2.

Mineral Exploration, Development, and Production: Technology, Participants, and the Role of Federal Onshore Land

Mineral Exploration, Development, and Production: Technology, Participants, and the Role of Federal Onshore Land

A continuing supply of newly mined minerals is essential to maintain the U.S. economy. Federal onshore land has been and is expected to remain a major source of domestic mineral discoveries.

In general, mineral activity occurs in several stages, ranging from target identification and target investigation to development and production. Each stage involves the application of more discriminating and expensive techniques to smaller land areas. Large areas containing thousands of square miles must be available for exploration in the initial stages, from which smaller target areas of only a few square miles or less can be selected for actual detailed investigation and possible development. Each successful exploration project must pay for 10 to 100 failures.

Conventional prospecting, which was until recently the source of almost all mineral discoveries, is no longer a significant source except perhaps in Alaska, because practically all visible indications of mineralization have already been identified in more than 100 years of intensive prospecting. The individual prospector has been largely replaced by modern exploration groups in medium- and large-sized companies as the source of almost all new mineral discoveries.

A. Minerals in the Economy

Mineral materials provide the physical basis for almost all activities of each U.S. citizen, whose per capita share of domestic consumption of new (mined) mineral materials in 1976 amounted to almost 40,000 pounds.[1] The pervasive use of minerals in the economy has been aptly illustrated by McDivitt and Manners, who noted in 1974 that:

> Today the mineral products of the earth are so commonly used that they affect every aspect of our lives, and today the average American is the largest consumer of minerals the world has ever known. Each year he uses, or has used on his behalf, a remarkable variety of minerals in quantities that would overwhelm him if his quota

[1] U.S. Bureau of Mines, *Status of the Mineral Industries, 1977*, at 2 (1977)

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for the year were to be dumped on his doorstep on New Year's morning! In 1970, per capita consumption of minerals in the United States (the average amount of material devoted directly or indirectly to each person) included nearly 1,400 pounds (620 kilograms) of steel—a man's car perhaps; 44 pounds (20 kilograms) of aluminum—for containers, kitchenware, house siding, etc.; 20 pounds (9 kilograms) of copper—much of this used in the electrical industry; less than a pound (0.4 kilogram) of tin—one-third of which went into tin cans; and a host of other less easily identifiable metals.

This is by no means the end. Few of us have any idea of the amount of fuel we consume in a year. The 3.4 tons of crude oil allocated to every American on a per capita basis and used for transport, industrial, and heating purposes, may not come as a surprise. But less directly that same person consumes (in oil equivalent tons) a further 2.5 tons of natural gas and 1.6 tons of solid fuels. This latter figure is equivalent to nearly **2.3** tons per person of actual coal and lignite, over 60 percent of which is converted into electricity, and much of the rest is used to produce each person's 1,400 pounds of steel, In addition to these minerals, each American uses some 440 pounds (ZOO kilograms] of salt, only a very small part of which takes the form of food seasoning: nearly 70 pounds (over 30 kilograms) of sulfur, the bulk of which is used to produce sulfuric acid, which in turn goes into fertilizer production; and over 994 tons of sand and gravel, most of which is used by the construction industry for buildings and highways. The list goes on, and the quantities continue to mount.'

Adequate supplies of minerals are essential for the maintenance of our economy. Reliable and reasonably priced supplies are essential to the smooth functioning of the economy and to our national security in a world subject to frequent political and military conflict,

Conservation, recycling, reuse, and substitution of minerals and mineral products are worthwhile objectives, However, there are limits on the contribution they can make, especially under present practices, policies, and attitudes, toward meeting the present and projected requirements for individual mineral commodities.[3]

Furthermore, a significant portion of our national economic activity and employment, particularly in certain regions, is based on the mineral-producing sectors of the economy, '

Considering all of the above, as well as the increasing difficulties of exploring for and producing minerals in foreign countries,[5] it is clearly in the national interest to consider carefully opportunities for the discovery, development, and production of domestic mineral resources.

], hlcIhvltt and C. kfanners, M1nerols ond Men 3-4 (rev'd eci. 1974],

'See National Araderny of !+ lenccs and Nat]onal Academy of Engineering, Nuhonul ,Muterj(l/s Pol]cy; Proceedings of u Joinf Meeting (1975); Ntitional Cummisslon on Nlaterlals Policy, Moterl-(JI N(wis un(i the Environment 7'oda} (Ind T(mmorrow (1973); U.S. Bureau of Nflnes, (l]mmod]t}' I)otu SummorIes, 1!)76 (1976): U.S. Bureau of hlines, Mlner{d F(lct$ (Jn(l Proh]ems, 1975 Edit] on. Bull. 667 [1976); U.S. Council on [nternatlonal Economic Poli(y, SpeC;Iu) Report: Critlca) Imported Mu(eriu]s (1974); U.S. Department of the Interior, ivflrurw und Minerals Policy, 1976 (1976),

'U.S. Bureau of Mines, Status of the Mineral Industr]cs, 1977, at 4-5 (1 977].

'W'althler, ''The Shrinking W'orld of F;xploratlon, " pts, 1 and z, M]nlnx Englneerlng, April and Nlav 1976,

B. The Role of Federal Onshore Land

The Federal Government owned one-third of the onshore land in the United States in 1975. (The Federal percentage will drop to just over 27 percent when the transfer of about 150 million acres to the State of Alaska and the Alaskan Natives is completed.) More than 93 percent of the Federal onshore land was in the 11 contiguous Western States and Alaska, and the Federal acreage amounted to 64 percent of the total land in those States. (When ,the Alaskan land transfers are completed, more than 91 percent of the Federal onshore land will be in the 11 contiguous Western States and Alaska, and, the Federal acreage will amount to 51 percent of the total land in these States.) The Federal Government also has reserved mineral rights in an additional 5 percent of the acreage of these States,'[6] (See figure 2.1.)

'In the past, the Federal onshore land has proven to be a source of large reserves of a. wide variety of essential minerals. In addition, for some minerals (for example, coal) large resources[7] on Federal onshore land can be predicted on the basis of current knowledge, while for some other minerals (for example, copper) a large potential can be inferred on the basis of past experience and geologic evidence.

Minerals in Federal onshore land are explored for, developed, and produced under a variety of laws, which are summarized in chapter 3. The principal laws are the Mining Law of 1872, as amended, the Mineral Leasing Acts of 1920 and 1947, as amended and supplemented, the Geothermal Steam Act of 1970, and the Surface Resources Act of 1955, as amended. In general, the Mining Law applies to metallic mineral deposits (for example, copper, silver, and uranium) and deposits of most nonmetallic minerals (for example, asbestos and fluorite). The Mineral Leasing Acts apply to the fossil fuel minerals, the fertilizer minerals (phosphate and potash), and the chemical minerals (sodium and sulfur), The Geothermal Steam Act applies only to geothermal steam and associated resources. The Surface Resources Act applies to common varieties of sand, stone, gravel, pumice, pumicite, or cinders. Minerals subject to the Mining Law are generally referred to as "locatable" or "hardrock" minerals; those subject to the Mineral Leasing Acts or the Geothermal Steam Act are referred to as "leasable" minerals; and those subject to the Surface Resources Act are referred to as "saleable" or "common variety' or "construction" minerals.

In 1975, petroleum and natural gas production from about 5.5 million acres of producing leases on Federal onshore land amounted to approximately 6 percent of the national total and was valued at over $1.64 billion.' Large areas of the Federal onshore land not yet thoroughly drilled are considered favorable for the occurrence of petroleum and natural gas, In 1975, more than 84 million acres were under lease for petroleum and natural gas exploration and development. More than 90 percent of the leased acreage was in the 11 Western States and Alaska.[9]

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[6] Derived from data in U.S. Bureau of Land Management, *Public Land Statistics, 1976*, tables 7 and 17 (1977). The 11 contiguous States are Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

[7] For definitions of reserves, resources, etc., see app. A.

[8] U.S. Geological Survey, Conservation Division, *Federal and Indian Lands Oil and Gas Production, Royalty Income, and Related Statistics, Calendar Year 1975* (1976).

[9] Ibid.

Figure 2.1.—Principal Federal Landholdings in 1976

SOURCE: U.S. Geological Survey, Special Maps Branch, 1977.
Note: Alaska is shown here at a reduced scale.

Includes areas of interspersed ownership containing at least 25-percent Federal land.

Substantial deposits of coal, phosphate, and sodium compounds are also known to exist on Federal onshore land, and large resources of these minerals are under lease. The value of production at the mine or wellhead of all leasable minerals on Federal onshore land[10] in 1975 was more than $2.21 billion. Their cumulative production value for 1920 through 1975 was more than $22.5 billion,]'

Detailed records are not kept for production of hardrock minerals on Federal land unless they are produced from leases on Federal acquired land. (The value of production of hardrock minerals on acquired land was included in the $22.5 billion cumulative production value of all leasable minerals given above.) Nevertheless, some idea of the importance of Federal land for hardrock mineral production can be obtained from the data on mineral production in the Western States because, as was pointed out above, 64 percent of the acreage in the Western States, including Alaska, is owned by the Federal Government, and most hardrock mines on what is now private land in the Western States have passed into private ownership through location on Federal land under the Mining Law, In 1975, the Western States produced the following approximate amounts of the Nation's domestic primary[12] mineral supply: 92 percent of the copper, 84 percent of the silver, and almost 100 percent of the nickel. In fact, the bulk of the known domestic resources of a majority of the metallic minerals is situated in the West.[13]

The role of Federal onshore land in the production of 14 representative essential" mineral commodities is described in appendix A. Of the 14 mineral commodities, 7 (coal, copper, nickel, phosphate rock, silver, sodium carbonate, and uranium) have a relatively high potential for occurrence on Federal onshore land, 6 (geothermal steam, fluorspar, lead, natural gas, petroleum, and potash) have a more moderate potential, and 1 (iron ore) has only limited, but possibly locally important, potential. Even minerals with lesser Federal land potential may take on added significance when viewed within the context of national needs and the reliability of imports.

