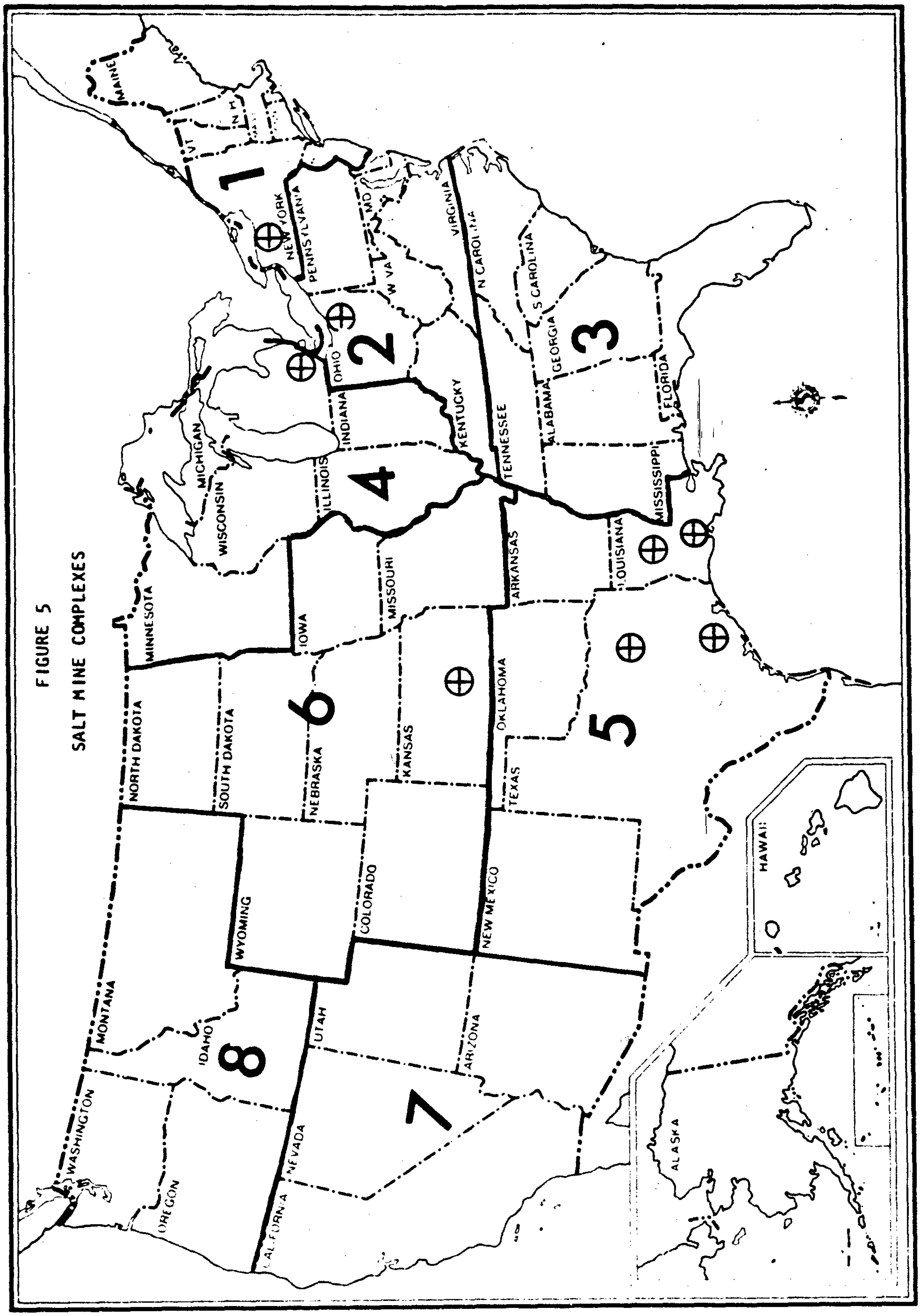


FIGURE 5
SALT MINE COMPLEXES

Limestone, Sandstone, and Gypsum Mines

Shelter potential in these geological formations, especially in limestone, will generally be of most interest to us. Limestone mines contain most of the suitable space in terms of distribution, access, ease of adaptation and growth potential.

The 1946 data identified about 100 mines in 16 states with a total space of about 200 million square feet. The 1957 sampling of 10 mines in Pennsylvania, Missouri, and Kansas which were known to be operating* (and still are) showed an increase from 62 million to 131 million square feet. If the other working mines increased at the same rate, the 1957 potential could not have been less than 400 million square feet.

A sampling of six working mines shows an increase in space between 1946 and 1964 of over 300 per cent (see Table 4). We therefore judge the current minimum space in the known mines at about 600 million square feet. To this must be added the space available in working mines not originally listed and space in inactive mines and in the new operations. Of the 24 mines listed in Table 4, only 9 appeared in the 1948 or 1956 published reports. Of the remaining 15, we were not able to obtain data on 9 (other than of their existence). Four of the newly located mines have about a million square feet or over. One mine near Kansas City (Midwest Precote Co.) was investigated in 1957 and increased from 2 million to 10 million square feet as of 1964.

*Some of the mines in the original 20-mine sample have ceased operations and converted the space to storage facilities (e.g., Medusa Mine, Wampum, Pa.; and Kerford Quarries, Atchison, Kansas).

TABLE 4

LIMESTONE, SANDSTONE, AND GYPSUM MINES

NAME OF MINE	TOWN	STATE	TYPE OF ACCESS	ROOM WIDTH & HEIGHT (FT.)	MIN. COVER (FT.)	AREAS - SQ.FT. x 10^{-3} 1946 (1)	1952 (2)	1957 (3)	1964 (4)	INCREASE PER YEAR (5)
NATIONAL GYPSUM COMPANY										
Shoals	Shoals	Indiana	3 shafts	40x15	350	-	-	-	3,700	400
Sun City	Sun City	Kansas	Drift	40x8-12	12-80	290	-	-	-	-
Clarence Ctr.	Clarence Center	New York	No Information							
Bellefonte	Bellefonte	Penna.	1 drift 1 shaft	35-10x15-6	300	-	250?	-	200	10
Kimballton	Kimballton	Virginia	1 drift	20x10 min.	40*	-	-	-	998	25
York	York	Penna.	Drift	30x6-10	7-28	No Information				**
UNITED STATES GYPSUM COMPANY (Active Mines)										
Gypsum	Gypsum	Ohio	1 drift	10-20x11	50-60	1,500	-	-	-	-
Heath	Heath	Montana	No Information							
Oakfield	Oakfield	New York	No Information							
Plasterco	Plasterco	Virginia	No Information							
Shoals	Shoals	Indiana	2 shafts	30x10	350	-	-	-	3,485	440
Sperry	Sperry (Des Moines)	Iowa	No Information							
UNITED STATES GYPSUM COMPANY (Inactive Mines)										
Fort Dodge	Fort Dodge	Iowa	No Information							
Midland	Midland (Riverside)	Cal.	No Information							
Southard	Southard	Oklahoma	No Information							
Sweetwater	Sweetwater	Texas	No Information							

KEY:

1. From "Report-Underground Installations-Sites and Geological Formations," October 31, 1948. Prepared for Chief of Engineers, U.S. Army, under Contract W-49-129-Eng.-59, Guy B. Panero, Engineers, New York, N.Y. (data-1946).
2. From "Underground Plants for Industry," DOD-DOA-OCD. January 1956 (material from (1) except data gathered in 1952).
3. From "Preliminary Report for the RAND Corporation, Santa Monica, California, on Usable Existing Mines and New Sites."
4. Data gathered in 1964 by Hudson Institute.
5. Increase Per Year estimated by Mine Operator; data gathered by Hudson Institute.

*Dips to 900-foot cover under mountain.

**Not listed as currently operating.

TABLE 4 (Continued)

LIMESTONE, SANDSTONE, AND GYPSUM MINES

NAME OF MINE	TOWN	STATE	TYPE OF ACCESS	ROOM WIDTH & HEIGHT (FT.)	MIN. COVER (FT.)	AREAS - SQ.FT. x 10^{-3} 1946 (1)	1952 (2)	1957 (3)	1964 (4)	INCREASE PER YEAR (5)
BAY CITY SAND COMPANY										
Bay City	Bay City	Wisconsin	3 drifts	40x40	400	300	-	-	2,500	104
BLACK WHITE LIMESTONE COMPANY										
Black White	Quincy	Illinois	4 drifts	50x12-24	100	392	300	-	1,800	150
FORT DODGE LIMESTONE COMPANY										
Fort Dodge	Fort Dodge	Iowa	1 drift 1 shaft	60-90x20-30	105	260	-	-	800	50
MIDWEST PRECOTE COMPANY										
Randolph	Kansas City	Missouri	15 drifts	20x10 min.	60	-	-	2,000	10,000	400
MISSOURI PORTLAND CEMENT COMPANY										
Kansas C. Plant	Sugarcreek	Missour'	2 drifts	36x18-36	40	5,000	-	-	8,700	Min.
SOUTHWEST LIME COMPANY										
Neosho	Neosho	Missouri	2 drifts	20x20	40	-	80	1,750?	1,100	None
THOMASVILLE STONE & LIME COMPANY										
Thomasville	Thomasville	Penna.	2 drifts	40x17x-60	37	-	-	-	135	Min.
PITTSBURGH PLATE GLASS COMPANY										
Barberton	Barberton	Ohio	2 shafts	32x17-46-70	2,200	955	-	-	7,400	370

The limestone industry currently operates about 1,800 mines and quarries (see Figure 6 on page 37). The National Limestone Institute represents the owners of about 1,000 of these, 90 of which are underground, working complexes. The NLI people estimate that, nation-wide, there are more than 200 underground workings which extract between 15 and 20 per cent of the total production.* Their rough estimate, based upon production figures obtained over the last 20 years, is that the excavated space amounted to around 400 million cubic yards. Assuming an average ceiling height of 7 yards, this is equivalent to about 500 million square feet. Therefore, assuming a minimum figure of 200 million square feet in 1946, we should expect to find at least 600-700 million square feet in limestone mines alone.

For gypsum and sandstone mines, the space and production data we collected seems to indicate that their potential is much smaller than that of the limestone mines. The gypsum industry currently operates 16 underground mines. We also know of four inactive mines. Using our very limited sample, we guess the aggregate space at about 50 million square feet. The potential in sandstone mines is probably much less. Some individual mines, each over 2 million square feet, exist in Missouri and Illinois. All have multiple-drift entries.

Current limestone production is about 500 million tons. Using the NLI estimates, 75-100 million tons comes from the mines. Solid limestone

*Nearly two-thirds of the production goes into making concrete aggregate and roadstone and manufacturing Portland cement.

weighs about 2.25 tons per cubic yard. The estimated space increase is then:

$$\frac{75 \text{ to } 100 \times 10^6 \text{ tons}}{2.25} = 33.3 \text{ to } 44.4 \times 10^6 \text{ cubic yards}$$

Assuming an average ceiling height of 7 yards, this is equivalent to:

$$\frac{33.3 \text{ to } 44.4 \times 10^6}{7} \times 9 = 43 \text{ to } 57 \text{ million square feet per year.}$$

Adding the gypsum and sandstone mine space increase, we estimate the total at between 45 and 60 million square feet per year.

Lead and Zinc Mines

The original data on these mines showed that most of the available mines are located around the town of Picher, Oklahoma, which is in the extreme northeast corner of the state. The potential area in 1946 was about 65 million square feet that is accessible only by shaft.

In our small attempt to gather additional data, we were only able to obtain information in two additional mines (Table 5).* However, from a list of leading lead and zinc producing mines and the NFSS (Table 6), it appears that the potential might be significant or, at least, worthwhile investigating. The Graham mine, for example, contains 2 million square feet of floor space, and this increased at about 100,000 square feet per year, and ranks last in a list of 25 leading zinc-producing mines.

*As with mines of other minerals, the lead-zinc mine operators treat space and production data as confidential information. They are reluctant to supply such figures on the basis that the disclosure might become available to competitors.

TABLE 5

LEAD-ZINC MINES

NAME OF MINE	TOWN	STATE	TYPE OF ACCESS	ROOM WIDTH & HEIGHT (FT.)	MIN. COVER (FT.)	AREAS - SQ.FT. x 10^{-3} 1946 (1)	1952 (2)	1957 (3)	1964 (4)	INCREASE PER YEAR (5)
OZARK-MAHONING COMPANY										
Hill-Ledford	Rosiclare	Illinois	1 shaft	20x10 min.	700	-	-	-	500	25
EAGLE-PICHER COMPANY (DUBUQUE, IOWA)										
Graham	Galena	Illinois	3 shaft	20x10 min.	200	-	-	-	2,000	100

KEY:

1. From "Report-Underground Installations-Sites and Geological Formations," October 31, 1948. Prepared for Chief of Engineers, U.S. Army, under Contract W-49-129-Eng.-59, Guy B. Panero, Engineers, New York, N.Y. (data - 1946).
2. From "Underground Plants for Industry," DOD-DOA-OCD. January, 1956 (material from (1) except data gathered in 1952).
3. From "Preliminary Report for the RAND Corporation, Santa Monica, California, on Usable Existing Mines and New Sites."
4. Data gathered in 1964 by Hudson Institute.
5. Increase Per Year estimated by Mine Operator; data gathered by Hudson Institute.