Figures 2.2 and 2,3 provide an overview of the importance of Federal onshore land for mineral exploration, development, and production. Figure 2.2 overlays the Federal onshore land map in figure 2.1 with the base and precious metal mining districts. Figure 2.3 shows the location of the major coalfields in the coterminous United States. As can be seen from the figures, most of the Nation's known mineral resources are concentrated in Federal land areas.

All the data support the conclusion of the Public Land Law Review Commission in its 1970 report that:

> Present knowledge about the geology of mineralization in the United States, combined with the geographic pattern of established mining districts, indicates a strong probability that the public land areas of the West generally hold greater promise for future mineral discoveries than any other region.

Indian land is not included as 'Federal land'' in this report.

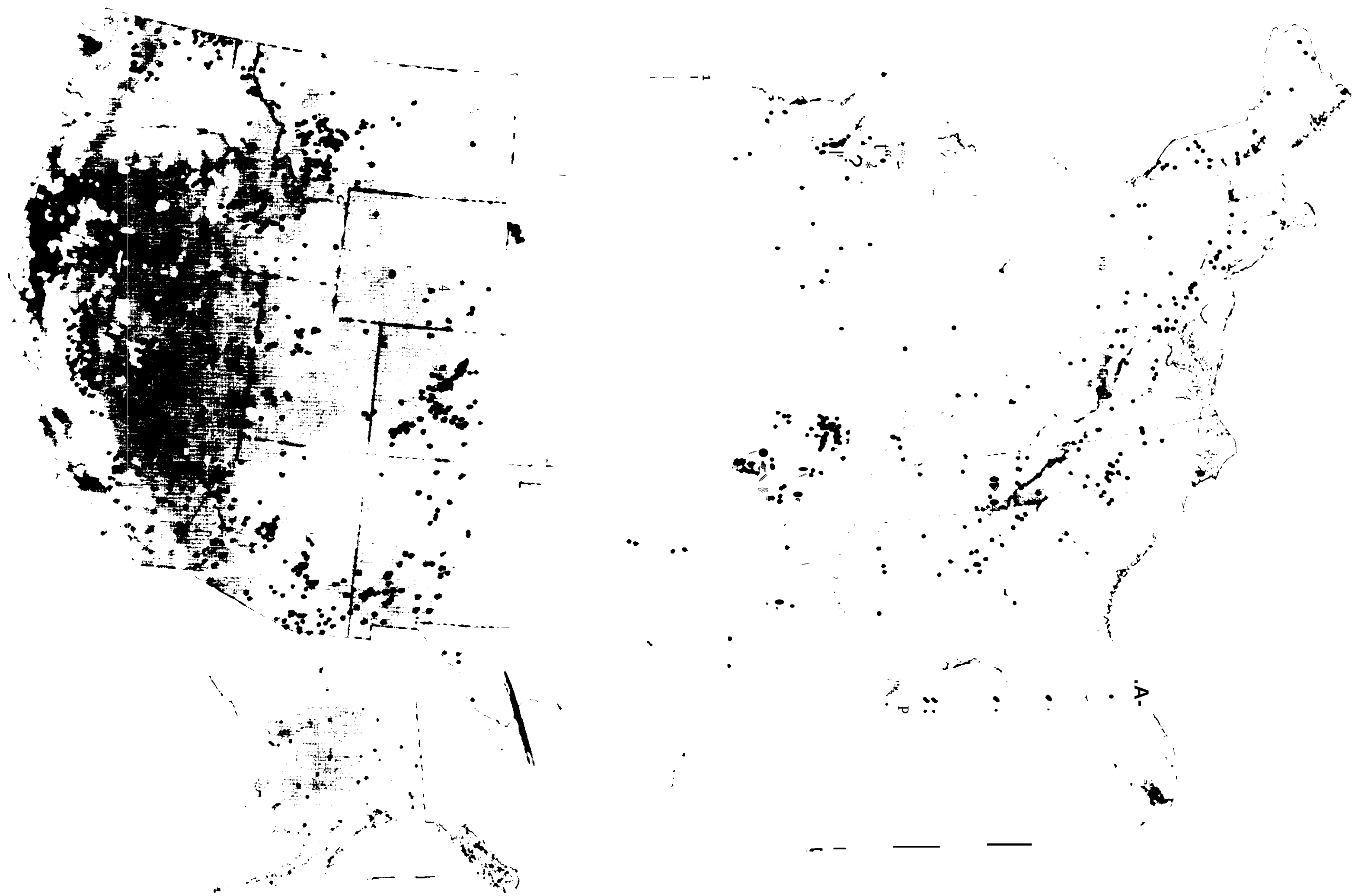
'U. S Geological Survey, Conserva tiun Division, *Federal find Indian Lands Coal Phospha te. Potash. Sodium. and o h e r Mineral Production Royalty Income and Rela ted Sta tis tics. Fiscal Year* 1975 (1 976).

¹²As used here, primary mineral commodities a r-e new materials, not recycled, reconditioned, or reused, which have been produced frnm deposits of naturally' occurring materials in the Earth's crust.

'U S. Bureau o f Mines, *Commodity Data Summaries. 1976* (1976).

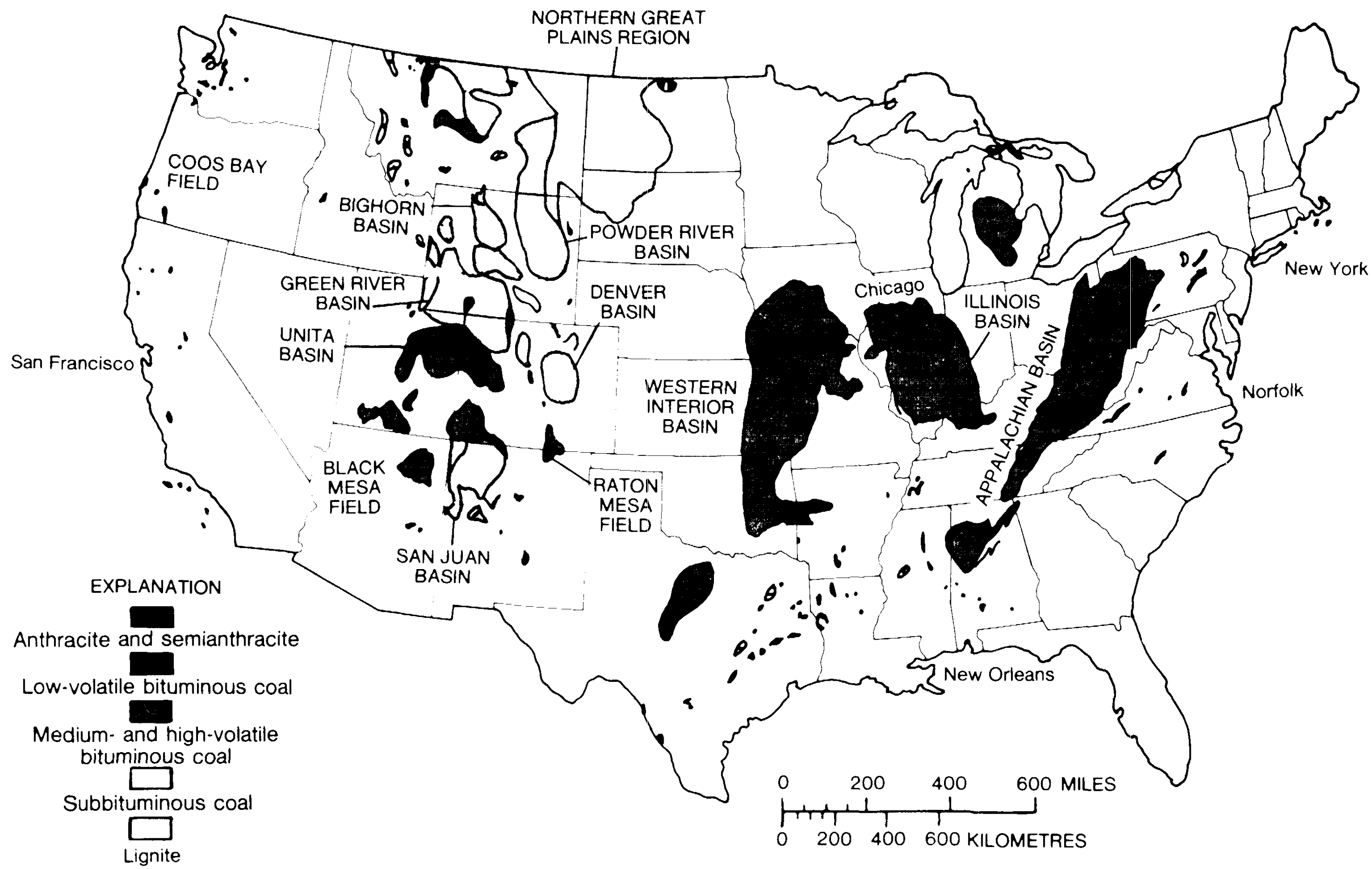
'Essential in the sense that industry requires an assured supply In order to perform its funct ions,

Figure 2.2.—Base and Precious Metal Mining Districts in Relation to Federal Landholdings in 1976



SOURCE: U.S. Geological Survey, Special Maps Branch, 1977.
Note: Alaska is shown here at a reduced scale

Figure 2.3.—Coalfields of he Conterminous Un ted States



SOURCE P. Averitt. *Coal of the United States, January 974* U S Geological Survey Bul 1412. at 5 (1975).

Consequently, we have concluded that it is in the public interest to acknowledge and recognize the importance of mineral exploration and development in public land legislation. '5

C. Mineral Exploration, Development, and Production: Stages and Technology

1. Stages

Mineral activity can be roughly divided into six stages, which require application of successively more discriminating (and more expensive) techniques to successively smaller land areas in order to identify, develop, and produce an economic mineral deposit.

A "full sequence" mineral project would involve the following stages:[16] 1) appraisal of large regions in one or more countries, primarily if not exclusively through review of office records and published maps and literature, to select particular regions considered favorable for occurrence of the mineral or minerals being sought; 2) reconnaissance of the selected region, through airborne or on-the-ground instrument surveys and sampling, to identify particular target areas considered likely to contain economic mineral deposits; 3) detailed investigation of the surface of the target area through more closely spaced surveys and sampling and the use of more discriminating (and more costly) techniques; 4) drilling or other three-dimensional physical sampling of the target area to discover whether an economic mineral deposit actually exists; 5) development of mine workings, processing plants, roads, and the infrastructure necessary for production from the deposit; and 6) actual production.

The first two stages are collectively referred to as target identification. The next two stages are collectively referred to as target investigation. The process of identifying and investigating targets in order to discover an economic mineral deposit is known as mineral exploration.

Development is the work required to bring a deposit, once discovered, to the point of production. Production is the actual mining, concentration, and shipment of the mineral to market.

Full-sequence mineral activity occurs for only a few projects. A project will be abandoned at any stage if the results are not encouraging. Some of the initial stages may be skipped or abbreviated if the information ordinarily obtained in those stages is already available to the company as a result of its or others' prior work, or is easily obtainable through surface inspection (for example, an economic mineral deposit that shows or "outcrops" on the surface).

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[15] Public Land Law Review Commission, *One Third of the Nation's Lend* 122(1970).

[16] Bailly, 'exploration Methods and Requirements, " in American Institute of Mining Engineers, *Surface Mining*, at 19 (1968]: [J, S. Department of Agriculture, Forest Service. *Anatomy of a Mine From Prospect to Production*, Gen. Tech. Rep. INT-35, at 23-68 (1977) (hereinafter cited as Anatomy of a Mine); Halbouty, "Giant Oil and Gas Fields in the United States,'" 52 Am. *Ass'n Petr. Geol Bull.* 1115 (1968).

2. Technology

The six stages of mineral activity and the techniques typically used in each are listed in table Z. I. Only rarely will an actual mineral project utilize all or even most of the techniques listed for each stage. Many of the techniques, owing to cost or physical characteristics, are suitable only for certain types of deposits in certain types of geologic environments.

Table 2.1 .— Typical Techniques for the Six Stages of Mineral Activity

		Stages	Typical techniques
EXPLORATION	TARGET IDENTIFICATION	Regional appraisal (Stage 1)	Geologic compilatlon (includlng geophysical and geochemical data) from office files and published maps and literature. Photogeologic study of available land photographs Analysis of available remote sensing data. Field inspection from air or on the ground.
EXPLORATION	TARGET IDENTIFICATION	Reconnaissance of region (Stage 2)	Reconnaissance geologic mapping and sampling. Reconnaissance geochemical (stream sediments, water, soils, etc.) surveys. Reconnaissance geophysical (magnetic, gravity, electromagnetic, seismic, radiometric, Induced polarizatlon, etc.) surveys (usually airborne). Reconnaissance (stratigraphic) drilling. Rapid laboratory analysis of samples. Field inspectlon of outcrops and anomalous areas.
EXPLORATION	TARGET INVESTIGATION	Detailed surface investigation of target area (Stage 3)	Detailed geologic mapping and sampling Detailed geochemical surveys Detailed geophysical surveys (usually on-the-ground). Detailed laboratory analysis of samples. Field Inspect Ion.
EXPLORATION	TARGET INVESTIGATION	Detailed three-dimensional physical sampling of target area (Stage 4)	Drilling, logging, trenching, pitting, sinking shafts. Detailed laboratory analysis of samples and amenability testing. Down-hole geophysical surveys. Recovery of bulk samples and ore dressing tests. Investigation of suitability of water, land surface, and infrastructure for mine-related facilities. Feasibility and evaluation studies.
		Development (Stage 5)	Drilling to block out deposit or drilling of production wells. Construction of mine workings, plants, facilities, roads, powerlines, pipelines, town sites, etc.
		Product ion (Stage 6)	Operation of mine (surface, pit, or underground) or wells and related facilities.

SOURCE Adapted from similar tables prepared by Paul Baily See appendix C

An understanding of geologic concepts, the geology of ore deposits and their geologic settings, and geologic maps is essential in each stage of mineral activity. In particular, mineral exploration is increasingly based on conceptual models developed by analyzing the geologic setting or environment of all the known occurrences of a particular type of deposit, The "occurrence model" developed prior to or during the first one or two stages of exploration (regional appraisal and reconnaissance) is used to guide the exploration for additional deposits of that type through identification of target areas with similar geologic environments .17

Most mineral exploration techniques other than geologic compilation, conceptualization, investigation, and mapping are based on specific chemical or physical properties, and are applicable only to mineral occurrence types that possess the appropriate properties, For example, geophysical exploration techniques are designed to detect mineral deposits (or geologic environments favorable for the occurrence of those deposits) through measurement of their characteristic physical properties, such as density (e.g., gravity and seismic surveys for geologic settings favorable for oil and gas deposits or certain sodium and sulfur deposits); magnetic behavior (e.g., magnetometer survey for magnetic iron, copper skarn, and nickel ores and for magnetic geologic environments favorable for asbestos-bearing serpentine); electromagnetic response (e.g., electromagnetic survey for massive sulfide ores on the Canadian Shield); electrical behavior (e.g., self potential (SP) survey of natural electrical current developed during weathering of certain metallic sulfides); electric response (e.g., induced polarization (1P) survey of mineralized ground); and radioactivity (e.g., geiger counter or scintillometer radiometric survey for surface or near surface uranium, thorium, and potassium deposits). " Many mineral occurrence types cannot be detected by using some or even all of these techniques. This is due to either the lack of the required physical characteristics, the "washout" of those characteristics by background "noise" from the surrounding rock, the existence of similar behavior or response characteristics in nonmineral rock, or the high cost of using a particular technique over large areas.

Similarly, geochemical analysis of water, stream sediments, vegetation, soil, and rocks can determine a pattern of trace elements indicative of nearby surface or subsurface ore bodies of a particular type. This works better for some mineral occurrence types and some areas than for others, although it is more widely applicable than the various geophysical techniques,

Trenching, digging of pits, exploration drilling, or sinking of exploration shafts is usually required in the final stages of exploration for each mineral occurrence type, in order to obtain proof of the existence of the ore body. Drilling is the most common technique, and it is sometimes used in earlier exploration stages (for example, the reconnaissance stage) to investigate the geologic setting of an area. Such reconnaissance drilling is referred to as stratigraphic or "off structure" drilling.

Many of the techniques are applied rapidly to broadly spaced sample points in the earlier stages of exploration, and then are applied more thoroughly in a tighter pattern in the later stages.

] .M]ller, "Corporfltlons, ore Discovery, and the Geologist, " 71 Econorn]c Geology 836 [1976); Ad Hoc Geologlca] Committee on Remote Sensing From Spare, Geolo~Icd Remote Sens]ng From Sp(lce (1977).

¹⁸An[lt(Jmv of o Mine, note 16, at 35-38,

3. The Relative Roles of the Various Exploration Techniques

The mineral exploration techniques discussed in the previous subsection can be divided into four general methods: conventional prospecting, geologic inference, geophysical anomaly, and geochemical anomaly.

"Conventional prospecting" refers to the search of surface areas for outcropping ore bodies or oil seeps— the type of exploration popularly typified by the Old Sourdough prospector and his burro. This romantic image of conventional prospecting was not completely accurate even during the era of the California Gold Rush, It has now given way to prospecting by individuals with four-wheel-drive vehicles, bulldozers, and varying degrees of geologic training or knowledge, The principal feature of prospecting is the search for surface expressions of economic mineral deposits.

Geologic inference is the mental "search" of the subsurface for hidden ore bodies through the use of geologic expertise. It includes projections of continuations of known ore bodies, which have been separated and significantly displaced from those bodies as a result of faulting, shearing, and folding of subsurface strata. Increasingly, as was pointed out in the previous subsection, geologic inference includes the formulation of a conceptual model for all the known occurrences of a specific type of deposit, and the use of that model to predict the locations of undiscovered occurrences and to guide the instrumented and physical exploration of the predicted locations,

"Geophysical anomaly" refers to the measurement of specific physical properties (magnetism, electrical conductivity, density, radioactivity, etc.) of the subsurface to locate anomalies that could indicate the presence of a particular type of mineral deposit. (An anomaly is a variation from the usual behavior or response of the nonmineralized host rock.)

Similarly, "geochemical anomaly" refers to the measurement of specific chemical properties and constituents of surface soils, vegetation, water, and sediments to locate anomalies that could indicate the presence of a hidden ore body.

Conventional prospecting accounted for most of the mineral discoveries made in the United States prior to 1940. In fact, one estimate attributes at least 90 percent of the ore produced to date to conventional prospecting.[19] However, data on recent discoveries in the United States and Canada indicate that conventional prospecting now plays a very small role in the discovery of economic mineral deposits.

Albers has recently published data on 62 U.S. metal mines discovered between 1941 and 1970, inclusive. Only those mines with a production capacity of at least 150,000 tons per year were included. Table 2.2 shows the distribution by principal exploration method of the 62 discoveries.

Bailly has added 10 discoveries to the 51 shown by Albers for the 1951-70 period to arrive at the distribution of discoveries shown in table 2.3.