TABLE 6

LEADING LEAD AND ZINC PRODUCING MINES (1962)[13]

Mine	District or Region	State	Operator	Listed in Previous data	Listed in NFSS (Spaces)
Balmat	St. Lawrence County	New York	St. Joseph Lead Co.	No	No
Badger State	Summit Valley	Montana	The Anaconda Co.	No	No
Star and Morning Unit.	Coeur d'Alene	Idaho	The Bunker Hill Co. and Hecla Mining Co.	No	No
Eagle	Red Cliff (Battle Mountain)	Colorado	The New Jersey Zinc Co.	No	No
Friedensville	Lehigh County	Pennsylvania	The New Jersey Zinc Co.	No	No
United States & Lark	West Mountain (Bingham)	Utah	United States Smelting, Refining and Mining Co.	No	No
Austinville & Ivanhoe	Austinville	Virginia	The New Jersey Zinc Co.	No	Yes (880)
Young	Eastern Tennessee	Tennessee	American Zinc Co. of Tennessee	No	No
Iron King	Big Bug	Arizona	Shattuck Denn Mining Corp.	No	No
Bunker Hill	Coeur d'Alene	Idaho	The Bunker Hill Co.	No	No
Zinc Mine Works	Eastern Tennessee	Tennessee	United States Steel Corp., Tennessee Coal & Iron Div.	No	No
Sterling Hill	New Jersey	New Jersey	The New Jersey Zinc Co.	No	Yes (685)
Pend Oreille	Metaline	Washington	Pend Oreille Mines and Metals Co.	No	Yes (0)
Mascot No. 2	Eastern Tennessee	Tennessee	American Zinc Co. of Tennessee	No	No
Page	Coeur d'Alene	Idaho	American Smelting and Refining Co.	No	No
Idarado	Eureka (Red Mountain) & Upper San Miguel	Colorado	Idarado Mining Co.	No	No

TABLE 6 (continued)

LEADING LEAD AND ZINC PRODUCING MINES (1962)

Mine	District or Region	State	Operator	Listed in Previous data	Listed in NFSS (Spaces)
Hanover	Central	New Mexico	The New Jersey Zinc Co.	No	No
Edwards	St. Lawrence County	New York	St. Joseph Lead Co.	No	Yes (1200)
Boyd, Calloway, Eureka and Mary	Eastern Tennessee	Tennessee	Tennessee Copper Co.	No	Yes (13800)
Kearney	Central	New Mexico	Hydrometals, Inc., American-Peru Mining Co.	No	No
United Park City	Park City Region	Utah	United Park City Mines Co.	No	No
Gray	Upper Mississippi Valley	Illinois	Tri-State Zinc, Inc.	No	No
Bowers-Campbell	Rockingham County	Virginia	Tri-State Zinc, Inc.	No	No
Old Dick	Eureka	Arizona	Cyprus Mines Corp.	No	No
Graham-Snyder-Spillane	Upper Mississippi Valley	Illinois	The Eagle-Picher Co.	Yes	No
Federal	Southeastern Missouri	Missouri	St. Joseph Lead Co.	Yes	No
Lucky Friday	Coeur d'Alene	Idaho	Lucky Friday Silver-Lead Mines Co.	Yes	Yes (870)
Viburnum	Southeastern Missouri	Missouri	St. Joseph Lead Co.	No	No
Leadwood	Southeastern Missouri	Missouri	St. Joseph Lead Co.	Yes	No
Indian Creek	Southeastern Missouri	Missouri	St. Joseph Lead Co.	No	No
Ophir Unit	Ophir	Utah	United States Smelting, Refining and Mining Co.	No	No
Sunshine	Coeur d'Alene	Idaho	Sunshine Mining Co.	No	No
Emperius	Creede	Colorado	Emperius Mining Co.	No	No

TABLE 6 (continued)

LEADING LEAD AND ZINC PRODUCING MINES (1962)

Mine	District or Region	State	Operator	Listed in Previous data	Listed in NFSS (Spaces)
Deardorff Group	Upper Mississippi Valley	Illinois	Ozark-Mahoning Co.	No	No
Fairview-Blue Diggings	Upper Mississippi Valley	Illinois	Aluminum Company of America (Alcoa)	No	No
Flux	Harshaw	Arizona	Nash & McFarland	No	No
Camp Bird	Sneffels	Colorado	Camp Bird Colorado, Inc.	No	No
Blue Goose No. 1	Picher-Cardin	Oklahoma	The Eagle-Picher Co.	Yes	No

In summary, we estimate the current minimum mine shelter potential as one billion square feet in salt, limestone, gypsum and sandstone mines alone. It is felt, over all, that this figure is on the low side because:

1. The basic data used for estimating purposes was primarily concerned with space adaptable to industrial use and was never considered to represent the total available mine area in the country.

2. We have not included estimates of space available in high-priced ore mines or in iron mines.

3. Coal mine space is not included. Over the years, shelter researchers have eliminated such space from consideration because using coal mines was considered impractical due to "robbing the pillars" which leads to unstable excavations or collapse, frequent presence of natural gas and uneven dimensions. Presumably, this is an overcautious viewpoint to take. Over 100 coal mines are identified in the NFSS, totaling at least 370,000 spaces;* 270,000 in Kentucky alone (10 per cent of the population of that state and one-third of the total spaces identified). One mine near Evanston, Kentucky, is stocked for 45,000 spaces.

Our estimate of the minimum yearly increase in potential mine space is between 55 and 70 million square feet not including high-priced ore or coal mine space. This is the "normal" potential of the mining industry and could be much greater given proper incentives.

---

*Our NFSS information does not distinguish mine space according to the type of material extracted. This is the total of spaces in mines specifically identified as coal mines (e.g., XYZ Coal Co., Acme Collieries, etc.).

NATIONAL FALLOUT SHELTER SURVEY

A detailed listing of mines and spaces located including stocking information is given in Appendix I. This date, complete as of June 1964, is an excellent source of information for those interested in undertaking more detailed studies of mine space potential.

Besides its value as a directory, the NFSS data summarized in Table 7 is significant in the following ways:

1. The list indicates space (and potential for more space) in states and regions where previously little was thought to exist. This is notable in Vermont, New Jersey, Virginia, Alabama, Georgia, Colorado, Utah and Washington. In other states, the NFSS spaces greatly exceed the previous estimates. Kentucky (coal mines), Tennessee, and Arkansas are examples.

2. It tends to corroborate the evidence that mine space may be difficult to find in the southeastern states and in some of the New England states.

3. It contains facilities which probably set precedents or indicate feasibility for very large single-unit shelters. The largest mine is listed at 155,520 spaces and another is stocked for 83,600.

4. Most of the space is probably "vent" space, that is, based on 500 cubic feet per person. Assuming an average ceiling height of from 20 to 25 feet, we estimate the potential capacity in the located mines to be 2 to 2.5 times greater than the listed capacity or from 10 million to 13 million spaces with adequate ventilation and without using overcrowding options.

In addition, the number of spaces located in any given mine does not necessarily represent its maximum capacity even at 500 cubic feet per space. A sampling of 10 gypsum and limestone mines from Table 4, which are also listed in the NFSS, indicates the potential space (at 500 cubic feet) to be ten times greater than the number actually located. If this proportion held true across-the-board, spaces available in the 1,000 mines might be as much as 50 million without ventilation additions and as much as 100 million or so with ventilation and other adaptations (entries, water, sewerage, etc.).

Of course, this does not mean that all of this potential would be usable. This depends on the distribution of the space with respect to the population, movement capabilities, allowable time and other performance factors. However, we would argue that the potential exists and could prove valuable for shelter programs which specify some redistribution of the population.

TABLE 7

NATIONAL FALLOUT SHELTER SURVEY

MINE SPACES BY REGION AND STATE
(as of June 10, 1964)

Regions	Spaces	Spaces Stocked
REGION 1		
Connecticut	305	0
Maine	0	0
Massachusetts	1180	0
New Hampshire	0	0
New Jersey	10822	685
New York	315327	1449
Rhode Island	0	0
Vermont	5624	22580
TOTALS:	383876	24714
REGION 2		
Delaware	0	0
Washington, D.C.	0	0
Kentucky	992670	372564
Maryland	1050	0
Ohio	71115	6600
Pennsylvania	128799	6620
Virginia	88828	44568
West Virginia	72383	34586
TOTALS:	1354845	464938
REGION 3		
Alabama	71881	34150
Florida	0	0
Georgia	242808	0
Mississippi	0	0
North Carolina	0	0
South Carolina	0	0
Tennessee	427582	53130
TOTALS:	742271	87280

TABLE 7 (Continued)

NATIONAL FALLOUT SHELTER SURVEY

MINE SPACES BY REGION AND STATE
(as of June 10, 1964)

Regions	Spaces	Spaces Stocked
REGION 4		
Illinois	407598	0
Indiana	94011	0
Michigan	170208	600
Minnesota	21034	0
Wisconsin	18239	10000
TOTALS:	711090	10600
REGION 5		
Arkansas	216765	33353
Louisiana	1018	0
New Mexico	35741	25880
Oklahoma	80530	0
Texas	27883	0
TOTALS:	361937	59233
REGION 6		
Colorado	107565	12971
Iowa	173636	45016
Kansas	364504	20000
Missouri	791283	89424
Nebraska	2520	1440
North Dakota	0	0
South Dakota	13850	12869
Wyoming	8284	0
TOTALS:	1461642	181720
REGION 7		
Arizona	20949	0
California	73801	5922
Nevada	35189	17717
Utah	111318	22904
TOTALS:	241257	46543

TABLE 7 (Continued)

NATIONAL FALLOUT SHELTER SURVEY

MINE SPACES BY REGION AND STATE
(as of June 10, 1964)

Regions	Spaces	Spaces Stocked
REGION 8		
Idaho	4805	1080
Montana	16652	11720
Oregon	2915	0
Washington	118947	4116
TOTALS:	143319	16916
TOTALS FOR ALL REGIONS:	5400237	891944

Largest mine in the list is 4351 KENT County, Michigan 0064 Grand Rapids Gypsum Co., 1660 Butterworth, Grand Rapids	155520	0
Largest stocking mine listed is 23R1 ANDERSON County, Kentucky 0002 Limestone Mine, Tyrone	83600	83600
Total Number of Mines	994	

NEW SITE POTENTIAL

In the event that the area in existing mines is insufficient or too poor in quality to meet the regional needs, new excavations in suitable formations or the conversion of open-pit operations to underground mining can be considered.

Limestone far exceeds the other types of formations in frequency of occurrence and in the volume of generally massive formations. Limestone is most commonly mined as dolomite having a porosity of less than 2 per cent and a compressive strength ranging from 11,000 to 35,000 psi, as compared with a compressive strength of good structural concrete of 3,500 psi and about 5,000 psi for rocksalt.

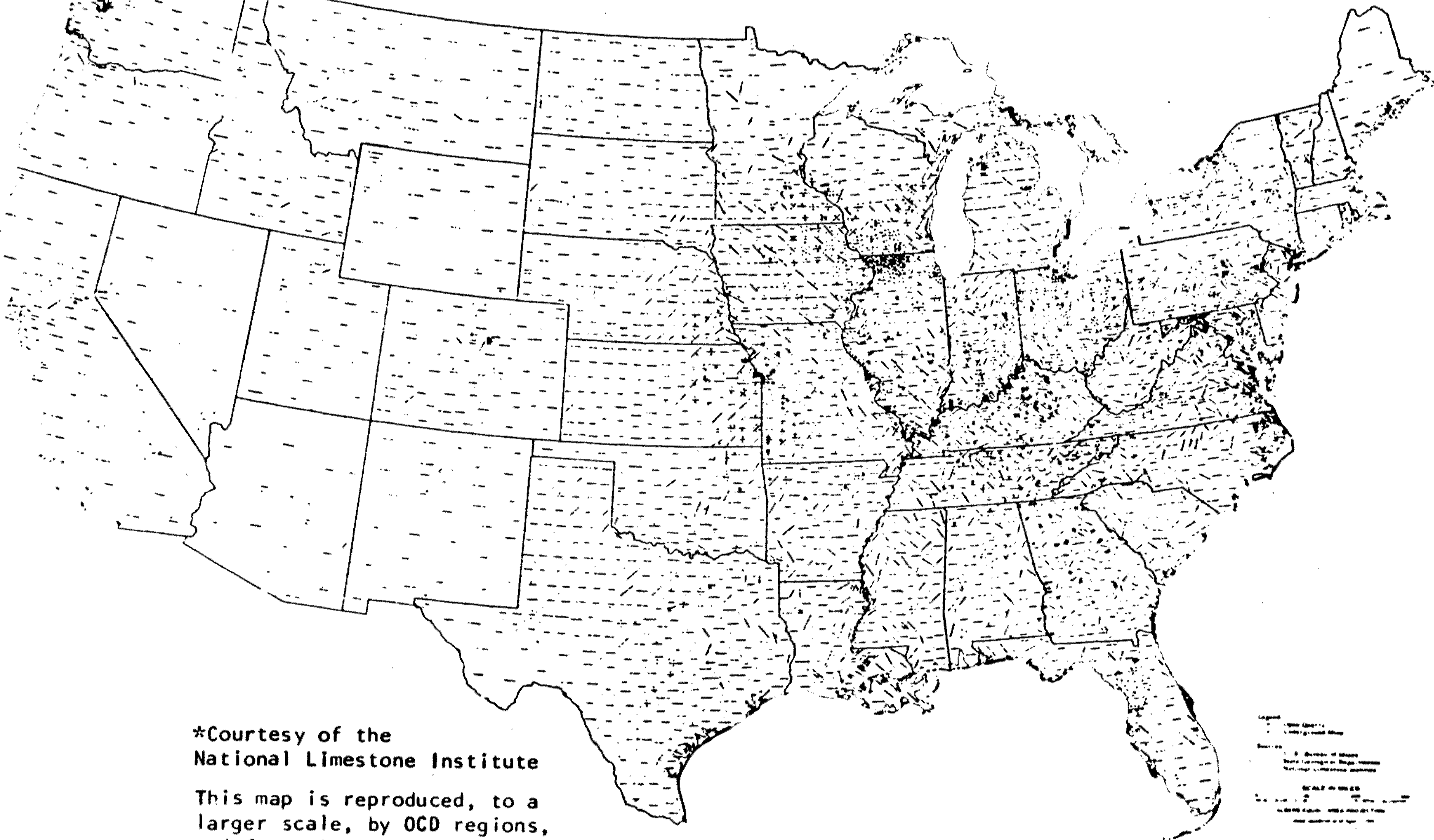
Limestone formations can be found in almost every state. Present quarrying operations are widely distributed. A map of existing mines and quarries is shown in Figure 6. A rough comparison between this map and the current distribution of population indicates that most of the quarrying operations could qualify as sites for potential shelter.

There are two basic ways to develop a new facility. One is to arrange with the mine operator to open a new site by normal operations and the second is to convert the existing operation to underground mining. The National Limestone Institute addressed itself to these possibilities in 1962 at the request of Secretary Pittman. The Institute estimated that at least one-third of the open-pit operations could convert to below-ground mining by opening existing faces. The cost incentive, where such conversion was clearly feasible, was estimated at up to 2.5 cents per cubic foot of space.[14]

The NLI estimates of incentive based on unit volume led to our investigation of optimum ceiling height. We found that 14 feet is a practical

FIGURE 6

LIMESTONE MINES AND QUARRIES IN THE UNITED STATES *



*Courtesy of the National Limestone Institute

This map is reproduced, to a larger scale, by OCD regions, and forms Attachment #1 to this report.

limit due to the type of mucking equipment used. However, the actual ceiling height for any given location will depend on the extent of the limestone formation and the economics involved in digging it out. It was suggested that an arbitrary height of 21 feet should be used for computing prices on a square-foot basis. Using this data a bare non-vent space would cost $12.50 and a vent space (10 square feet) would cost $5.25. This, the NLI agrees, would include the cost of some drift access. They also concluded that development cost could be much less depending on location and the extent of competitive bidding. Their Shelter Committee stated:

> Because of the many variables, it was agreed that the only practical means of developing suitable shelter space would be through a contract based on competitive bids on Government specifications. In some cases, the unit incentive would provide the Government with a rough space after the desired area was obtained by mining. In others, rental agreements would have to be consummated by the owner and the Government inasmuch as some properties, because of their location, would be worthless while others could have a market value. It was suggested that bid invitation(s) include alternatives with respect to unit incentive payments and rentals and their combinations. Provision in contract agreements would have to be made in those cases where the operator wants to retain the right of occupancy in order to continue mining, or for some other reason, after he has provided the required space desired by the Government. Known examples show that this is practical.[15]

Legal and contract problems aside, ~50 cents a square foot with high ceilings is evidently a source of very cheap shelter space. New shelter construction would cost much more, at least $5 per square foot without land costs, in large units (1,000 spaces and up), and with lower headrooms. The mine space is also of higher quality with respect to protection factor and blast protection.

If such conversion was clearly feasible, one might be interested in determining the development times involved. The NLI made inquiries of its members asking them to estimate the amount of production which they considered convertible to underground operations. The sample showed this to be between one-third and one-half of the total production. As an example, let us assume that we were interested in a dispersed shelter system involving mine space and desired to create 100 million spaces and were able to funnel one-third of the annual limestone production into the program. One-third of the production (167×10^6 tons) would result in about 10 million (10 square foot) spaces per year. We estimate the program could be completed within 15 years including a lot of planning but without trying very hard. The cost would be about $50 million per year for developing the bare space.

Suppose we wanted to try harder, that is, to have a rapid "mobilization" program. In this case we ignore some production requirements and concentrate on excavating rock. We pay the operators a premium for converting and relocating to underground operations near population centers and guarantee the going market price for any rock they cannot sell. We believe this could automatically double (at least) the production (2 shifts) and result in 60 million spaces per year. The maximum cost for 100 million spaces would be $\underline{\$2 \times 10^9}$* including the premium and buying the excess rock (1 billion) and the program would be completed in 18 months.