Similar data for Canada have been compiled by Derry and Booth for discoveries made through 1975 of nonferrous metallic deposits and asbestos. Discoveries prior to

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Table 2.2.—Discoveries of U.S. Metal Mines, 1941-70

Year of discovery	Principal exploration method								Total number
	Conventional prospecting		Geologic inference		Geophysical anomaly		Geochemical anomaly		
	Number	%	Number	%	Number	%	Number	%	
1941-45	1	25	2.5	63	—	—	0.5	12	4
1946-50	1	14	6	86	—	—	—	—	7
1951-55	0.5	5	7.5	68	3	27	–	—	11
1956-60	1	7	10	77	1	8	1	8	13
1961-65	—	—	11	79	3	21	—	—	14
1966-70	—	—	9.5	73	2.5		1	8	13
1951-70	1.5	3	38	74	9.5	19	2	4	51

SOURCE: Derived from Albers, "Discovery Rates and Exploration Methods for Metallic Mineral Deposits in the U. S., 1940 -1976," 178 *Eng. & Mining J. 71 (1977).*

Table 2.3.—Discoveries of U.S. Metal Mines, 1951.70

Year of discovery	Principal exploration method								Total number
	Conventional prospecting		Geologic inference		Geophysical anomaly		Geochemical anomaly		
	Number	%	Number	%	Number	%	Number	%	
1951-55	1	8	9	75	2	17	—	—	12
1956-60	2	13	10	67	2	13	1	7	15
1961-65	—	—	13	87	2	13	—	—	15
1966-70	—	—	15	79	2	11	2	10	19
1951-70	5	3	47	77	8	13	3	5	61

SOURCE: Bailly, "Changing Rates of Success in Metallic Exploration, " paper presented at the GAC-MAC-SEG-CGU Annual Meeting, Vancouver, British Columbia, April 25, 1977.

1965 are limited to those for which production was commenced or recommenced since 1955 or for which production was planned, The distribution of discoveries by principal exploration method is shown in table 2.4,

All these data are incomplete and based on limited knowledge of actual discoveries (which are often kept secret, particularly the most recent ones).[20] Nevertheless, they clearly demonstrate the greatly reduced role of conventional prospecting as a method for discovering new metal deposits in both the United States and Canada, Con-

[20] Bailly, "Changing Rates of Success in Metallic Exploration," at 2, paper presented at the GAC-MAC-SEG-CGU Annual Meeting, Vancouver, British Columbia, Apr. 25, 1977; Cranstone and Martin, "Are Ore Discovery Costs Increasing?" in Canadian Department of Energy, Mines and Resources, Mineral Resources Branch, *Canadian Mineral Exploration, Resources and Outlook*, MR 137, at 5, 6, 8, 10 (1973).

Table 2.4.– Discoveries of Canadian Metal Mines Through 1975

Year of discovery	Principal exploration method: Conventional prospecting Number	%	Geologic inference Number	%	Geophysical anomaly Number	%	Geochemical anomaly Number	%	Total number
Pre-1 920	26	93	2	7	—	—	—	—	28
1920-29	12	80	3	20	—	—	—	—	15
1930-39	13	87	2	13	—	—	—	—	15
1940-50	13	76	4	24	—	—	—	—	17
1951-55	16	46	14	40	5	[redacted]	—	—	35
1956-60	6	25	4	17	14	[redacted]	—	—	24
1961-65	4	27	4	27	5	[redacted]	2	13	15
1966-70	2	10	4	20	13	[redacted]	1(?)	5	20
1951-70	28	30	26	28	37	[redacted]	3	3	94
1971-75	1	4	4 + 1 (?)	19	15	[redacted]	[redacted]	11	26*

● No principal exploration method was given for 2 discoveries in 1971-1975

SOURCE: Derry, "Exploration Expenditure, Discovery Rate and Methods, " 63 *C/M Bu//etin 362(1970)* (Pre-1920 through 1964); Derry and Booth, "Mineral Discoveries and Exploration Expenditure—A Revised Review 1965 -1976," paper prepared for 1977 CIM Symposium (1965 through 1975).

ventional prospecting was the principal exploration method for only 7 out of 61 of the reported metal discoveries in Canada and for none of the reported metal discoveries in the United States after 1960.

There is fairly uniform agreement on the reason for this sharp decline. Most of the metallic ore bodies that are exposed or directly indicated through visual inspection of the surface have already been identified in more than 100 years of fairly intensive surface exploration. The remaining deposits are hidden beneath the surface with no direct visual clues as to their existence, and they can be discovered only through careful geologic analysis aided in varying degrees by geophysical and geochemical techniques.[21] This is less true in the remoter regions of Canada and Alaska than in the lower 48 States,[22] but the trend is unmistakable in all three regions,

The decline in conventional prospecting as a successful exploration method is not confined to the metallic minerals. Almost all of the easily found visible indications of economic mineral deposits in the lower 48 States have been identified. For example, conventional prospecting for oil and gas deposits through visual identification of oil seeps, salt domes, and other surface indications gave way during the early 1920's to geophysical techniques (primarily seismic) since most visible surface indications had already been found and tested.[23] Similarly, although there was a brief revival of conventional prospecting, aided by inexpensive radiation detectors, when uranium

[21] *Geological Remote Sensing From Space*, note 17, at 5-1; Pennsylvania State University, Department of Geosciences, *Report on the Workshop: Research Frontiers in Exploration for Non-Renewable Resources* 4, 16, 21-23, 64-65 (1976); U.S. Department of the Interior, *Mining and Minerals Policy, 1977*, at 82-83, 85 (1977).

[22] U.S. Geological Survey, Office of Resource Analysis, *Comparative Study of Canadian-United States Resource Programs*, ch. A, at 52 (Comm. Print, U.S. Senate Comm. on Appropriations, 1976); Hawley and Whitney, "The Economic Importance of the Small Miner and Small Mining Businesses in Alaska," in Office of Technology Assessment, U.S. Congress, *Analysis of Laws Governing Access Across Federal Lands*, vol. II, Working Papers (1978).

[23] *Geological Remote Sensing from Space*, note 17, at 3-3.

emerged as a valuable mineral in the wake of World War H, "most of North America is now considered explored for high-grade surface [uranium] ore bodies because of the efficiency of radiometric techniques; virtually all serious exploration is now done by subsurface drilling."[24]

Mineral exploration today, therefore, relies primarily on geologic inference based on substantial geologic knowledge and creativity. Geophysical and geochemical surveys are included in most exploration projects, and they are the principal method used to locate target areas in a large number of successful Canadian exploration projects and a smaller (because of differences in geology) but still significant number of U.S. exploration projects. The targets in almost all cases must be explored by drilling to determine the actual existence and location of the hypothetical mineral deposit.

Conventional prospecting has rarely resulted in the discovery of an economic mineral deposit over the past 30 years. It does, however, serve as a source of information on mineral "showings" (surface "expressions" of mineralization insufficient in themselves to indicate the presence of an economic mineral deposit) that can be combined with other sources of information (for example, company files, maps, and published articles) on the geology and mineralization of a region or area in order to serve as the basis for sophisticated exploration, utilizing geologic inference. In essence, conventional prospecting today is a device whereby new or, more often, old mineral showings are continually brought to the attention of mining company exploration groups to serve as a supplement to the geologic and mineral data stored in company files.

D. Mineral Exploration, Development, and Production: Cost, Acreage, and Time Requirements

1. General Considerations and Statistics

Mineral activity is an expensive business with long leadtimes between investment and payout, if any. Although the figures vary for different types of mineral occurrences, and also for individual projects within each type, in general each successive stage of mineral activity is more expensive and takes more time than prior stages. Each successive stage, up to the development stage, also focuses on smaller tracts of land.

The costs, acreages, and times for a particular mineral project depend in large part on the type of mineral occurrence. Table 2.5 lists most of the known types, excluding common-variety minerals such as limestone, common clay, and sand and gravel. They are broken down into four general categories of geologic configuration, which, reading from left to right, result in increasing difficulty in discovering a deposit, all other things being equal.

Surficial mineral occurrences are generally unconsolidated, unburied mineral deposits and result from weathering or deposition during late geologic time. Examples

[24]Ibid., at 5-3; see *Anatomy of a Mine*, note 16, at 37.