Salt formations may be of interest in planning high-quality blast shelter programs. The known formations are deep (~1,000 feet) and extensive.

*Not including habitability items. These would probably cost less in mines than in new shelter construction mainly because of lower environmental control due to the high heat absorption characteristics of the rock.

They exist from Albany to Detroit in the northeast, from New Orleans to Dallas in the south-central regions, and cover most of central Kansas.

Site Adaptation

The cost and time required to adapt existing mine space to shelter use will depend upon many factors. Among these are:

1. Existing access capability--shaft or drift and their number, roads, etc., and the desired access rate
2. Geographical location
3. Geology
4. Existing utilities
5. Protection criteria--stay times, blast rating, degree of habitability ("plushness")
6. The design scenarios.

The range in cost is from zero to "very expensive," depending on the design factors. A "zero cost" facility might be one which has been converted to storage use or one of many listed in the NFSS which is undercrowded and has sufficient power, water, sanitation and ventilation to support the shelter population for extended periods.

Converted facilities can be found in New York, Pennsylvania, Missouri, Oklahoma and Kansas. The Atchison mines of the Kerford Quarry Company contain 3 million square feet of developed space with dehumidification and ventilation and other utilities sufficent for at least 100,000 people.* This and other similar facilities are essentially "zero cost" facilities--immediately available, clean, pleasant, and well lighted.

---

*Even in the areas under storage lease the space available is enormous due to allowances for wide loading aisles and truck areas.

Beyond using these installations, we have "easy" and "hard" problems in adapting mine space, roughly according to the difficulties involved in providing access. Relatively, the multiple-drift mines are "easy" and the deep, limited-access shaft mines are "hard."

A 1957 report[16] included detailed estimates for adapting a West Winfield, Pennsylvania, drift mine for 156,000 people and the International Salt Mine, 1,300 feet under Detroit, for 1,125,000 people. The first mine contains multiple entries and was assumed not to require additional access. The estimates of the salt mine included four 16-degree inclined drifts with three entrances each to achieve a maximum entry rate of 7,000 persons per minute.* The estimates were based on very plush habitability criteria and up to 90-day occupancy. The adaptation cost for the drift mine was about $7 per square foot and for the shaft mine, about $11 per square foot, the difference apparently attributable to cost of providing inclined drift access.

A recent study[17] estimated (more austerely) that a typical drift access mine rated at 20 psi could be adapted for about $0.95 per square foot. The same study budgeted a 20-psi, about 80-foot deep, abandoned lead mine at about $1.15 per square foot.**

These examples are especially indicative of the extra costs involved in providing entries. Now this will depend on required entry rate. The first study assumed an optimistic walking rate of 4 miles an hour and calculated that a 20-foot drift could accommodate up to 2,300 persons per

---

*Both the figures are highly optimistic. Inclined drifts will rarely exceed 10 per cent slope due to equipment limitations. Drifts from surface portals are most economically driven with rubber-tired equipment which must return to the surface loaded. The Building Exits Code[16] rates exiting capacity at about 2 persons per minute per inch opening. For a 20-foot tunnel, this is equal to 500 persons per minute or 2,000 for the four drifts.

**No ventilation improvements for either mine.

minute. The study team was interested in a very fast entry capability and included four such drifts which (with their assumption) would allow everyone to enter in under 3 hours. The cost of the inclined drifts was about $8 million or $7 per person sheltered.

The existing access capabilities of the deep mines is, of course, very limited. For example, there is an excellent limestone mine located near Akron, Ohio, containing over 7 million square feet and increasing at over 350,000 square feet per year. Although there is much room, accessibility is a difficult problem for mass use. The floor is 2,200 feet below the ground and the facility has one elevator which takes 8-10 minutes for a round trip. The elevator is limited to 16 persons, although it is equipped with a second platform which could increase the rated capacity to about 30 persons. If efficient loading schemes could be worked out (i.e., mixture of adults and children), this might be increased to 50 persons. So, at best, the elevator would accommodate 375 people per hour and 9,000 per day. At this rate, it would take months to utilize the space.

At some sites it may not be possible to fully utilize the space potential due to movement limitations. An example is the Retsof, New York, salt mine, with a potential of 100 million square feet of space. The mine is 1,100 feet below the surface and is situated about 35 road miles east of Buffalo. The population within 60 miles is about 2.5 million, which the mine could conceivably accommodate.

We estimated a potential of 4 lanes of continuous traffic to the site while preserving an additional lane for official traffic and another for return traffic. Assuming 1,000 cars per hour, 4 persons per car, and that the cars could be parked and unloaded without slowing down the operation, autos might deliver 16,000 people per hour to the site under good conditions.

The Retsof site also contains rail facilities. The Delaware, Lackawanna and Western, the Pennsylvania, and the Genesee and Wyoming all spur into a loading yard at the mine mouth. We did not have sufficient data on the loading yard and the available rolling stock to make a good estimate of movement by rail. However, from another study[18] we guess it to be much less than by private cars.

Over all, the potential might be 20,000 persons per hour or roughly half a million per day. It takes a minimum of 5 days to move 2.5 million people to the mines and probably a month to utilize the full space potential.* The rate of arrival of people is one way of determining access requirements, and assumed movement time will determine the limits of the design capacity.

The minimum size of access tunnel is about 10 feet in diameter and has a horeshoe-shaped section. Horizontal drifts of this size, driven from portals in dry, crystalline formations, will cost about $200 per foot without lining. A 10 per cent downslope drift will pass through many different formations and would probably be concrete-lined throughout. The inclined drift will also possibly incur additional costs due to flooding at the working face. The total cost is then estimated at $250-300 per linear foot (10 feet finished) including (for this job) site

---

*Concentrating millions of people at one site may turn the place into an attractive target. It would probably need a blast rating of several hundred psi to compete with smaller, more dispersed shelter systems.

and portal preparations, cleanup and profit and contingencies.* Each entry required would be almost 2 miles long and cost about $3.5 million, including vestibules, ventilation ductwork, lighting, piping, and finishing, and would normally take a year to complete.

If we used the fire exits design criteria, the drift would have a capacity of 250 persons per minute. If we assumed an optimistic walking rate for mass groups of people at 4 miles per hour and each person occupying 24 inches of width and 24 inches in the direction of flow, we calculate that 5 persons abreast can move down the drift at the rate of 900 persons per minute. Consultation with elevator and escalator companies (Westinghouse and Otis) experienced in mass movement indicate that for ramps the exits design criterion is too low and the 4-mph computation is too optimistic. It was their feeling that for extended periods a realistic maximum is more like 500 people per minute.

The drift capacity is then somewhere between 15,000 and 54,000 persons per hour and probably capable of accommodating the expected rate of arrivals. Cost per space now depends on time allowed for movement. For 10 hours the entry costs $11 per person; for 50 hours, $3.50 per person. In either case, the Retsof mine is underused.

Ventilation and Heat Dissipation

Among the most critical habitability requirements in the adaptation of underground facilities are those involving ventilation, heat dissipation, and moisture control. The rated capacity and total adaptation costs will be influenced by these requirements.

---

*The 10-foot tunnel may not be optimum. Larger double-deck drifts may be more economical. These costs are applicable to other deep mines. Exception will be found where the geological conditions are unfavorable, such as at the Louisiana salt mines. The shafts to these mines were sunk in very poor soil. At one mine the soil had to be stabilized by freezing techniques to support the construction operations. These mines require further geological analyses to determine feasibility and cost of increasing entry capabilities.

The minimum amount of air required in any shelter is usually determined by a limitation in the concentration of carbon dioxide. This limit is taken at 3 per cent by volume. Studies indicate that the oxygen limit when the CO_2 reached 3 per cent would not be critical in terms of damaging pathological changes. For unventilated spaces the allowable time may be calculated as follows:

$$T = 0.04\ V/N$$

where: T is the time after entry, hours
V is the total volume of the space, cubic feet
N is the total number of shelter spaces

Using this equation, 500 cubic feet of volume would possibly afford one day's supply of air per person.

The minimum ventilating rate required to prevent excess carbon dioxide is about one-half cubic foot of outside air per minute per person. Current OCD practice calls for a minimum of 3 cfm per person, which corresponds to a terminal concentration of about 0.5 per cent CO_2.

In selecting the capacity of underground space in terms of ventilation requirements, several options are possible. Among these are the following:

1. In limited-access mines with no ventilation, long periods of occupancy are available by grossly undercrowding the space (thousands of cubic feet per person). Such shelters may require equipment to monitor the CO_2 level and to provide some air movement to prevent high CO_2 pockets.

2. In multiple-access mines, some natural ventilation may be produced by wind action or when a pressure differential exists between the cavity air and the outside air. Installations with tunnels and shafts tend to be self-ventilating during all seasons. Others will ventilate better during the winter than during the summer. The effect of natural ventilation on capacity ratings will vary from site to site but should be valuable in most places in reducing area allocations.

3. In other mines it may be desirable to provide for mechanical ventilation and air distribution systems to augment existing ventilating capacity, further reduce space allocations, or increase performance.

Some means must also be available to control psychrometric conditions within acceptable physiological limits. For normally occupied shelters, this turns out to be a problem of dissipating the metabolic heat produced by the occupants. In unventilated underground mines it is a function of a variety of parameters such as shelter shape, surface area, rock temperature, air temperature, rock diffusivity and conductivity and the film coefficient of heat transfer at the mine surfaces.

Given these parameters, the quantity of heat (and moisture) produced and the physical data of the mine space, it is possible to estimate habitability performance at various levels of occupancy and shelter stay times. In mines with suitable rock characteristic, it is possible to allocate space such that the total heat production could be absorbed by the surfaces by radiation, convection and moisture condensation. In other mines (or for increased occupancy) it may be necessary to provide environmental control equipment to provide for heat dissipation to the outside air or to another heat sink (e.g., water).

Most of the usable mine space is initially cold (50°-60°F) and, except for salt mines, humid. In underground mines, this may be uncomfortable. For normally occupied space, we would expect the occupants to be uncomfortable only during a short initial warmup period (a few hours).

The cost of providing for environmental control will vary between sites and may range from zero to about $30 per space.* The latter figure is for a large shaft-access mine with a water-cooled refrigeration system including auxiliary power.

---

*An adaptation estimate of the International Salt mine under Detroit, used about $17 per person without auxiliary power.

CAVES AND TUNNELS

The current NFSS information concerning available space in caves is tabulated in Appendix II. Summaries are given in Table 8. The total number of located spaces is about 570,000 in 660 caves.

The National Speleological Society (NSS) has been cooperating with the Office of Civil Defense in locating caves and determining habitability factors. The NSS maintains a library containing detailed listings of noncommercial caves, their locations and physical characteristics. The list totals some 10,000 individual grottos.

The several NSS chapters are currently investigating a selected group of 200-300 caves for safety, accessibility, habitability, and proximity to utilities. This is being done by questionnaires sent to the local groups. From a sample of 59 returns, about half the sites were considered unsuitable* because of poor access, irregularity, or instability within the cavities, because of flooding or the possibilities of flash flooding or other hazardous features.

The average number of located spaces per cave in the sample of "good" caves is about 800, which is roughly equal to the number of spaces in the average NFSS located cave. If only half the caves were suitable and this average held true for the total known caves, then we might expect the potential to be about 4 million spaces. Adaptations to these spaces and/or modifications to unsuitable grottos might increase the potential to about 10 million spaces.

---

*The criteria for suitability was not <u>clearly</u> defined in the instructions to the questionnaire.

TABLE 8

NATIONAL FALLOUT SHELTER SURVEY

CAVES BY REGION AND STATE
(as of June 10, 1964)

Regions	Spaces	Spaces Stocked
REGION 1		
Connecticut	0	0
Maine	0	0
Massachusetts	271	470
New Hampshire	0	0
New Jersey	841	53
New York	5014	-
Rhode Island	0	0
Vermont	149	126
TOTALS:	6275	649
REGION 2		
Delaware	0	0
Washington, D.C.	0	0
Kentucky	69088	53939
Maryland	1567	235
Ohio	1726	543
Pennsylvania	17943	121
Virginia	29659	0
West Virginia	17185	511
TOTALS:	137168	55349
REGION 3		
Alabama	68551	20594
Florida	2499	75
Georgia	9737	7786
Mississippi	0	0
North Carolina	0	0
South Carolina	0	0
Tennessee	78187	14001
TOTALS:	158974	42456

TABLE 8 (Continued)

NATIONAL FALLOUT SHELTER SURVEY

CAVES BY REGION AND STATE
(as of June 10, 1964)

Regions	Spaces	Spaces Stocked
REGION 4		
Illinois	191	84
Indiana	3751	0
Michigan	0	0
Minnesota	7244	2168
Wisconsin	1879	1296
TOTALS:	13065	3548
REGION 5		
Arkansas	71662	5340
Louisiana	0	0
New Mexico	1264	1200
Oklahoma	0	0
Texas	26667	100
TOTALS:	99593	6640
REGION 6		
Colorado	2570	-
Iowa	32	-
Kansas	0	0
Missouri	51972	6290
Nebraska	250	-
North Dakota	0	0
South Dakota	54870	4082
Wyoming	3667	1667
TOTALS:	113361	12039
REGION 7		
Arizona	581	550
California	2333	-
Nevada	3329	3329
Utah	2816	-
TOTALS:	9059	3879

TABLE 8 (Continued)

NATIONAL FALLOUT SHELTER SURVEY

CAVES BY REGION AND STATE
(as of June 10, 1964)

Regions	Spaces	Spaces Stocked
REGION 8		
Idaho	10139	1176
Montana	1112	998
Oregon	14886	1229
Washington	2536	0
TOTALS:	28673	3403
TOTALS FOR ALL REGIONS:	566168	127963
Largest cave in the list is 23T2 BUTLER County, Kentucky 0004 Stanley Roman's Cave, Dimple	39300	39300
Largest stocking cave listed is same as above	39300	39300
Total Number of Caves:	661	

A summary of total area in railroad and vehicular tunnels is shown in Tables 9 and 10. The over-all potential is rather small, perhaps 2-3 million spaces. However, for particular locations tunnels might be a very important source of shelter. A detailed list of tunnels and a series of location maps are given in Appendix III. This information may prove useful to those interested researchers.

Subway and utility tunnels are not included.