Table 2.5.—illustrative Mineral Occurrence Types

SURFICIAL		NONSURFICIAL					
		Strata bound-extensive		Stratabound-discrete		Discordant	
Geologic Environment	**Typical Ores**	**Geologic Environment**	**Typical Ores**	**Geologic Environment**	**Typical Ores**	**Geologic Environment**	**Typical Ores**
Aluminous Clays and Laterites	•Bauxite, •Kaolinite	Bedded Precambrian	•Iron, Copper, Gold	Marine Sedimentary	“ 011 and Gas Bromine Barite	Breccia Pipes	“ Uranium, Molybdenum, Copper Gold, Diamond
Laterites	‘ Nickel (Cobalt)	Marine Sedimentary	•Phosphate, Iron, 011 Shale, Manganese	Continental Sedimentary (Sandstones and Fossil Placers)	•Uranium (Vanadium), Gold, Titanium	Porphyries	•Copper-Molybdenum, Gold, Tin
Stream Placers	Gold, Silver, Platinum, Tin, Rare Earths, Iron, Gem Stones	Marine Evaporite	•Potassium, * Sodium, *Sulfur “ Gypsum, Lithium Magnesium	Lacustrine Evaporates	•Gypsum, “ Trona “ Boron	Pegmatities	Lithium, Fluorine, Beryllium, Rare Earths Mica, Feldspar, Columbium, Tantalum
Coastal Placers	Titanium, Zirconium, Chromium, Rare Earths, Gem Stones	Continental Sedimentary	•Coal, 011 Shale ‘ Boron, “ Sodium	Fossil Laterites	Bauxite	Vein and Replacement Deposits	*Gold, •Silver Copper Alunite, Mercury, Lead, Zinc, Barite, Fluorine, Tungsten, Molybdenum, Uranium, Iron Graphite, Gem Stones, Native Sulfur Gilsonite
Residual Deposits	Barite, Iron, Manganese Tifanium, Phosphate, Columbium Vermiculite	Continental Volcanlc	Bentonite	Young Tuffs and Related Sedimentary	Beryllium, Mercury Fluorite, Native Sulfur	Massive Sulfide Pipes	Copper-Lead-Zinc - Sliver (Gold, Pyrite)
Brines m Evaporates	Ž Sodium, • Potassium, • Magnesium, • Boron, Lithlum, Tungsten	Stratiform Igneous Complexes	* Iron, Chromium, Platinum Group Metals, Vanadium	Shale Hosted Massive Sulfides	•Copper-Lead-Zinc-Silver	Rhyolitic Volcanic	•Tin Tungsten, Bismuth
Supergene Enrichment	Copper, Silver, Lead Zinc, Gold, Manganese			Carbonate Stratiform	• Zinc-Lead-Barite-Fluorine (Copper, Cobalt)	Mafic and Ultramafic Intrusive	Nickel-Copper, Olivine
				Volcanogenic Massive Sulfides	• Copper Lead-Zinc-Silver (Gold Pyrite Barite)	Podiform Ultramafic	Chromium Copper, Iron Nickel, Asbestos
				Metamorphic	Garnet, Kyanite Graphite	Anorthosite Complexes	Titanium, Iron, Vanadium
						Veins in Ultramafic	Asbestos, Talc
						Veins m Metamorphosed Dolomites	Talc
						Salt Domes	* Sulfur
						Carbonatite and Alkalic Complexes	Phosphate Rare Earths Iron, Titanium Columbium, Copper

•Described In Ad Hoc Geological committee on Remote Sensing from Space

Geological Remote *Sensing from Space* (1977) are sodium and potassium deposits in evaporite brines and gold and silver deposits in stream placers.

Stratabound-extensive mineral occurrences are large, laterally continuous mineral deposits confined to a single stratum in the earth. Examples are coal and oil shale in continental sedimentary basins, iron in bedded Precambrian strata, and stratiform igneous complexes.

Stratabound-discrete mineral occurrences are randomly distributed and/or discontinuous mineral deposits largely confined within specific strata in the earth. Examples are oil and gas in marine sedimentary basins and copper-lead-zinc in shale-hosted and volcanogenic massive sulfides.

Discordant mineral occurrences are mineral deposits that cut through strata and/or are related to intrusive rocks, volcanic activity, or other geologic intrusions. Examples are sulfur in salt domes and copper in porphyrins.

Figure 2.4 depicts the differences among the four geologic configurations.

The difficulty, and hence cost and time, of discovering a mineral deposit of any geologic configuration is increased when the deposit is buried rather than exposed on the surface entirely or in an outcrop. The deeper the deposit, the more difficult it will be to find, especially since currently available geophysical and geochemical exploration techniques generally cannot penetrate very far beneath the surface.

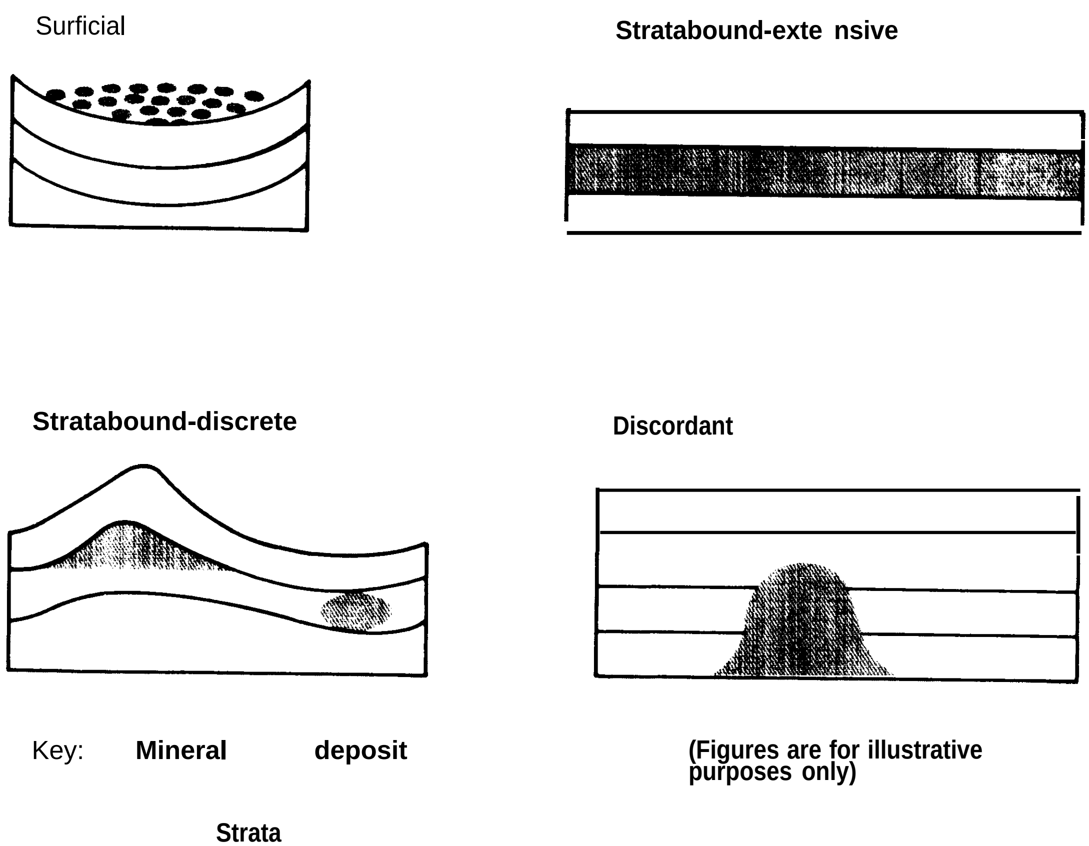
The depth of the deposit will also affect the costs, acreages, and times involved in development and production. Generally, surface mining is less expensive than underground mining. Open pits can be used at shallow to intermediate depths for large ore bodies, but they require large acreage just for the sloping pit walls. Minerals such as oil, gas, and sulfur, which can be produced in liquid form, can be developed at fairly great depths using wells.

Table 2.6 presents estimated cost, acreage, and time ranges for the exploration and development stages of typical mineral projects involving surficial, stratabound-extensive, stratabound-discrete, and discordant mineral deposits in 1977. The table is based on the data collected in appendix C for 32 of the mineral occurrence types listed in table 2.5. Acreages through stage 2 are for the extent of land included in the search; acreages from stage 3 on are for the land for which a land position has been established through purchase, option, lease, or claim. Costs are direct costs only and do not include overhead or the cost of land acquisition. Times assume normal progress without substantial delays caused by adverse economic climate or regulatory processes.

2. Target Identification

In the first two stages of exploration (regional appraisal and reconnaissance), regions ranging from 1,000 to 100,000 square miles are assessed through compilation and analysis of available data, and portions of a region covering 10 to 100 square miles each are studied through field inspections, widely spaced geochemical sampling, and airborne geophysical surveys. The results are brought together on maps. They are then geologically analyzed in light of the characteristics of known occurrences of the type of

Figure 2.4. —Mineral Occurrence Configurations



mineral deposit being sought, in order to select smaller target areas for detailed investigation in stages 3 and 4. The first two stages may cost anywhere from a few thousand to more than a million dollars, and will usually take anywhere from a few months to a couple of years to complete, assuming continuing success.[25]

The two most significant aspects of the first two stages both have to do with the acreage involved. First, there is usually no need to establish a land position (that is, acquire mineral development and production rights) on any or all of this acreage in order to protect the exploration investment made during these two stages. Although that investment may total several million dollars for the largest and most complex exploration projects, it is spread over thousands of square miles, and the reconnaissance techniques utilized [except for reconnaissance stratigraphic drilling) do not involve significant occupation or disturbance of any particular area, Thus, the competition is unlike-

[25] Bailly, "The Problems of Converting Resources to Reserves," *Mining Engineering*, January 1976, at 1, 3-4; Bailly, "Mineral Exploration and Mine Developing Problems," paper presented at the Public Lands Law Conference, University of Idaho, Oct. 10, 1966, updated by author initially on June 30, 1967, and subsequently in communications with OTA in 1976.