TABLE 9

RAILROAD TUNNELS BY REGION AND STATE

Regions		No. of Tunnels	Length (Feet)	Approx. Area (Square Feet)
REGION 1				
Connecticut		7	5984	160321
Maine		0	0	0
Massachusetts		2	25380	732300
New Hampshire		0	0	0
New Jersey		9	27229	768900
New York		24	30437	1140322
Rhode Island		1	5079	152400
Vermont		1	341	5460
	TOTALS:	44	94450	2959703
REGION 2				
Delaware		0	0	0
Washington, D.C.		3	8174	82905
Kentucky		5	2437	37260
Maryland		41	57143	1453552
Ohio		43	29147	557200
Pennsylvania		126	144233	3132574
Virginia		36	47613	891325
West Virginia		135	127729	2717132
	TOTALS:	389	416476	8871948
REGION 3				
Alabama		5	6303	91840
Florida		0	0	0
Georgia		1	725	11230
Mississippi		3	709	10635
North Carolina		0	0	0
South Carolina		0	0	0
Tennessee		1	1275	17850
	TOTALS:	10	9012	131555
REGION 4				
Illinois		5	13722	214610
Indiana		4	4505	96890
Michigan		0	0	0
Minnesota		6	1044	17165
Wisconsin		8	12163	182455
	TOTALS:	23	31434	511120

TABLE 9 (Continued)

RAILROAD TUNNELS BY REGION AND STATE

Regions		No. of Tunnels	Length (Feet)	Approx. Area (Square Feet)
REGION 5				
Arkansas		7	27193	333580
Louisiana		0	0	0
New Mexico		2	3808	59880
Oklahoma		0	0	0
Texas		1	689	1240
	TOTALS:	10	31690	394700
REGION 6				
Colorado		50	56549	913736
Iowa		0	0	0
Kansas		0	0	0
Missouri		10	10367	187574
Nebraska		1	713	12120
North Dakota		0	0	0
South Dakota		5	1606	25558
Wyoming		16	43186	725439
	TOTALS:	82	112421	1864427
REGION 7				
Arizona		11	4225	63391
California		197	203393	3013173
Nevada		11	21826	335185
Utah		9	5166	82462
	TOTALS:	228	234610	3494211
REGION 8				
Idaho		31	17341	243866
Montana		41	40539	632934
Oregon		58	55916	816014
Washington		23	81205	1007777
	TOTALS:	153	195001	2700591
TOTALS FOR ALL REGIONS:		939	1125094	20928255

TABLE 10

VEHICULAR TUNNELS BY REGION AND STATE

Regions	No. of Tunnels	Length (Feet)	Approx. Area (Square Feet)
REGION 1			
Connecticut	0	0	0
Maine	0	0	0
Massachusetts	2	11270	225400
New Hampshire	0	0	0
New Jersey	5	40639	848200
New York	4	30920	661300
Rhode Island	0	0	0
Vermont	0	0	0
TOTALS:	11	82829	1734900
REGION 2			
Delaware	0	0	0
Washington, D.C.	0	0	0
Kentucky	0	0	0
Maryland	1	7655	248800
Ohio	0	0	0
Pennsylvania	8	39225	836400
Virginia	3	22500	652600
West Virginia	1	2640	66000
TOTALS:	13	72020	1803800
REGION 3			
Alabama	2	3109	65250
Florida	1	863	12080
Georgia	0	0	0
Mississippi	0	0	0
North Carolina	1	Unknown	Unknown
South Carolina	0	0	0
Tennessee	0	0	0
TOTALS:	4	3972	77330
REGION 4			
Illinois	0	0	0
Indiana	0	0	0
Michigan	1	5137	107800
Minnesota	0	0	0
Wisconsin	0	0	0
TOTALS:	1	5137	107800

TABLE 10 (Continued)

VEHICULAR TUNNELS BY REGION AND STATE

Regions		No. of Tunnels	Length (Feet)	Approx. Area (Square Feet)
REGION 5				
Arkansas		0	0	0
Louisiana		0	0	0
New Mexico		1	520	11180
Oklahoma		0	0	0
Texas		2	5945	216900
	TOTALS:	3	6465	228080
REGION 6				
Colorado		6	6311	187565
Iowa		0	0	0
Kansas		0	0	0
Missouri		0	0	0
Nebraska		0	0	0
North Dakota		0	0	0
South Dakota		7	Unknown	Unknown
Wyoming		2	Unknown	Unknown
	TOTALS:	15	6311	187565
REGION 7				
Arizona		0	0	0
California		23	21552	696051
Nevada		1	3310	59600
Utah		2	999	28220
	TOTALS:	26	25861	783871
REGION 8				
Idaho		0	0	0
Montana		0	0	0
Oregon		9	8586	220240
Washington		15	8894	231306
	TOTALS:	24	17480	451546
TOTALS FOR ALL REGIONS:		97	220075	5374892

CONCLUSIONS

In this study, which is limited in its coverage of the shelter potential in underground space, we believe the following general observations are in order:

1. Though the use of mine space has always been included in civil defense planning, we believe it deserves some renewed interest because the previous estimates of usable space were grossly underestimated. We estimate that the current high-quality space potential is at least one billion square feet. This is augmented by a minimum growth rate of 55 to 70 million square feet per year. These figures do not include space in high-priced ore mines or in coal mines which could be considered in some programs.

2. Mine space might prove to be an important asset in making up NFSS non-city deficits and for possible use by part of the urban population. This presumes willingness to have shelter space further than the 25-mile limit currently used in the NFSS.

3. The superior protection afforded in mines (or tunnels, or caves) as compared to home basements and many NFSS shelters could save many lives. Mines offer the possibility of providing almost perfect protection from fallout and thermal effects and of providing some blast protection. In comparison, home basements are generally rated at 10-20 PF with the possibility of improvising additional protection up to 100 PF, but they afford very little thermal and blast protection.

4. It may be possible to create new space in some deficit areas and near population centers by encouraging the operators of limestone quarries to convert to underground operations or to develop new mines. The required premium to the mine operator is estimated at up to $12.50 per 500 cubic foot space. Competitive bidding and/or ventilation improvements might result in lower costs (i.e., $5 per 10 square foot space with 20-foot headroom plus $1-3 for ventilation improvements). New shelter space with such qualities of protection would be much more expensive (i.e., $5 per square foot minimum for bare shelter space with 7- to 8-foot headroom plus ventilation cost).

5. Adaptation costs will range from zero to about $100 per shelter space depending on existing facilities, access capability, location, and geological factors. The "zero" figure is for a mine that has been converted to a storage facility. The Kerford Mine in Kansas was converted to dehumidified storage space for $2 per square foot. The $100 figure applies to the deep salt mines in the North. Adaptation costs for "difficult" mines (i.e., the Louisiana salt mines and the 2,200 foot deep Barberton, Ohio, limestone mine) might prove to be more than $100 per space. These estimates do not include the costs of acquiring, leasing, or maintaining the space. In a national program using mines to a large extent, we believe it is possible to develop 100 million high-quality spaces for under $5 billion.

6. The development of underground space might be an attractive alternative to building shelters for accelerated programs (1-4 years), since the construction force of the mining industry is already in place and the requirements for structural materials would be reduced.

RECOMMENDATIONS

1. It is necessary to increase our knowledge of the existing and potential mines and quarries to provide a basis for determining the feasibility of using underground space in nationwide shelter programs. We recommend an underground assets survey which would assemble, catalogue, and evaluate such information. Sources of information include the NFSS, the Corps of Engineers, state geologists, the National Geological Survey, the Bureau of Mines, mineral institutes, and mine and quarry operators.

2. A study of the feasibility of underground shelter systems utilizing existing and new mine space. This might be part of the "5 City Study" and would include design and adaptation examples, protection, habitability, and other performance ratings and costs. The examples should reflect variations in urgency and austerity.

3. An investigation of alternative means of acquiring shelter space when needed. This study should include subsidies required to encourage the development of suitable mine space at specific locations.

4. Alternative implementation plans and preparations should be considered for the use of mines in Increased Readiness Programs of various kinds.

REFERENCES

1. William M. Brown, A New Look at the Design of Low-Budget Civil Defense Systems, HI-478-RR (Draft). Hudson Institute, Harmon-on-Hudson, New York, March 10, 1965.

2. William M. Brown, Some Aspects of Effectiveness of Active-Passive Defense Programs, HI-381-RR. Hudson Institute, Harmon-on-Hudson, New York, July 2, 1964.

3. A Series of Nine Reports Prepared for the Chief of Engineers, U.S. Army, under Contract W-49-129-Eng-59 by Guy B. Panero, Engineers, 420 Lexington Avenue, New York, New York.
    1. Report--Underground Installations--Summary (AD-144-574)
    2. Report--Underground Installations--Foreign Installations (AD-144-578)
    3. Report--Underground Installations--Precision Manufacturing Plant (AD-144-573)
    4. Report--Underground Installations--Chemical Process Plant (AD-144-601)
    5. Report--Underground Installations--Storage Depot (AD-144-580)
    6. Report--Underground Installations--Sites and Geological Formations (AD-112-342)
    7. Report--Underground Installations--Adaptations of Existing Mines for Emergency Use (AD-144-575)
    8. Report--Underground Installations--Working Conditions (AD-144-576)
    9. Report--Underground Installations--Excavation and Construction Methods (AD-144-577)

    Report--Underground Installations--Storage Depot--Appendix (AD-144-579)

    Report--Underground Installations--Precision Manufacturing Plant--Appendix Volume 1 (AD-144-602)

    Report--Underground Installations--Precision Manufacturing Plant--Appendix Volume 2 (AD-144-603)

4. Department of Defense. Underground Plants for Industry. Department of the Army, Office of the Chief of Engineers, Washington, D.C., January, 1956.

5. Guy B. Panero, Engineers. Manhattan Shelter Study for Federal Civil Defense Administration, Battle Creek, Michigan. Volumes I and II and Appendices. 420 Lexington Avenue, New York, New York April, 1958.

6. Ibid.

7. E. D. Callahan, et al. Shelter from Fallout. Report No. TO-B-60-30. Technical Operations Incorporated, Burlington, Massachusetts, April 7, 1961.

8. *Ibid.*

9. *Manhattan Shelter Study*, *op. cit.*

10. *A Series of Nine Reports...*, *op. cit.*

11. Bureau of Mines. *Mineral Yearbook*, Vol. I, "Metals and Minerals." U. S. Department of the Interior, Washington, D.C., 1962.

12. *Skillings Mining Review*, "International Salt's Retsof Mine." Vol. 51, No. 16. Duluth, Minnesota, April 21, 1962.

13. *Mineral Yearbook*, *op. cit.*

14. Personal Communication to Steuart L. Pittman, Assistant Secretary of Defense for Civil Defense, from The National Limestone Institute, May 4, 1962.

15. *Ibid.*

16. National Fire Protection Association. *Building Exits Code for Life Safety from Fire*. Boston, Massachusetts, 1961.

17. Office of Civil Defense. *Incorporation of Shelter into Tunnels, Mines, Caves and Similar Structures*. Professional Guide Series, Washington, D.C. (Not Released).

18. William M. Brown. *Strategic and Tactical Aspects of Civil Defense with Special Emphasis on Crisis Situations*. HI-160-RR. Hudson Institute, Harmon-on-Hudson, New York, January 7, 1963.

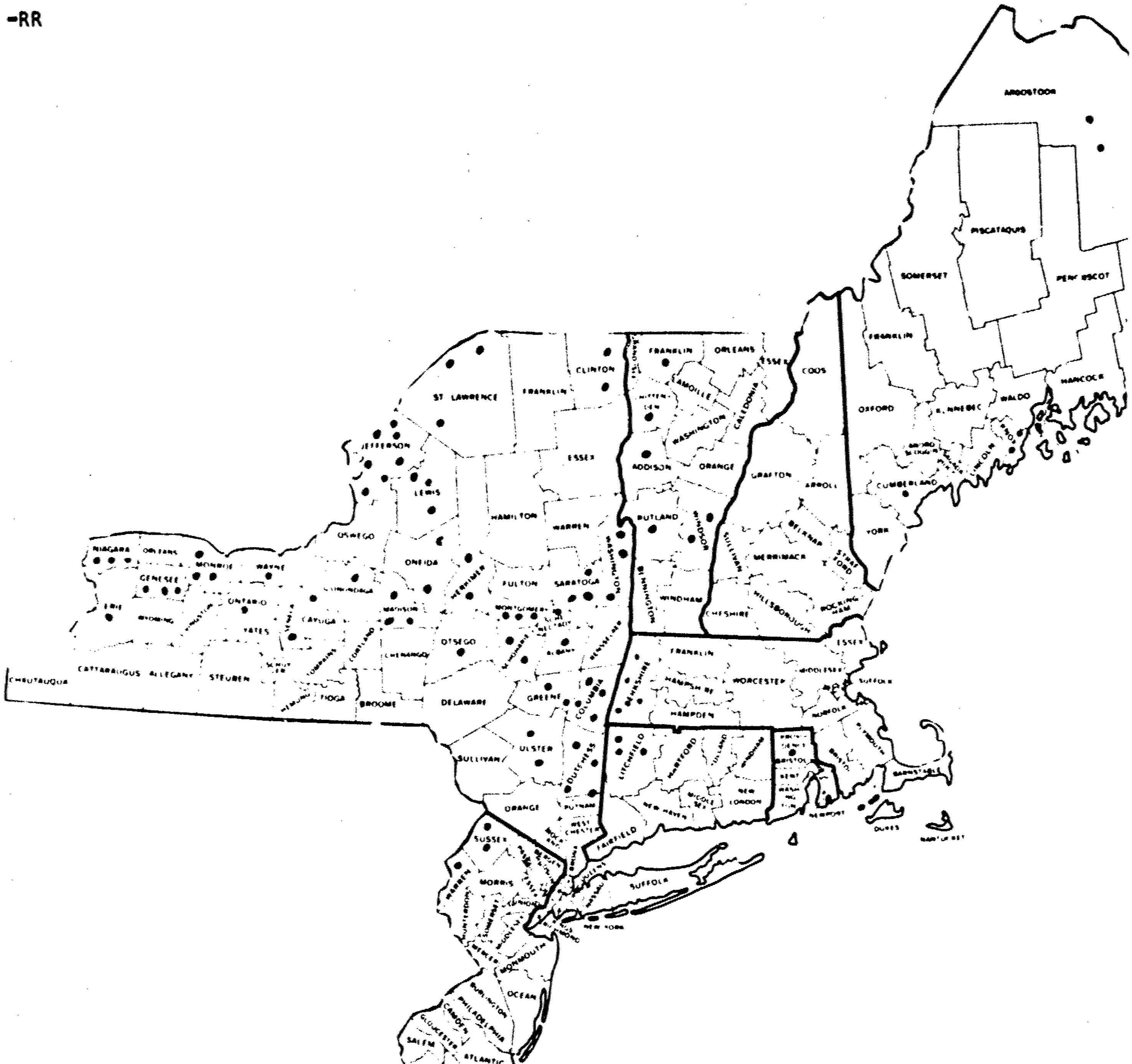
ATTACHMENT #1

LIMESTONE QUARRIES AND MINES

(NATIONAL LIMESTONE INSTITUTE MAP)

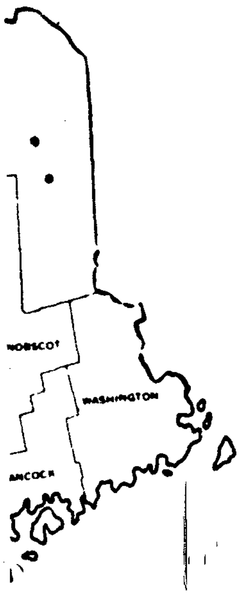
BY OCD REGIONS

-RR



AROOSTOOK
PISCATAQUIS
SOMERSET
FRANKLIN
OXFORD
WALDO
HANCOCK
CUMBERLAND
YORK
COOS
GRAFTON
BELKNAP
MERRIMACK
CHESHIRE
FRANKLIN
ORLEANS
ESSEX
CALEDONIA
WASHINGTON
ADDISON
ORANGE
RUTLAND
WINDSOR
BENNINGTON
WINDHAM
FRANKLIN
WORCESTER
HAMPDEN
BERKSHIRE
ESSEX
SUFFOLK
NORFOLK
BRISTOL
PLYMOUTH
BARNSTABLE
DUKES
LITCHFIELD
HARTFORD
TOLLAND
NEW LONDON
NEW HAVEN
FAIRFIELD
BRISTOL
KENT
NEWPORT
ST LAWRENCE
FRANKLIN
CLINTON
JEFFERSON
LEWIS
ESSEX
HAMILTON
WARREN
OSWEGO
ONEIDA
HERKIMER
FULTON
SARATOGA
WASHINGTON
NIAGARA
ORLEANS
MONROE
WAYNE
GENESEE
ONTARIO
ERIE
WYOMING
YATES
CAYUGA
MADISON
OTSEGO
CORTLAND
CHENANGO
ALBANY
RENSSELAER
CHAUTAUQUA
CATTARAUGUS
ALLEGANY
STEUBEN
TIOGA
BROOME
DELAWARE
GREENE
COLUMBIA
ULSTER
DUTCHESS
SULLIVAN
ORANGE
PUTNAM
WEST CHESTER
SUFFOLK
NEW YORK
SUSSEX
WARREN
MORRIS
HUNTERDON
MERCER
MONMOUTH
OCEAN
BURLINGTON
PHILADELPHIA
CAMDEN
GLOUCESTER
SALEM
ATLANTIC
CUMBERLAND
CAPE MAY