Table 2.6.—Estimated Cost, Acreage, and Time Ranges for the Exploration and Development Stages of Typical Mineral Exploitation Projects in 1977

Costs do not include land or overhead costs. (K = Thousand) (M = Million)

				MINERAL OCCURRENCE CONFIGURATION															
				Surficial				Stratabound-extensive				Stratabound-discrete				Discordant			
				Cost ($,	Acres	Time (mos.)	$ Per Acre p. yr.	Cost ($)	Acres	Time (mos.)	$ Per Acre p. yr.	Cost ($)	Acres	Time (mos.)	$ Per Acre p. yr.	Cost ($)	Acres	Time (mos.)	$ Per Acre p. yr.
EXPLORATION	TARGET IDENTIFICATION	STAGE 1	Low	2K	640	1		1K	3.2K	0.2		2K	640K	1		1K	640	0.5	
			Avg.	39K	21M	7	.003	38K	146M	8	.0004	96K	18M	9	.007	25K	86M	6	.0006
			High	590K	640M	18		362K	640M	42		680K	640M	62		635K	640M	60	
		STAGE 2	Low	8K	640	1		1K	3.2K	0.2		8K	2.6K	1		2K	640	0.5	
			Avg.	80K	216K	10	0.44	135K	982K	10	0.16	783K	1.9M	11	0.45	82K	266K	9	0.41
			High	1.0M	6.4M	40		1.1M	6.4M	90		22M	25.6M	60		1.5M	6.4M	48	
	1 + 2		Avg.	119K		17	0.26	173K		18	0.09	879K		20	0.25	107K		15	0.25
	TARGET INVESTIGATION	STAGE 3	Low	2K	100	2		0	200	1		5K	100	1		2K	40	0.3	
			Avg.	72K	4K	11	20	536K	6.5K	12	82	205K	26K	10	9.5	123K	3.9K	10	38
			High	360K	60K	40		5.7M	25K	48		1.8M	1.5M	88		1.3M	40K	90	
		STAGE 4	Low	49K	600	6		25K	200	6		24K	100	1		23K	40	3	
			Avg.	2.5M	4.1K	29	252	1.7M	6.6K	29	107	4.3M	7.3K	27	262	1.5M	1.7K	22	481
			High	14.3M	60K	186		7.7M	25K	78		30M	128K	160		16M	30K	72	
	3 + 4		Avg.	2.6M		40	188	2.2M		41	100	4.5M		37	194	1.6M		32	343
	1 to 4		Avg.	2.7M		57		2.4M		59		5.4M		57		1.7M		47	
DEVELOPMENT		STAGE 5	Low	5.1M	1K	36		22M	1K	12		362K	500	4		3.5M	50	12	
			Avg.	81M	4K	52	4.7K	81M	9K	25	4.3K	79M	6.8K	22	6.3K	26M	—	30	—
			High	502M	13K	156		185M	25K	42		361M	100K	90		406M	6.4K	84	

ly to be able to discern and preempt the potential target areas. In fact, the explorer himself will not be sure precisely which areas are desirable as targets until the first two stages have been completed: target identification is the very purpose of these two stages. However, the explorer may wish to establish some sort of limited land position in areas where reconnaissance stratigraphic drilling is done, if only because the drilling may uncover economic mineralization (even though its primary purpose is knowledge of general subsurface geology).

Second, although it is unnecessary (and usually impractical) to establish a land position prior to the first two stages, it is imperative that mineral rights be obtainable at the end of those stages (or at least prior to detailed surface disturbance in stage four) for the selected target areas. Because it is not known initially where specific targets may be identified, all or almost all of the acreage being investigated in stages 1 and 2 must be available for the establishment of a land position. That is, large areas containing thousands of square miles must be available for mineral development and production in these stages, from which smaller target areas of only a few square miles can be selected for actual acquisition of mineral rights at the end of the stages. If the large areas are not available, the smaller areas are likely to be passed by or explored much less efficiently as a result of unwillingness to commit the large sums necessary for sophisticated regional modeling and reconnaissance.

If a mineral discovery were made as a result of the exploration efforts in stages 1 and 2, prior to any actual drilling or other three-dimensional physical exploration, the explorer would immediately want to acquire a land position for the area of the discovery,

3. Target Investigation

In the final two stages of exploration (detailed surface investigation and three-dimensional physical sampling of a target area), a target (ranging initially from 1 to 10 or more square miles) is investigated through detailed field inspections, geochemical sampling, and ground and airborne geophysical surveys. In this way, it is reduced to a smaller target (ranging from a fraction of a square mile to several square miles) for drilling or other three-dimensional physical sampling to determine if the hypothetical economic mineral deposit actually exists. These two stages may cost anywhere from tens of thousands to tens of millions of dollars, and they will usually take one to several years to complete, assuming continuing success.[26]

As was stated above, the explorer will want to acquire a land position as soon as the target area has been reduced to a few square miles or less, and is unlikely to do any three-dimensional physical sampling until mineral rights have been acquired for most of the target area.

Actual physical discovery of economic-grade mineralization usually does not occur until three-dimensional physical sampling is undertaken in stage 4, although, in increasingly rare cases, such a discovery may be made in earlier stages as a result of surface outcropping of the ore body. Exploration continues after the first discovery of

[26]Ibid

economic-grade mineralization until it has been determined that there is enough ore to support a commercial mining operation. Once it has been determined that there is an economic mineral deposit, perhaps 1 or 2 years after the initial physical discovery of economic grade mineralization, exploration ceases and development begins.

4. Development

In the development stage, the land position is adjusted and firmed up to cover the fraction of a square mile or few square miles actually containing the mineral deposit or required for mining-related facilities such as processing plants, waste disposal sites, roads, and powerlines. Enough of the deposit is blocked out to support the initial planned production capacity (usually the entire deposit is not blocked out until the very last years of production), production wells or mine workings are developed, and mining-related facilities are constructed in preparation for production.

Development costs and times vary widely, depending on the type of deposit and the planned production method. An onshore oilfield or gasfield can usually be developed for initial production in 1 to 3 years, at an average cost in 1973 of around $140,000 per development well,[27] or $7 million for a 50-well development effort. Typical coal mines, both strip and underground, can be developed in a few years at a cost, excluding land acquisition costs, of $25 million to $80 million. The typical surface mine will produce 2 to 4 times more coal per year than the typical underground mine.[28] One to four years were required for the development of each of 11 selected Arizona copper mines, including both open pit and underground mines, with underground mines generally taking longer to develop.[29] A typical large Arizona open pit copper mine would cost well over $100 million to develop.[30]

These development times and costs, however, assume normal progress on a mineral deposit that is currently economic in a region with fairly well-developed infrastructure (e.g., transportation and power network, public facilities, commercial organizations). The infrastructure issue will be considered in subsection 6 below. The economic issues will be discussed here.

Particularly for the metallic minerals, development may be delayed for many years, and a property may pass through various owners (including occasional abandonment) and various cycles of interest and renewed evaluation, owing to one or more of the following economic factors:

a. The deposit is of too low a grade to be economic, given current technology and prices;
b. The owners of the deposit have abundant reserves of higher grade or more profitable ore that can easily supply all the metal they can possibly sell;

"Estimates of the Economic Cost of Producing Crude Oil, Ser. No, 94-27 (92-1 17], Senate Comm. on In!. & Ins. Affairs, 94th Cong., 2d. sess. 250-251 IComm. Print 1976) (table 3, 1ine 10 plus line 11, divided by table 4, line 1 minus iine 6).

"U.S. Bureau of Mines, Busic Estimated Cap]ta] Investment und Operating Costs for Coal Strip 'Mines. Inf. Circ. 8703 [1976); U.S. Bureau of Mines, Basic Estimuted Capitol Investment and Operating Costs for Underground Bituminous Coal Mines Developed for Longwa)l Mining, Inf.Circ.8715 (1976).

z9U, S. Bureau of Mines, Time Required in Developing Selected Arizona Copper Mines, Inf. Circ. 8702, table 1 (1 976].

'0U.S, Bureau of Mines, Comparu!]ve Porphyry Copper Mining and Processing Costs—Alaska and Ar~zono, Inf. Circ. 8685 (1974].

c. The owners cannot raise the necessary capital, or cannot afford at the present time to take on the financial risk of bringing a new mine into production, or can finance only one deposit at a time to production;
d< Market outlets are not currently available; or
e. T'he owners prefer to await higher prices. "

Technically, there has not been a discovery of an economic mineral deposit if the first factor is the reason for nondevelopment: the subeconomic deposit is either "put on the shelf" for later development with improved prices or technology, or serves as part of the general geologic information base used to develop subsequent exploration.

Factors similar to those listed above are cited by Albers as affecting the discovery-to-production time for some of the 50 U.S. metal mines producing in mid-1976 that were developed from discoveries made between 1940 and 1975, inclusive. His data indicate that it took from less than a year to 23 years to proceed from initial discovery to initial production on the 50 mines, with an average interval of 7 years and a median of 6 years. All but two of the mines were developed in 14 years or less, the two exceptions taking 16 and 23 years, " Since part of the discovery-to-production interval includes much of stage 4 of exploration, Albers' data correlate fairly well with the 1 to 4 years for "normal progress" development cited above for an economic mineral deposit.

Although economic and technologic factors were the major causes of development delays in the past, and continue to be important factors in the present, regulatory delays due to social and environmental considerations are becoming increasingly important.

5. **Production**

Production generally lasts for 20 years or more, and the costs of production vary widely depending on the mineral deposit. Bureau of Mines studies estimate the annual production costs (excluding depreciation, royalties, rents, fees, and taxes) for typical coal strip mines to be $12 million to $18 million; for typical underground coal mines, $9 million to $17 million; and for a typical large Arizona open pit copper mine, $27 million.[33] Annual production costs for minerals such as oil and gas produced by well and transported from the field without processing are considerably lower, averaging less than $5,000 per producing oil or gas well in 1973[34] or around $250,000 for a 50-well production unit.

Production from metal mines tends to be more cyclic than production from nonmetal mines, and mines may be closed or abandoned and subsequently reopened with changes in technology or prices.[35]

"Factors (b) through (e) are taken from Cranstone and Martin, note 20, at 6. See also LT. S. General Accounting Office, Inocc urate ,%tlmates of W'estern Coal Reserve~ ShouJd Be Corrected. EMD-78.32, July 11, 1978, at 22-26.

"Albers, "Discovery Rates and Explanation Methods for Metallic Mineral Deposits in the [J. S., 1940-1976,"' 178 Eng **and** Mmmg] 71 (1977),

"See the sources cited in notes 28 and 30.

"Est~mates of the Economic Costs of Producing (jrude od, note 27, at 250-251 (table 3, line 16 divided b> table 4, Ilne 19)

'[l.S. Bureau of Mines, Time I?equlred m Develop]rtg SeJected Ar]zona Copper M]nes, Inf. Clrr. 8702 (1976).

6. Infrastructure Costs

The term "infrastructure" refers to a system that includes the transportation network, public facilities, housing, hospitals and other health facilities, utilities, and commercial organizations required to support the population and activities in a given geographic area.

The important role infrastructure plays in the success of a mineral project is discussed in this subsection. The impacts mineral activity can have on the existing infrastructure of an area are discussed in section B of chapter 6.

The importance of an adequate infrastructure for mineral activities cannot be overstated. For example, for many minerals the cost of transportation from mine to market equals or greatly exceeds the costs of finding and producing the mineral: prime examples are coal, construction minerals, and industrial minerals. High costs of transportation, or the complete lack of transportation (other than air access), can render even the highest grade metal deposit uneconomic.[36]

The importance of infrastructure can be dramatized best by reference to Alaska, although the same considerations apply to a lesser degree to the remoter areas of the lower 48 States.

Alaska has a very limited surface transportation and power network, primarily confined to the areas around and between Anchorage and Fairbanks and not extensive even in those areas.[37] The population is quite small, and there are no major manufacturing centers. All major items must be shipped in from Canada or the lower 48 States, and high wages and fringe benefits must be paid to attract labor.

This combination of elements raises the cost of almost every item or service in Alaska, and has rendered much of its timber and mineral resources uneconomic now and for the foreseeable future. '8 The total value of hardrock (metallic and industrial) minerals produced in Alaska in 1971 was less than $4 million,[39] although Alaska is believed to contain substantial hardrock mineral resources.

The impact of infrastructure-related costs on mineral activity in Alaska is graphically demonstrated by a Bureau of Mines analysis of the comparative costs of producing a hypothetical porphyry copper ore body in Alaska and Arizona.[40] The Alaska site chosen was an area 10 miles north of Lake Clark and approximately 145 air miles southwest of Anchorage in the Alaska Range just west of Cook Inlet. The Arizona site chosen was approximately 45 miles northwest of Tucson. Both sites were presumed to be within 10 miles of a highway: an existing highway in Arizona and a proposed highway corridor in Alaska.

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[36] U. S. Bureau of Mines, Estimated Costs to Produce Copper ut *Kennicott, Alaska*, Inf. Circ. 8602(1973); see *Comparative* Study *of Canadian-United* States Resource Programs, note 22, ch. A, at 26-27, 32-44, 58.

[37] U.S. Bureau of Land Management, Multimodal Transportation *and* Utility Corridor *Systems in Alaska: A Preliminary*, Conceptual *Analysis*, October 1974, at 27-33.

[38] Krutilla and Brubaker, "Alaska National Interest Land Withdrawals and Their opportunity Costs, ' m Background *Information for Alaska* Lands Designations, House Comm. on Int. & Ins. Affairs, 95th Cong., 1st sess. 158, 198-232 (Comm. Print No. 4, 1977).

[39] U.S. Bureau of Mines, *Minerals* Yearbook, 1972, *Volume II*, Areu Reports; Domestic 56, table 1 (1974) (antimony, barite, gold, mercury, platinum group metals, silver, tin, and uranium, all in relatively minor amounts),

[40] U.S. Bureau of Mines, Comparative Porphyry Copper Mining and Processing Costs —*Alaska* and *Arizona*, Inf. Circ. 8656 (1974].

The mineral price required to support a mine was calculated by the Bureau of Mines to be almost twice as high in Alaska as for the same size and grade ore body in Arizona. The Arizona mine would be an economic success; the Alaska mine would not. One of the major advantages of the Arizona operation was access to developed transportation and power systems. The Arizona operation required only construction of a spur railroad line and connecting gas service, while the Alaska operation required construction, equipping, maintenance, and operation of an electrical generator, gas pipeline, railroad line, barge dock, and air strip. There were also added costs in Alaska for a larger and more self-sufficient townsite, more substantial structures to protect personnel, machinery, and ore concentrate from the cold and to guard against damaging the permafrost, larger inventories of parts and supplies, a larger maintenance and support force, the overall higher cost of transportation for all materials and personnel, and the overall higher cost of labor.

Another Bureau of Mines study, comparing the cost of asbestos mining and processing at two equally remote sites 55 miles apart in Alaska and Canada, estimated that, for identical deposits, the Alaskan operation would cost about 30 percent more for development and 35 percent more for production, primarily because of higher Alaskan labor rates.” An asbestos deposit was actually being mined at the Canadian site, while an apparently “commercial” asbestos deposit at the Alaska site was not even being developed.

Perhaps the best known example of the problems and costs of developing infrastructure is the Prudhoe Bay Trans-Alaska Pipeline operation. The final cost of constructing the basic transportation system (the pipeline and pipeline road) was estimated in 1975 to be $7 billion to $10 billion, exclusive of the vast network of feeder pipelines leading into Pumping Station No. 1 at Prudhoe Bay. Another billion or so was estimated for workers’ housing, roads, docks, airport facilities, communications and utilities. and other forms of infrastructure.

E. Mineral Exploration, Development and Production: Chances of Success

Mineral activity is a very risky business, particularly in the exploration stages. For every successful project resulting in discovery of an economic mineral deposit, there are many unsuccessful projects. Therefore, the actual cost of discovery of an economic mineral deposit is not merely the cost of the successful project, but also includes the cost of all the related unsuccessful ones. The few successes must be profitable enough to cover the many failures.

However, calculation and interpretation of rates of success, and of cost per success (including the cost of failures), for mineral explorat on projects are complicated by several factors.

[9]U.S. Bureau of Mines, *Comparative Asbestos Mining and Processing Costs, Alaska Versus Yukon Territory*, Inf. Circ. 8672 (1975).

First, the division of projects into successes and failures, where success is defined as discovery of an economic (currently commercially developable) mineral deposit, is artificial and somewhat misleading. Many exploration projects result in the discovery of mineral deposits that, although not currently commercial because of low ore grade or lack of infrastructure, may be commercially developable in 10 to 50 years as a result of advances in technology, development of infrastructure, or simply higher prices for the minerals. Such discoveries, which are sometimes referred to as "technical successess"[42] or "on-the-shelf" deposits, are clearly not total failures, Furthermore, even when no significant concentration of mineralization is discovered, the information developed on the surface and subsurface geology and on trace mineralization is almost always valuable to future exploration activity. In fact, mines have been "discovered" in company files that contain such information formerly not thought to be worth following up, but subsequently found to be extremely significant in light of new technology or new theories of ore formation.'[43]

The value of such "unsuccessful" mineral exploration in Canada has been discussed by Cranstone and Martin as follows:

> Annual dollar exploration expenditures for metals in constant (1971) dollars have increased from about $12 million in the 1946-50 period to $87 million in 1971; it is therefore likely that a substantially greater amount of potentially useful information as well as currently uneconomic mineral deposits have been added to inventory than withdrawn from it in the form of previously discovered on the shelf deposits during the past 26 years.
>
> Consider the case of porphyry copper and porphyry molybdenum deposits in B.C. Ore tonnage discovered in these deposits during the period 1961-71 has a 'value' of $25.6 billion. However, available information suggests that additional submarginal ore in the 14 porphyry deposits counted herein as discoveries, plus submarginal tonnage in another 30 porphyry deposits, amounts to more than 5 billion tons, with metal 'value' of more than $17 billion almost equalling the $21 billion 'value' of total Canadian metal production during these 11 years, Most of these currently uneconomic deposits, as well as others discovered during the 1946-71 period, will likely be profitably mined in the future, constituting an additional but unknown present 'value' of discoveries, "[44]

They conclude that "The true discovery cost of orebodies found in the past 10 years is less than the apparent cost because of the vast tonnages of presently marginal and subeconomic mineral deposits also found in this period."[45]

Second, the published success/failure data often include mere listings, submittals, and cursory examinations of prospects, which involve minimal time and expense, together with the more intensive and expensive detailed suface and three-dimensional (e.g., drilling) investigation of particular targets. Consequently, it is difficult to sort out the really serious efforts in order to calculate success/failure ratios. For example, a 1967 compilation of success/failure data for various nonfuel mineral exploration programs,[46] when broken down into the exploration stages (as has been done in table z. 7)

[42] Miller, note I 7, at 840

[43] Lowell, "EXpll)ril tion Strategy,' in *Report on the Workshop: Research Fron tiers in Explora tion for Non-Renewable Resources*, note 21, at 52-64.

[44] Cranstone and Martin, note 20, at 11-12.

[45] Ibid., at 13.

[46] Bailly, "hllnera] Explora tion and Mine Developing Problems," note 25. at 10-1.1.

Table 2.7.—Success Data for Selected Nonfuel Mineral Exploration Programs

Exploration stages	Exploration program									
	Government/private			Private						
	Strategic Minerals 1939-49	AEC Uranium 1948-65	Defense Minerals 1951-58	Total Canada (Annual)	Phelps Dodge 1962	Phelps Dodge 1966	Int'1 Nickel pre 1958	Texas Gulf 1959-61	5 Sw Firms 7	Bear Creek 1963-66
TARGET IDENTIFICATION										
1. Regional appraisal and 2. Reconnaissance (Possible targets submitted or identified):	7	7	3888	7	7	3137	?	Several 1000	?	1649
(Possible targets examined):	10071	15000	?	60007	73	1077	?	Several 100	352	7
TARGET INVESTIGATION										
3 Detailed surface investigation:	1342	7	?	7	7	1077	100 +	?	47 +	7
4. Detailed 3-D physical sampling:	7	7	?	7	"few"	16	7	66 +	23	60
DISCOVERY										
(Mineralization):	?	7	7	?	?		7	7	?	15
(Some tonnage):	1053	4317	7	7	7	"Few Still being worked on"	7	7	?	8
(Mine tonnage):	7	6437	374	7	7		1	?	2	5
(Commercial ore deposit):	7	7	45+	5	0		7	1	7	1?
(Outstanding ore deposit):	1	7	Term Zinc	7	0		?	1	?	7

SOURCE Derived from data in Bailly, "Mineral Exploration and Mine Developing Problems" 10-12 (1967)

in order to sort out the serious efforts involving detailed target investigation (stages 3 and 4, or preferably stage 4 only, in which drilling is undertaken), has so many holes in the data that it is impossible to calculate any overall success rate. (The data suggest that certain programs resulted in the discovery of 1 to 10 deposits with sufficient tonnage for a mine, but with varying prospects for economic success, for each 100 targets investigated in stages 3 and 4).