A



REGION 1

Legend:

- • - Open Quarry
- \+ - Underground Mine

Sources:

U. S. Bureau of Mines
State Geological Departments
National Limestone Institute

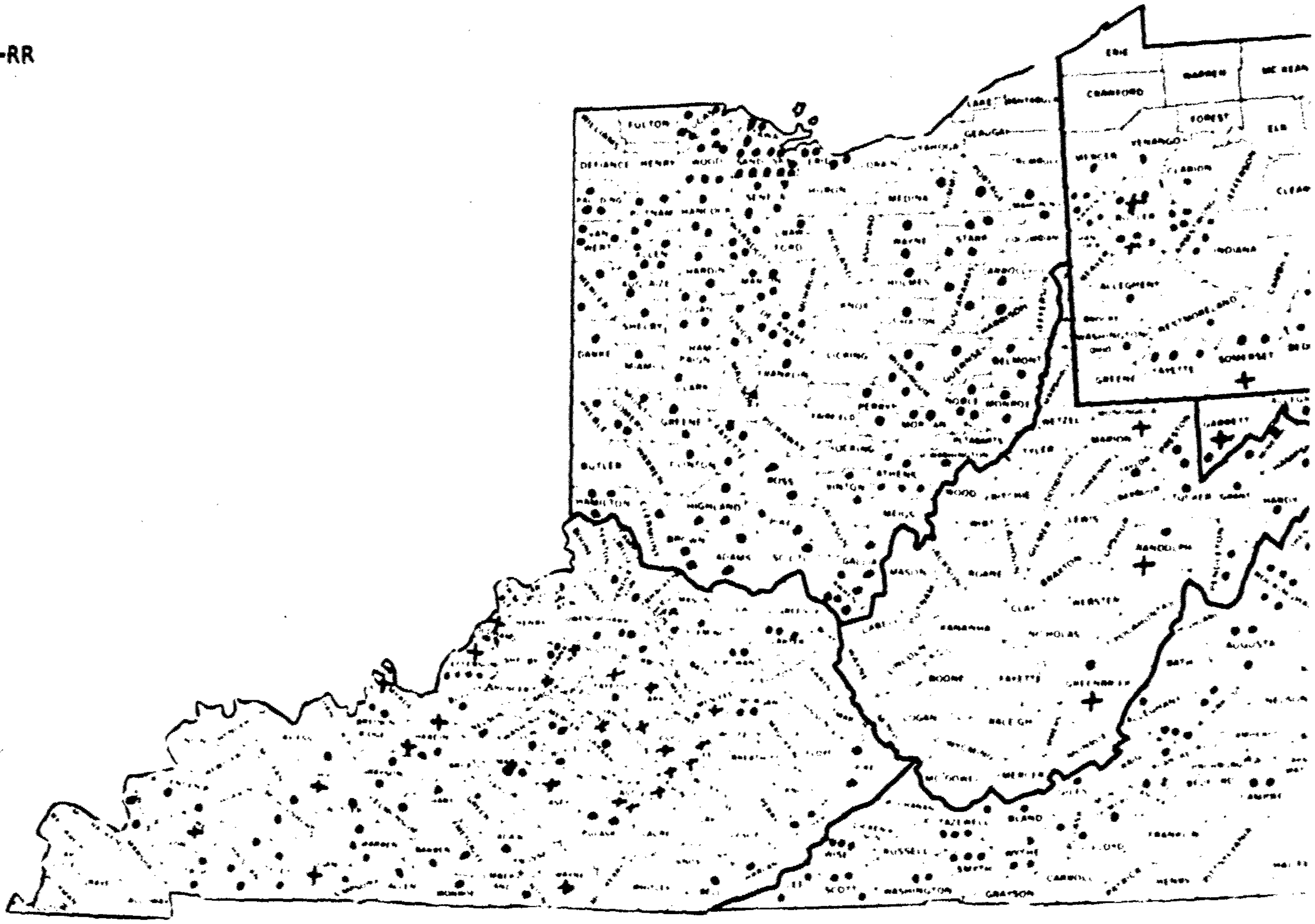
SCALE IN MILES

0 100 200 300

ALBERS EQUAL-AREA PROJECTION

County boundaries as of April 1, 1960

7-RR



REGION 2

Legend:
- • - Open Quarry
- + - Underground Mine

Sources:

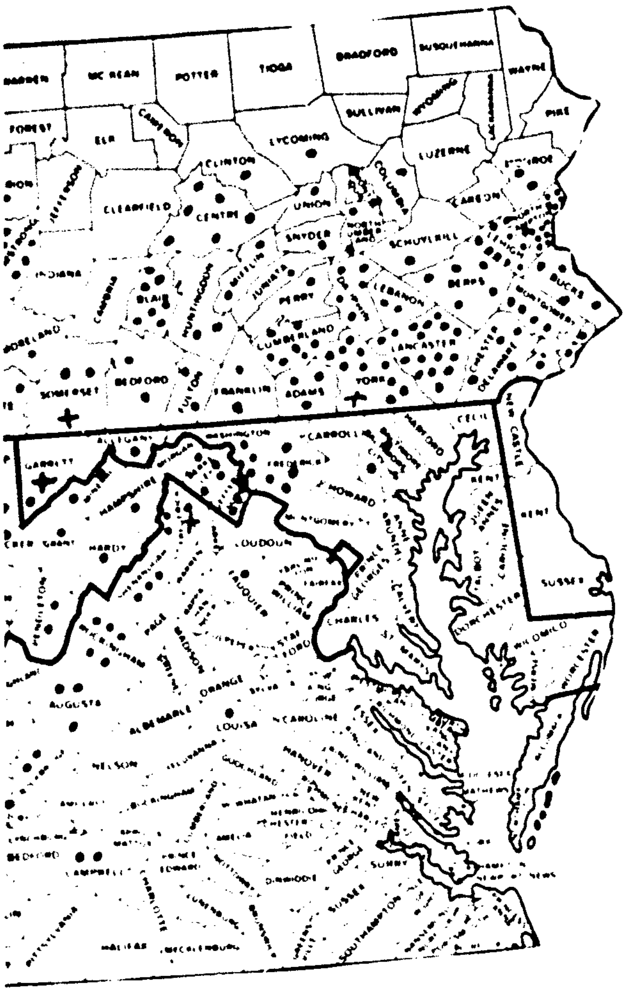
U. S. Bureau of Mines
State Geological Departments
National Limestone Institute

SCALE IN MILES

0 100 200 300

ALBERS EQUAL - AREA PROJECTION

County boundaries as of April 1, 1960

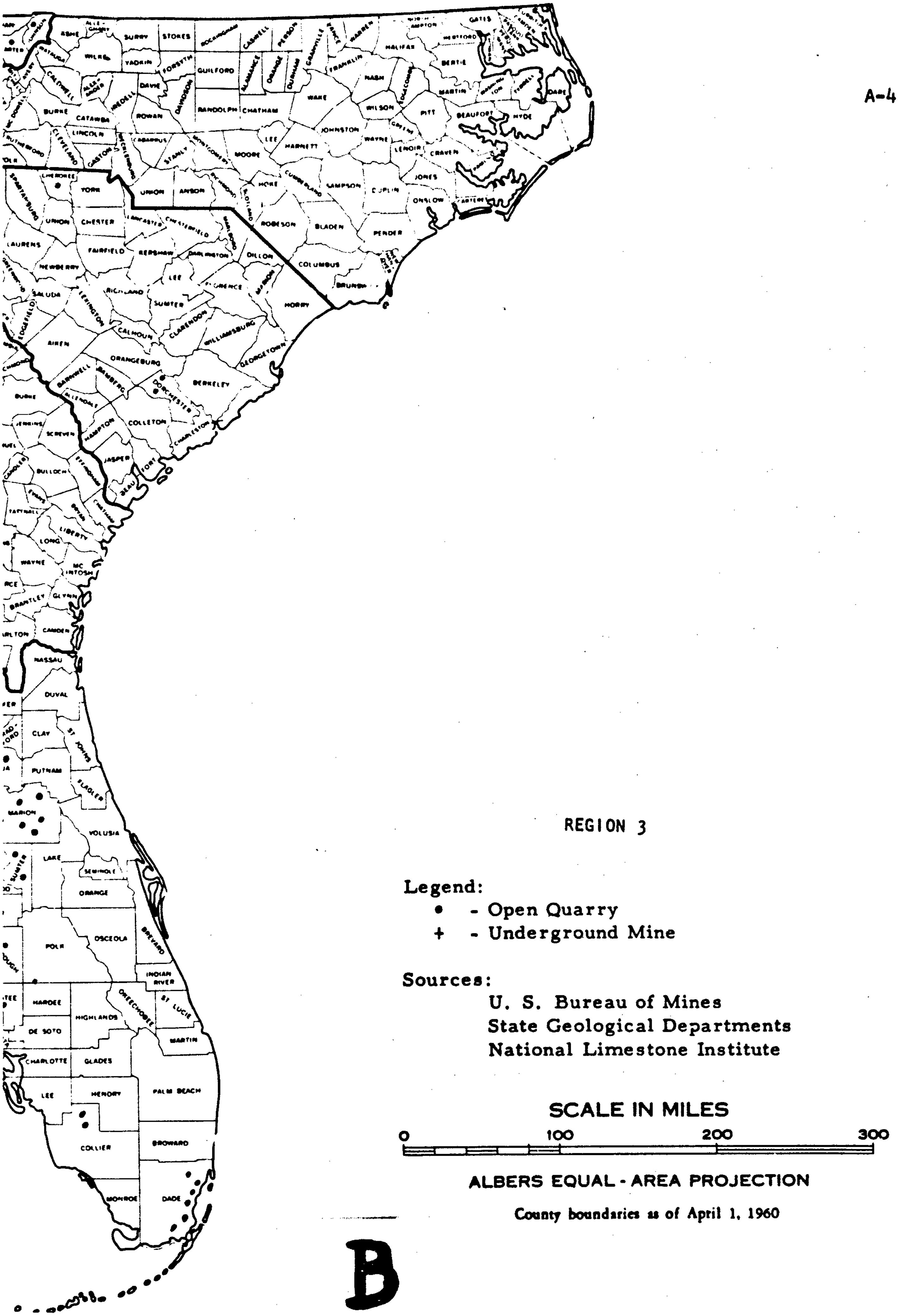

MC KEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
PIKE
FOREST
ELK
CAMERON
SULLIVAN
LYCOMING
LUZERNE
CLINTON
JEFFERSON
CLEARFIELD
CENTRE
UNION
SNYDER
SCHUYLKILL
CARBON
INDIANA
BLAIR
HUNTINGDON
PERRY
LEBANON
BERKS
BUCKS
CUMBERLAND
LANCASTER
SOMERSET
BEDFORD
FULTON
FRANKLIN
ADAMS
YORK
GARRETT
ALLEGANY
WASHINGTON
CARROLL
CECIL
FREDERICK
HOWARD
NEW CASTLE
KENT
SUSSEX
HARDY
LOUDOUN
CHARLES
DORCHESTER
WICOMICO
AUGUSTA
ORANGE
ALBEMARLE
LOUISA
NELSON
HANOVER
CAMPBELL
BEDFORD
SURRY
SOUTHAMPTON
HALIFAX
MECKLENBURG

B

HI-507-RR


OBION
WEAKLEY
HENRY
STEWART
HOUSTON
ROBERTSON
SUMNER
MACON
CLAY
JACKSON
OVERTON
FENTRESS
SCOTT
CLAIBORNE
HAWKINS
SULLIVAN
DYER
GIBSON
CARROLL
BENTON
DICKSON
WILSON
SMITH
PUTNAM
MORGAN
CAMPBELL
UNION
GRAINGER
GREENE
LAUDERDALE
CROCKETT
HAYWOOD
MADISON
HENDERSON
DECATUR
HICKMAN
WILLIAMSON
RUTHERFORD
DE KALB
WHITE
CUMBERLAND
ROANE
KNOX
SEVIER
COCKE
TIPTON
PERRY
LEWIS
MAURY
MARSHALL
BEDFORD
COFFEE
WARREN
VAN BUREN
BLEDSOE
RHEA
LOUDON
BLOUNT
MONROE
SWAIN
HAYWOOD
BUNCOMBE
HENDERSON
SHELBY
FAYETTE
HARDEMAN
CHESTER
MC NAIRY
HARDIN
WAYNE
LAWRENCE
GILES
LINCOLN
FRANKLIN
MARION
GRUNDY
HAMILTON
MC MINN
BRADLEY
POLK
GRAHAM
CHEROKEE
CLAY
MACON
DE SOTO
MARSHALL
BENTON
TIPPAH
ALCORN
TISHOMINGO
PRENTISS
TUNICA
TATE
UNION
PANOLA
LAFAYETTE
PONTOTOC
LEE
ITAWAMBA
COAHOMA
QUITMAN
TALLAHATCHIE
YALOBUSHA
CALHOUN
CHICKASAW
MONROE
BOLIVAR
SUNFLOWER
GRENADA
WEBSTER
CLAY
LEFLORE
CARROLL
MONTGOMERY
OKTIBBEHA
LOWNDES
WASHINGTON
HOLMES
ATTALA
CHOCTAW
WINSTON
NOXUBEE
HUMPHREYS
SHARKEY
YAZOO
MADISON
LEAKE
NESHOBA
KEMPER
ISSAQUENA
WARREN
HINDS
RANKIN
SCOTT
NEWTON
LAUDERDALE
CLAIBORNE
SMITH
JASPER
CLARKE
COPIAH
SIMPSON
JEFFERSON
LINCOLN
JEFFERSON DAVIS
COVINGTON
JONES
WAYNE
ADAMS
FRANKLIN
WILKINSON
AMITE
PIKE
WALTHALL
MARION
LAMAR
FORREST
PERRY
GREENE
PEARL RIVER
STONE
GEORGE
HANCOCK
HARRISON
JACKSON
LAUDERDALE
LIMESTONE
MADISON
JACKSON
COLBERT
FRANKLIN
LAWRENCE
MORGAN
MARSHALL
DE KALB
MARION
WINSTON
CULLMAN
ETOWAH
CHEROKEE
BLOUNT
LAMAR
FAYETTE
WALKER
ST CLAIR
CALHOUN
CLEBURNE
JEFFERSON
PICKENS
TUSCALOOSA
SHELBY
TALLADEGA
CLAY
RANDOLPH
GREENE
HALE
BIBB
CHILTON
COOSA
TALLAPOOSA
CHAMBERS
SUMTER
PERRY
AUTAUGA
ELMORE
LEE
MARENGO
DALLAS
MONTGOMERY
MACON
RUSSELL
CHOCTAW
LOWNDES
BULLOCK
WILCOX
BARBOUR
PIKE
BUTLER
CRENSHAW
CLARKE
MONROE
WASHINGTON
CONECUH
COFFEE
DALE
HENRY
COVINGTON
ESCAMBIA
GENEVA
HOUSTON
MOBILE
BALDWIN
ESCAMBIA
SANTA ROSA
OKALOOSA
WALTON
HOLMES
WASHINGTON
JACKSON
BAY
CALHOUN
GADSDEN
LEON
JEFFERSON
MADISON
HAMILTON
LIBERTY
WAKULLA
TAYLOR
LAFAYETTE
SUWANNEE
COLUMBIA
UNION
GULF
FRANKLIN
DIXIE
GILCHRIST
ALACHUA
LEVY
CITRUS
HERNANDO
PASCO
HILLSBOROUGH
MANATEE
SARASOTA
DADE
WALKER
CATOOSA
WHITFIELD
MURRAY
FANNIN
UNION
GILMER
GORDON
PICKENS
FLOYD
BARTOW
CHEROKEE
POLK
COBB
PAULDING
HARALSON
CARROLL
DOUGLAS
FULTON
HEARD
COWETA
TROUP
HARRIS
TALBOT
UPSON
MUSCOGEE
CHATTAHOOCHEE
MARION
TAYLOR
MACON
STEWART
WEBSTER
SUMTER
QUITMAN
RANDOLPH
TERRELL
LEE
DOOLY
CRISP
WILCOX
CLAY
CALHOUN
DOUGHERTY
WORTH
TIFT
TURNER
COFFEE
EARLY
BAKER
MITCHELL
COLQUITT
COOK
MILLER
SEMINOLE
DECATUR
GRADY
THOMAS
BROOKS
LOWNDES
ECHOLS
WARE
OCONEE
ANDERSON
GREENVILLE
PICKENS
ABBEVILLE
JONES
PUTNAM
HANCOCK
WASHINGTON
JOHNSON
LAURENS
TELFAIR
DODGE
ATKINSON
BACON
APPLING

A


REGION 3
Legend:
• - Open Quarry
+ - Underground Mine
Sources:
U. S. Bureau of Mines
State Geological Departments
National Limestone Institute
SCALE IN MILES
0
100
200
300
ALBERS EQUAL - AREA PROJECTION
County boundaries as of April 1, 1960

B


KITTSON
ROSEAU
LAKE OF THE WOODS
MARSHALL
PENNINGTON
RED LAKE
POLK
BELTRAMI
KOOCHICHING
NORMAN
CLEARWATER
ITASCA
ST LOUIS
LAKE
COOK
CLAY
BECKER
HUBBARD
CASS
OTTER TAIL
CROW WING
AITKIN
CARLTON
TODD
MORRISON
MILLE LACS
PINE
GRANT
DOUGLAS
STEVENS
POPE
STEARNS
BENTON
ISANTI
ANOKA
SWIFT
CHIPPEWA
MEEKER
WRIGHT
HENNEPIN
WASHINGTON
YELLOW MEDICINE
RENVILLE
MC LEOD
CARVER
SCOTT
DAKOTA
SIBLEY
LYON
REDWOOD
NICOLLET
RICE
GOODHUE
WABASHA
BROWN
MURRAY
COTTONWOOD
BLUE EARTH
STEELE
DODGE
OLMSTED
WINONA
ROCK
NOBLES
JACKSON
MARTIN
FARIBAULT
FREEBORN
MOWER
FILLMORE
HOUSTON
DOUGLAS
BAYFIELD
ASHLAND
IRON
BURNETT
SAWYER
PRICE
POLK
BARRON
RUSK
ST CROIX
DUNN
CHIPPEWA
TAYLOR
PIERCE
PEPIN
EAU CLAIRE
CLARK
BUFFALO
JACKSON
MONROE
VERNON
ONTONAGON
BARAGA
GOGEBIC
VILAS
ONEIDA
FOREST
LINCOLN
LANGLADE
MARINETTE
MARATHON
OCONTO
SHAWANO
WOOD
PORTAGE
WAUPACA
OUTAGAMIE
BROWN
DOOR
KEWAUNEE
MANITOWOC
ADAMS
WAUSHARA
SHEBOYGAN
MARQUETTE
ALGER
DELTA
LUCE
SCHOOLCRAFT
HOUGHTON
KEWEENAW
FLORENCE
MENOMINEE
SAUK
COLUMBIA
DODGE
DANE
JEFFERSON
WAUKESHA
RACINE
KENOSHA
WALWORTH
LAFAYETTE
GREEN
ROCK
MC HENRY
LAKE
CARROLL
OGLE
KANE
DU PAGE
COOK
WHITESIDE
LEE
WILL
HENRY
BUREAU
LA SALLE
GRUNDY
KANKAKEE
MERCER
STARK
MARSHALL
KNOX
PEORIA
WOODFORD
LIVINGSTON
IROQUOIS
HENDERSON
WARREN
FULTON
TAZEWELL
MC LEAN
FORD
HANCOCK
MASON
LOGAN
DE WITT
CHAMPAIGN
VERMILION
SCHUYLER
CASS
MENARD
PIATT
ADAMS
BROWN
MORGAN
SANGAMON
MACON
DOUGLAS
EDGAR
PIKE
CHRISTIAN
MOULTRIE
COLES
GREENE
MACOUPIN
MONTGOMERY
SHELBY
CUMBERLAND
CLARK
JERSEY
FAYETTE
EFFINGHAM
JASPER
CRAWFORD
MADISON
BOND
CLAY
RICHLAND
CLINTON
MARION
ST CLAIR
WASHINGTON
JEFFERSON
WAYNE
MONROE
RANDOLPH
PERRY
FRANKLIN
HAMILTON
WHITE
JACKSON
WILLIAMSON
SALINE
GALLATIN
UNION
JOHNSON
POPE
MASSAC
MASON
LAKE
OSCEOLA
OCEANA
NEWAYGO
MECOSTA
MUSKEGON
OTTAWA
KENT
ALLEGAN
VAN BUREN
KALAMAZOO
BERRIEN
CASS
BENZIE
MANISTEE
WEXFORD
GRAND TRAVERSE
ANTRIM
LA PORTE
PORTER
LAKE
ST JOSEPH
STARKE
MARSHALL
NEWTON
JASPER
PULASKI
FULTON
WHITE
CASS
BENTON
CARROLL
HOWARD
GRANT
TIPTON
CLINTON
FOUNTAIN
MONTGOMERY
BOONE
HAMILTON
MADISON
PARKE
HENDRICKS
HANCOCK
VIGO
CLAY
OWEN
MORGAN
JOHNSON
SHELBY
SULLIVAN
GREENE
MONROE
BROWN
KNOX
DAVIESS
MARTIN
JACKSON
LAWRENCE
ORANGE
GIBSON
PIKE
DUBOIS
SPENCER
PERRY
WARRICK
POSEY
SCOTT

A

REGION 4

Legend:

- • - Open Quarry
- + - Underground Mine

Sources:

U. S. Bureau of Mines
State Geological Departments
National Limestone Institute

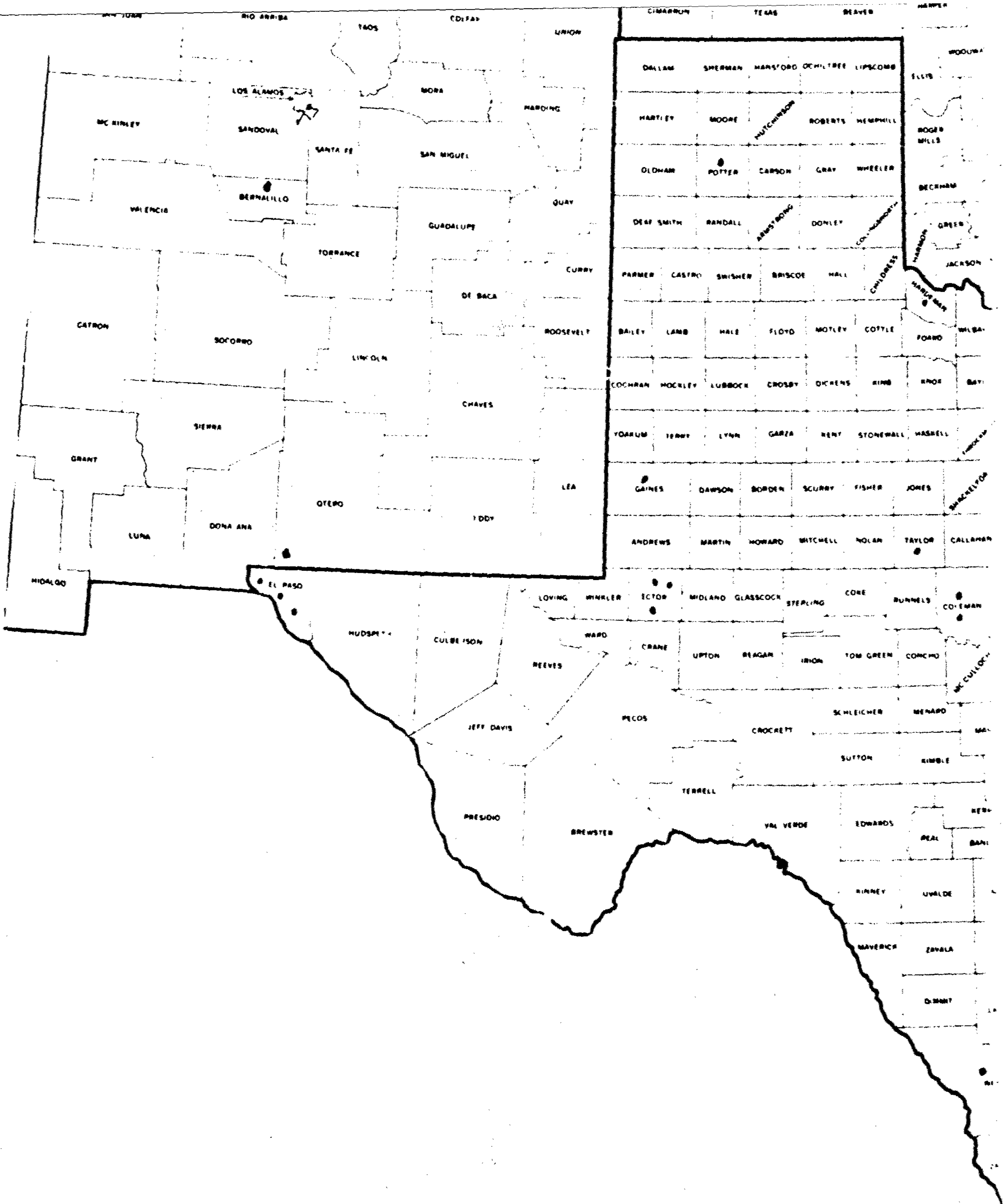
SCALE IN MILES

0 100 200 300

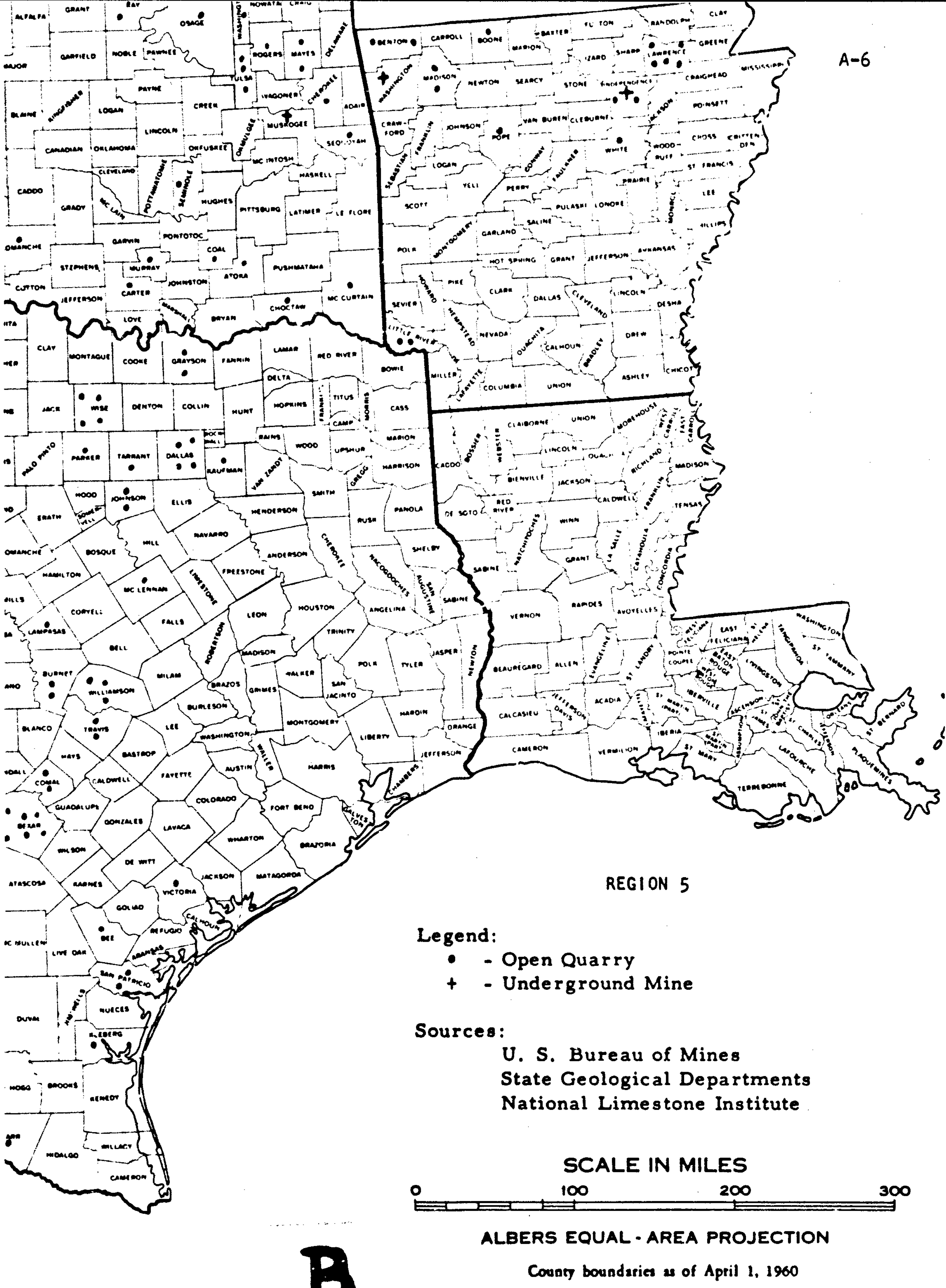
ALBERS EQUAL - AREA PROJECTION

County boundaries as of April 1, 1960

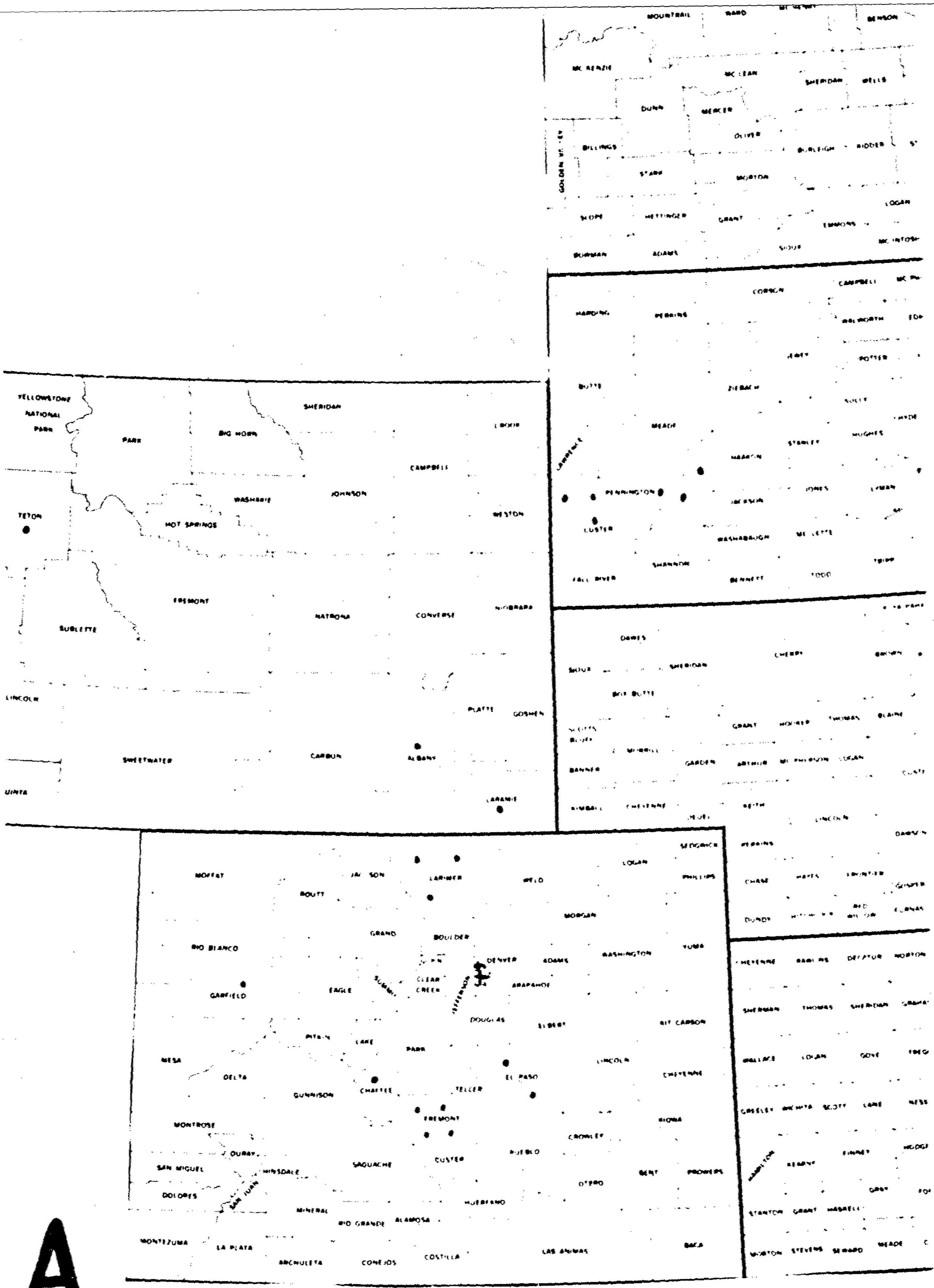
B


RIO ARRIBA
TAOS
COLFAX
UNION
CIMARRON
TEXAS
BEAVER
LOS ALAMOS
MORA
HARDING
MC KINLEY
SANDOVAL
SANTA FE
SAN MIGUEL
BERNALILLO
QUAY
VALENCIA
TORRANCE
GUADALUPE
CURRY
DE BACA
CATRON
SOCORRO
ROOSEVELT
LINCOLN
CHAVES
SIERRA
GRANT
LEA
OTERO
LUNA
DONA ANA
EDDY
HIDALGO
EL PASO
HUDSPETH
CULBERSON
DALLAM
SHERMAN
HANSFORD
OCHILTREE
LIPSCOMB
HARTLEY
MOORE
HUTCHINSON
ROBERTS
HEMPHILL
OLDHAM
POTTER
CARSON
GRAY
WHEELER
DEAF SMITH
RANDALL
ARMSTRONG
DONLEY
COLLINGSWORTH
PARMER
CASTRO
SWISHER
BRISCOE
HALL
CHILDRESS
BAILEY
LAMB
HALE
FLOYD
MOTLEY
COTTLE
COCHRAN
HOCKLEY
LUBBOCK
CROSBY
DICKENS
KING
KNOX
YOAKUM
TERRY
LYNN
GARZA
KENT
STONEWALL
HASKELL
GAINES
DAWSON
BORDEN
SCURRY
FISHER
JONES
ANDREWS
MARTIN
HOWARD
MITCHELL
NOLAN
TAYLOR
CALLAHAN
LOVING
WINKLER
ECTOR
MIDLAND
GLASSCOCK
STERLING
COKE
RUNNELS
COLEMAN
WARD
CRANE
UPTON
REAGAN
IRION
TOM GREEN
CONCHO
REEVES
PECOS
SCHLEICHER
MENARD
JEFF DAVIS
CROCKETT
SUTTON
KIMBLE
TERRELL
PRESIDIO
BREWSTER
VAL VERDE
EDWARDS
REAL
KINNEY
UVALDE
MAVERICK
ZAVALA
DIMMIT
ELLIS
ROGER MILLS
BECKHAM
GREER
HARMON
JACKSON
HARDEMAN
FOARD

A


REGION 5
Legend:
• - Open Quarry
+ - Underground Mine
Sources:
U. S. Bureau of Mines
State Geological Departments
National Limestone Institute
SCALE IN MILES
0
100
200
300
ALBERS EQUAL - AREA PROJECTION
County boundaries as of April 1, 1960

B


MOUNTRAIL
WARD
BENSON
MC KENZIE
MC LEAN
SHERIDAN
WELLS
DUNN
MERCER
OLIVER
BILLINGS
BURLEIGH
KIDDER
GOLDEN VALLEY
STARK
MORTON
LOGAN
SLOPE
HETTINGER
GRANT
EMMONS
MC INTOSH
BOWMAN
ADAMS
SIOUX
CORSON
CAMPBELL
HARDING
PERKINS
WALWORTH
DEWEY
POTTER
BUTTE
ZIEBACH
SULLY
MEADE
HYDE
LAWRENCE
STANLEY
HUGHES
HAAKON
PENNINGTON
JONES
LYMAN
JACKSON
CUSTER
WASHABAUGH
MELLETTE
SHANNON
TRIPP
FALL RIVER
BENNETT
TODD
DAWES
CHERRY
SIOUX
SHERIDAN
BROWN
BOX BUTTE
SCOTTS BLUFF
GRANT
HOOKER
THOMAS
BLAINE
MORRILL
BANNER
GARDEN
ARTHUR
MC PHERSON
LOGAN
KIMBALL
CHEYENNE
KEITH
LINCOLN
DAWSON
PERKINS
CHASE
HAYES
FRONTIER
GOSPER
DUNDY
FURNAS
YELLOWSTONE
NATIONAL
PARK
SHERIDAN
PARK
BIG HORN
CROOK
CAMPBELL
TETON
WASHAKIE
JOHNSON
HOT SPRINGS
WESTON
FREMONT
SUBLETTE
NATRONA
CONVERSE
NIOBRARA
LINCOLN
PLATTE
GOSHEN
SWEETWATER
CARBON
ALBANY
UINTA
LARAMIE
SEDGWICK
MOFFAT
JACKSON
LARIMER
WELD
LOGAN
PHILLIPS
ROUTT
MORGAN
GRAND
BOULDER
RIO BLANCO
YUMA
DENVER
ADAMS
WASHINGTON
CLEAR CREEK
EAGLE
SUMMIT
JEFFERSON
ARAPAHOE
GARFIELD
DOUGLAS
ELBERT
KIT CARSON
PITKIN
LAKE
PARK
MESA
LINCOLN
DELTA
EL PASO
CHEYENNE
GUNNISON
CHAFFEE
TELLER
FREMONT
KIOWA
MONTROSE
CROWLEY
OURAY
PUEBLO
SAN MIGUEL
HINSDALE
SAGUACHE
CUSTER
BENT
PROWERS
DOLORES
SAN JUAN
OTERO
MINERAL
HUERFANO
RIO GRANDE
ALAMOSA
MONTEZUMA
LA PLATA
BACA
ARCHULETA
CONEJOS
COSTILLA
LAS ANIMAS
CHEYENNE
RAWLINS
DECATUR
NORTON
SHERMAN
THOMAS
SHERIDAN
WALLACE
LOGAN
GOVE
GREELEY
WICHITA
SCOTT
LANE
NESS
HAMILTON
KEARNY
FINNEY
HODGEMAN
GRAY
STANTON
GRANT
HASKELL
MORTON
STEVENS
SEWARD
MEADE

A

REGION 6

Legend:
- • - Open Quarry
- + - Underground Mine

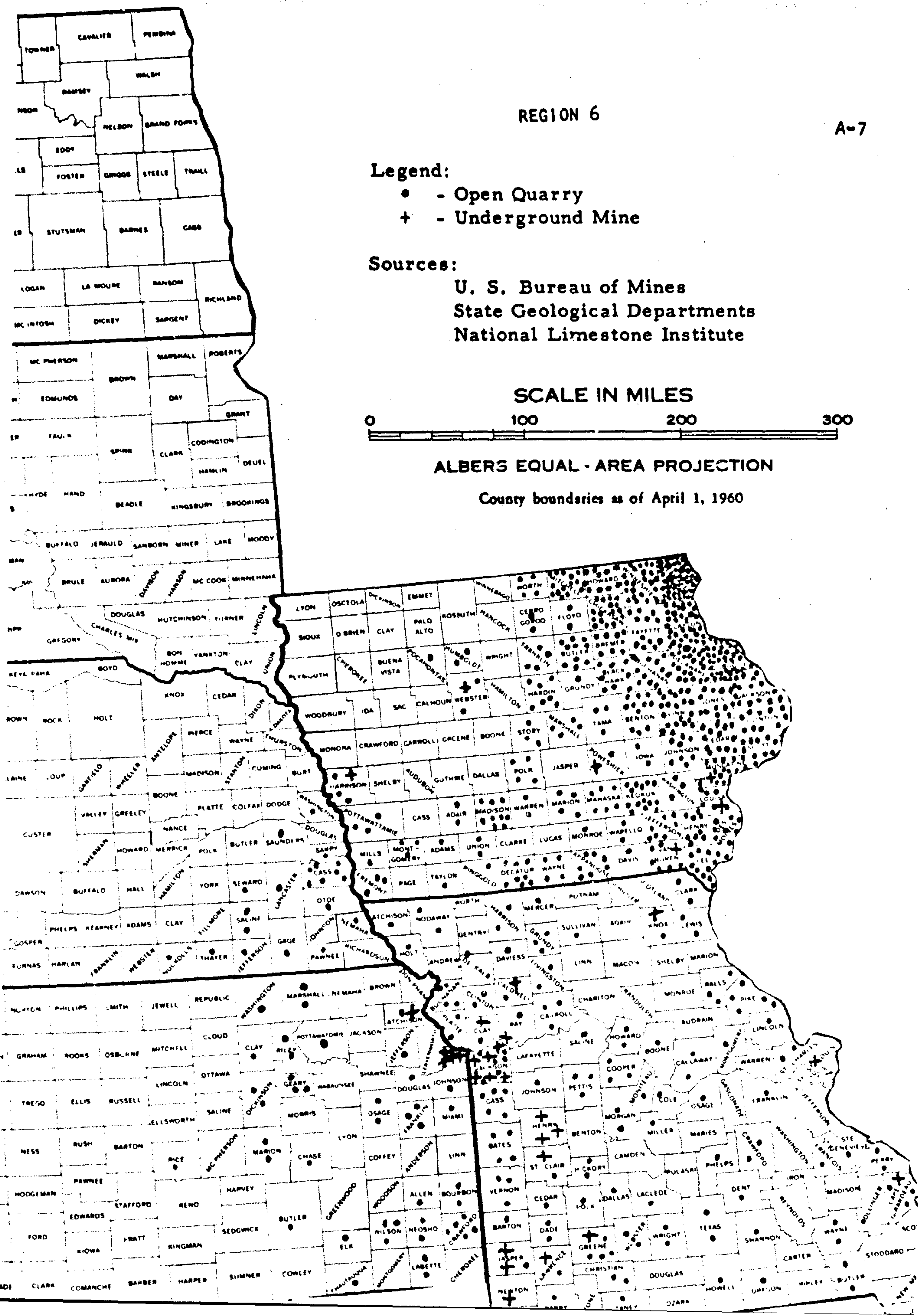
Sources:
U. S. Bureau of Mines
State Geological Departments
National Limestone Institute

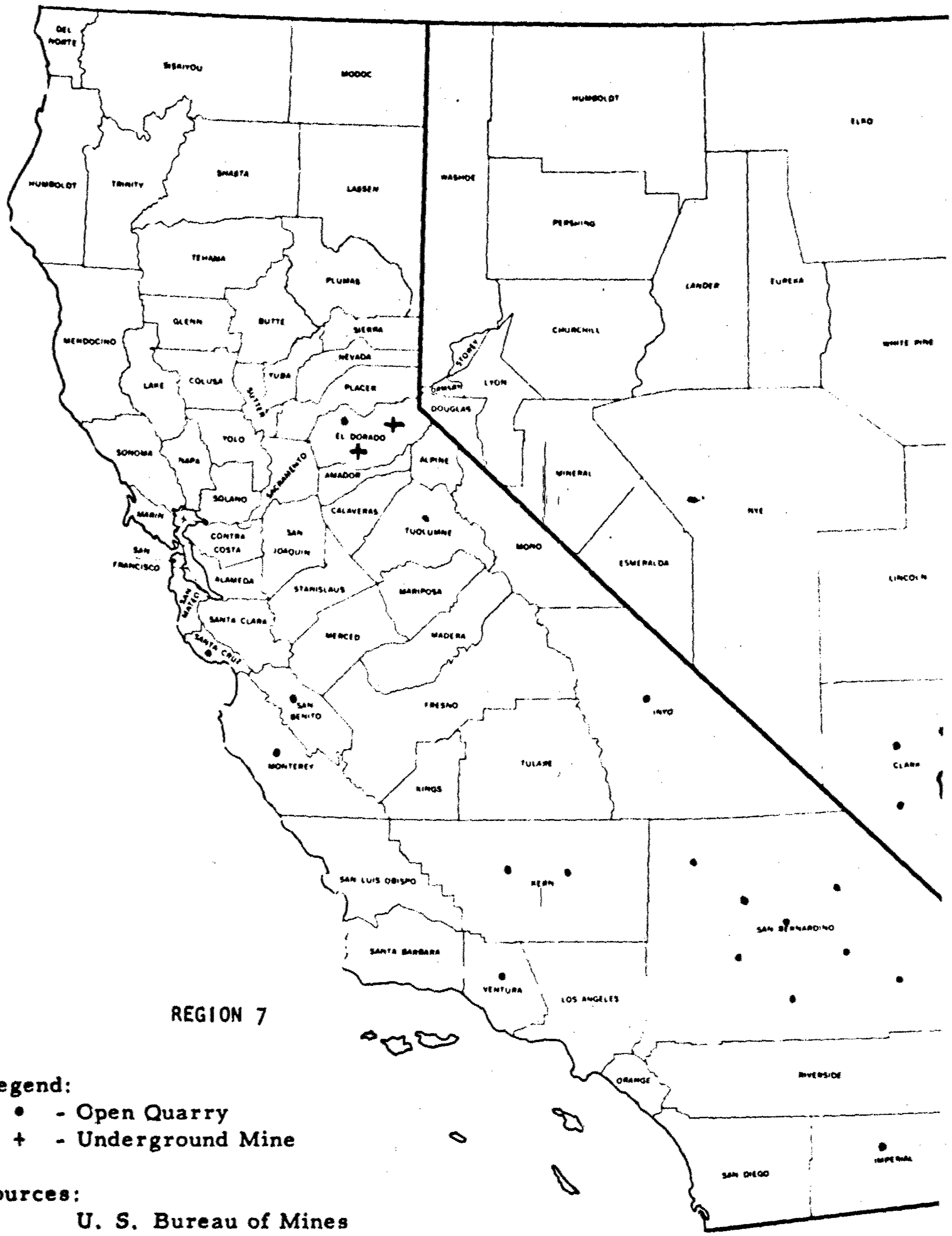
SCALE IN MILES

0 100 200 300

ALBERS EQUAL - AREA PROJECTION

County boundaries as of April 1, 1960





Legend:

- • - Open Quarry
- + - Underground Mine

Sources:

U. S. Bureau of Mines
State Geological Departments
National Limestone Institute

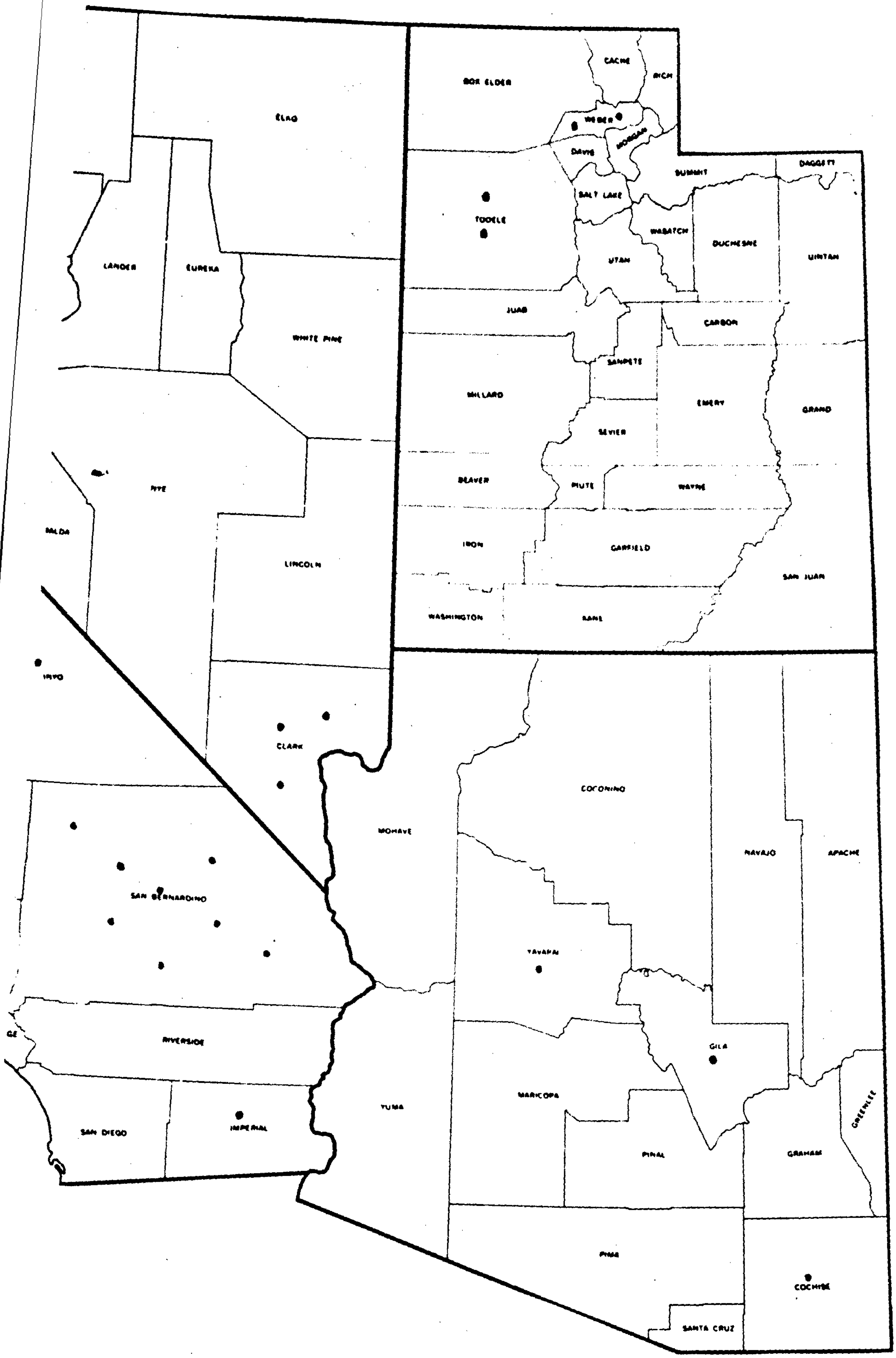
SCALE IN MILES

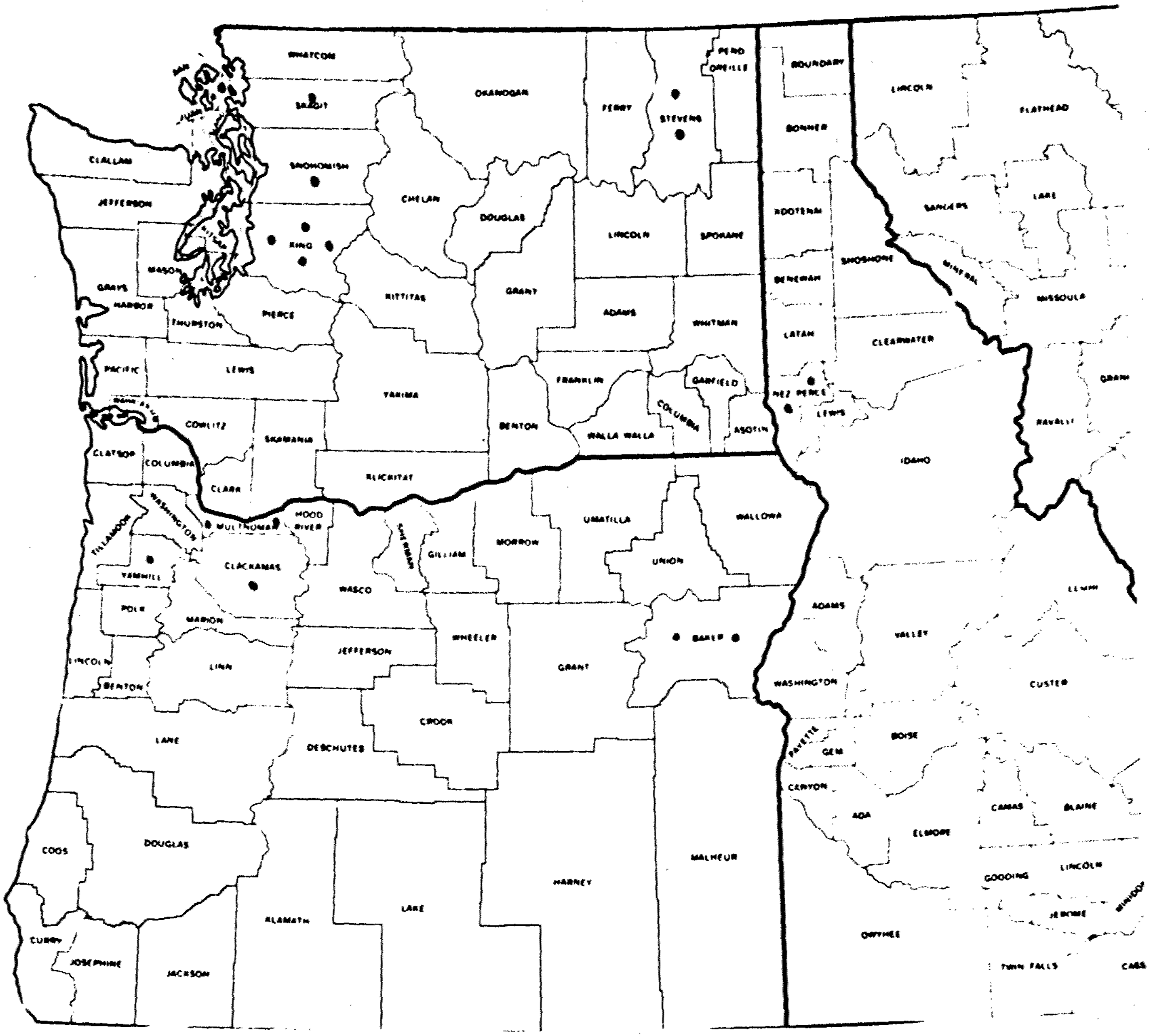
0 100 200 300

ALBERS EQUAL - AREA PROJECTION

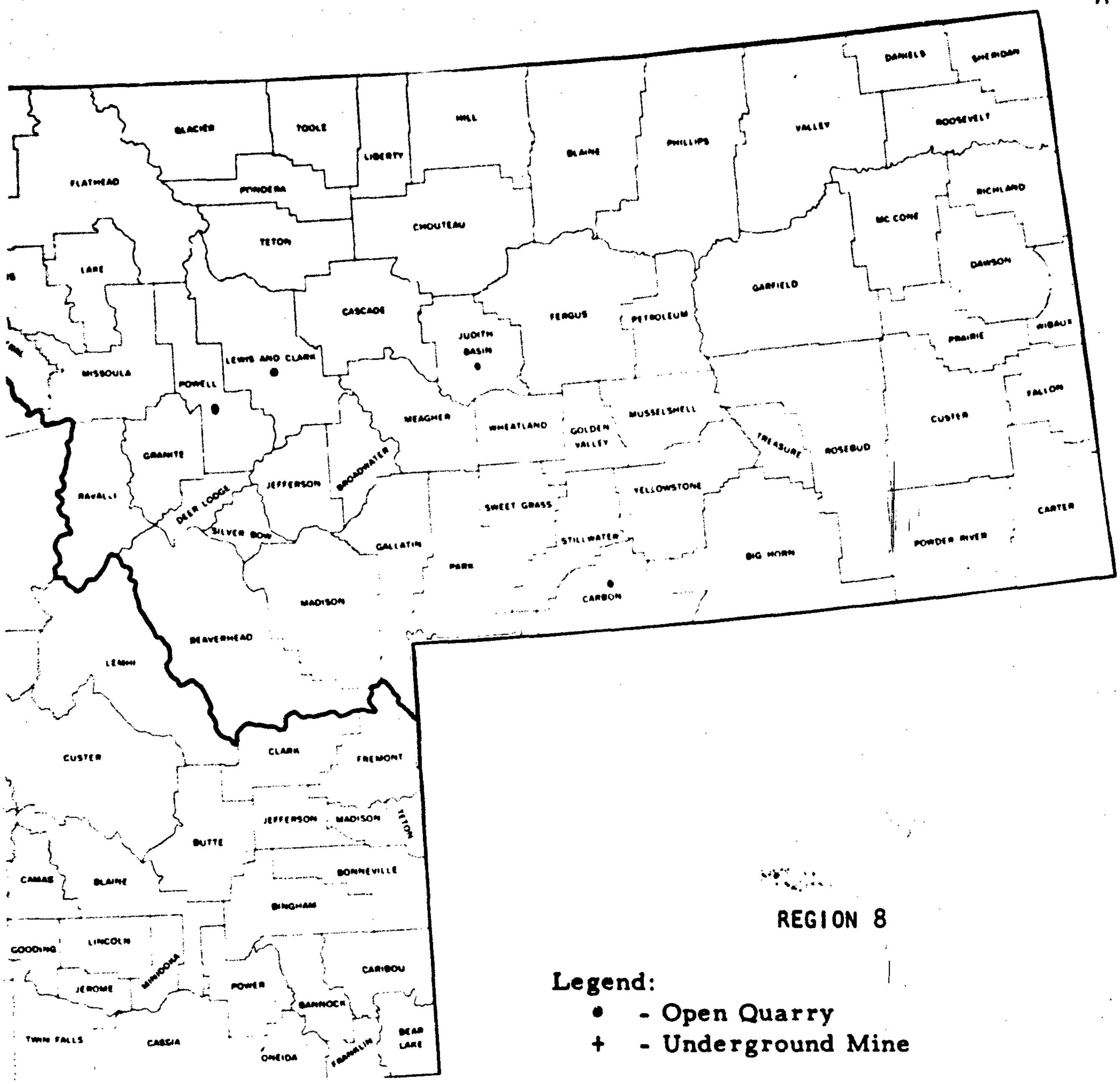
County boundaries as of April 1, 1960

A-8


ELKO
LANDER
EUREKA
WHITE PINE
NYE
LINCOLN
CLARK
INYO
SAN BERNARDINO
RIVERSIDE
SAN DIEGO
IMPERIAL
BOX ELDER
CACHE
RICH
WEBER
MORGAN
DAVIS
TOOELE
SALT LAKE
SUMMIT
DAGGETT
WASATCH
DUCHESNE
UINTAH
UTAH
JUAB
CARBON
SANPETE
MILLARD
EMERY
GRAND
SEVIER
BEAVER
PIUTE
WAYNE
IRON
GARFIELD
SAN JUAN
WASHINGTON
KANE
MOHAVE
COCONINO
NAVAJO
APACHE
YAVAPAI
GILA
MARICOPA
YUMA
PINAL
GRAHAM
GREENLEE
PIMA
COCHISE
SANTA CRUZ


WHATCOM
SKAGIT
OKANOGAN
FERRY
STEVENS
PEND OREILLE
CLALLAM
JEFFERSON
SNOHOMISH
CHELAN
DOUGLAS
KING
MASON
GRAYS HARBOR
THURSTON
PIERCE
LINCOLN
SPOKANE
GRANT
ADAMS
WHITMAN
PACIFIC
LEWIS
YAKIMA
FRANKLIN
GARFIELD
COWLITZ
SKAMANIA
BENTON
WALLA WALLA
COLUMBIA
ASOTIN
CLATSOP
CLARK
KLICKITAT
TILLAMOOK
WASHINGTON
MULTNOMAH
HOOD RIVER
SHERMAN
GILLIAM
MORROW
UMATILLA
WALLOWA
UNION
YAMHILL
CLACKAMAS
WASCO
POLK
MARION
BAKER
LINCOLN
JEFFERSON
WHEELER
LINN
BENTON
GRANT
CROOK
LANE
DESCHUTES
COOS
DOUGLAS
MALHEUR
HARNEY
KLAMATH
LAKE
CURRY
JOSEPHINE
JACKSON
BOUNDARY
BONNER
KOOTENAI
BENEWAH
SHOSHONE
LATAH
CLEARWATER
NEZ PERCE
LEWIS
IDAHO
ADAMS
VALLEY
WASHINGTON
PAYETTE
GEM
BOISE
CANYON
ADA
ELMORE
CAMAS
BLAINE
CUSTER
LEMHI
OWYHEE
GOODING
LINCOLN
JEROME
TWIN FALLS
LINCOLN
FLATHEAD
SANDERS
LAKE
MINERAL
MISSOULA
RAVALLI

A



REGION 8

Legend:

- ● - Open Quarry
- + - Underground Mine

Sources:

U. S. Bureau of Mines
State Geological Departments
National Limestone Institute

SCALE IN MILES

0 100 200 300

ALBERS EQUAL - AREA PROJECTION

County boundaries as of April 1, 1960

B