Third, the published success/failure data are usually calculated for targets or for individual applications of technology (e. g., drilling) to a target, rather than for mineral exploration projects, which may include a number of more or less intensively investigated targets as part of a coordinated regional exploration effort. For example, the Texas Gulf exploration program listed in table 2.7 was actually a single project staffed by a single geologist, who coordinated a series of airborne electromagnetic surveys and drilling of various targets based on a new theory of ore formation for the region. The Kidd Creek copper-zinc-silver discovery that resulted from the project is an outstanding deposit, which made the project an unqualified success. This was recognized from the beginning as the most promising target, although it was not drilled until late in the project because of delays in acquiring mineral rights."'

' Miller, note 17, at 843

The published data for oil and gas exploration similarly focus on parts of projects rather than on the projects themselves. In fact, the oil and gas data do not even focus on the targets that make up a project, but rather focus on the number of wells drilled. Several wells are often drilled for each oil and gas target before a discovery (if any) is made, Thus, success rates reported for oil and gas exploration, which are rates per well drilled rather than per target drilled or per project, may understate the success rate when considered in terms of targets or projects.

The published success rates per well drilled in 1975 indicate that one out of seven onshore and offshore new-field ‘‘wildcat” wells—exploration wells drilled in areas not already proved to contain commercially producible oil or gas—resulted in discovery of economic oilfields or gasfields. One out of 55 onshore and offshore new-field wildcat wells drilled in 1975 resulted in significant discoveries—i.e., discoveries estimated to have found fields with reserves of more than 1 million barrels of oil or 6 billion cubic feet of gas each, Almost one out of four of all onshore and offshore exploratory wells—including new-field wildcats, extensions or outposts, new-pool wildcats, deeper-pool tests, and shallower-pool tests—were completed successfully as producers.[48]

Fourth, the published data on rates and costs of successful exploration, when available at all, are almost always for the mineral industry as a whole. Thus, the complete failure records of many marginal firms, often formed to take advantage of tax shelters, are included with and dilute the success records of the more established and professional firms. Obviously, it is the success rate of the individual firm, and not the industry as a whole, that is crucial in terms of that firm’s ability to stay in business, Similarly, the cost of a discovery should be based on the total expenditures and success/failure ratio of the individual firm, rather than the industry-wide total expenditure and success/failure figures, which include many very unsuccessful firms.

When mineral exploration expenditures are available for an individual company, they are usually found in the company’s annual reports, and include overhead, land acquisition and holding costs as well as direct expenditures for actual exploration activity. They also generally cover exploration activities worldwide, rather than only in the United States (the latter is the relevant figure for discussions of domestic mineral exploration activities), Finally, the expenditures are rarely tied to annual projects or targets investigated, so that it is impossible to get a measure of exploration efficiency.

OTA sought to make up for the lack of data on success rates and expenditure levels for individual firms’ onshore U.S. exploration activities by surveying a small sample of firms in 1977 to find out what minerals they were exploring for, and how much effort (staff, money, projects, etc.) was being expended on such exploration with what results. The surveyed firms included some of the better known hardrock exploration firms active in the United States, All were exploring for most of the metals, including uranium, and to a lesser extent the fertilizer minerals. Some were exploring for the chemical and/or industrial minerals. A few were exploring for geothermal resources and/or construction minerals, The survey also included two of the larger U.S. oil companies (both of which were exploring for uranium, and one of which was exploring for the fertilizer and chemical minerals and, to a lesser extent, the metals),

“1’’ ‘U S. Wildcat-Success Rate Highest Ever, ” *Oil and Gas J.*, June 7, 1976, at 60, The survey confirmed that oil and gas exploration is almost always handled by distinct companies, or divisions within companies, which explore for oil and gas only. Coal and oil shale are also handled separately, and "exploration"' for them is mainly an engineering effort to secure information on the size and quality of deposits already known to exist. Exploration for all other minerals is generally lumped together in a single group (company or division).

The results of the survey are tabulated in table 2.8, which divides the companies into groups according to their annual (1976 or 1977) onshore U.S. exploration budget for the specified minerals. For each group, the table lists:

1. the range in exploration budget, excluding land costs, for the firms in the group,
2. the number of firms in the group,
3. the range in size of the domestic onshore exploration staff, divided into professional and support staff,
4. the range in number of possible target areas or prospects seriously considered (i.e., at least some field examination) for detailed exploration during the year,
5. the range in number of target areas for which a land position had been established or maintained during the year,
6. the range in number of projects actively underway in stages 3 and/or 4 (detailed surface investigation or three-dimensional physical sampling) during the yea r,
7. the range in cumulative number of such active projects (counting each multi-year project only once) over a lo-year period, based on the cumulative number reported for the last X years (X being defined by various companies as anywhere from 3 to 25 years),
8. the range in cumulative number of immediate successes (development begun or projected in the near term) over the same lo-year period,
9. the range in cumulative number of technical successes (development begun or projected within the next 25 years— i.e., a property being held with that expectation, whether or not it is immediately developable),
10. the range in immediate success rate (cumulative immediate successes divided by cumulative active projects), and
11. the range in technical success rate.

For the companies surveyed, 0.6 to 8.6 out of every 100 onshore U.S. detailed exploration projects for minerals other than oil, gas, coal, or oil shale were immediately successful, i.e., led to actual or imminent development and production, while 5 to 12.8 out of every 100 onshore U.S. exploration projects for oil and gas were immediately successful. The oil and gas success rates are not improved by including "on the shelf" technical successes, whereas the nonfuel mineral success rates climb to 2 to 16 out of 100 when technical successes are included. This difference is probably explained by the current high prices for oil and gas that are making completion of smaller oil and gas wells profitable'" and thus keeping such wells "off the shelf. "

When the immediate and technical success rates for oil and gas are compared with those for the nonfuel minerals, it appears that the chances of complete failure are approximately the same for both. If this is indeed true, it may reflect the fact that ex-

Oil and Gas J June 20, 1977, at 134

Table 2.8.–Selected Individual Firm Exploration Statistics (Ranges) for Onshore United States

			Minerals other than oil, gas, coal, oil shale			Oil & gas
1976 (1977) onshore United States exploration budget, excluding land cost		Low Average High	$1.5 Million $3.4 Million $5 Million	$6.5 Million $8.4 Million $10 Million	$14 Million $18 Million $22 Million	$30 Million
Number of firms within specified budget range			5	3	4	2
1976 domestic onshore exploration staff	Professional	Low	15	11	50	—
		Average	26		64	110
		High	55	35	75	—
	support	Low	8	5	50	—
		Average	15	16	65	95
		High	31	24	90	—
1976 possible target areas seriously considered		Low	50	43	20	50
		Average	105	70	125	—
		High	200	160	150	100
1976 targets for which land position existed		Low	12	25	10	25
		Average	20	37	40	
		High	40	45	80	25
1976 active projects (Stage 3 and/or stage 4)		Low	6	23		25
		Average	10	28	25	—
		High	12	35	40	25
Cumulative active projects for 1 O-year period		Low	51	116	60	200
		Average	98	168	185	—
		High	150	245	400	250
Cumulative immediate successes for 10-year period		Low	0.5	7	4	10
		Average	2.6	10	7	—
		High	6	13	12	32
Cumulative immediate and technical successes for 10-year period		Low	1.9	9.1	8	10
		Average	7	13.8	11.5	—
		High	15	22.5	18	32
Immediate success rate (successes divided by active projects)		Low	0.6%	5.0%	2.0%	5.0%
		Average	2.6%	6.2%	5.5%	—
		High	5.1%	8.6%	8.3%	12.8%
Technical (includes immediate) success rate		Low	2.5%	6.3%	2.0%	5.0%
		Average	6.7%	8.0%	9.7%	—
		High	1 0.0%	9.2%	16.7%	12.8%

ploration for oil and gas today, at least onshore, involves a search for increasingly smaller fields,[50] with increasingly complex geology, at greater depths.[51] The chance of missing a discovery by siting a drill a few hundred feet off target may be as large today for oil and gas as it is for the nonfuel minerals. '2

No matter how the data in table 2.8 are interpreted, it is clear that, for each company surveyed, 80 percent or more of the exploration projects for both oil and gas and the nonfuel minerals were failures. These were projects that involved some detailed

[50] Ibid., at 32, 33, 34.
[51] U.S. Department of the Interior, 1 *Final Report of the Task Force on the Availability of Federally Owned Mineral Lands* 54 (1977).
[52] See ibid., at 55.

exploration in stages 3 and/or 4, and thus required substantial effort in terms of time and money.

The cost and duration of an unsuccessful project would normally be less than those of a comparable successful project, with the amount of reduction depending on how early in the exploration sequence the project is abandoned (see appendix C for the costs and durations of successful projects). Bailly estimated in 1964 that the total cost of all failures in hardrock exploration was perhaps 5 to 10 times as high as the total cost of all successes.[53] Given such a cost ratio, an exploration company should expect to spend 80 to 90 percent of its budget on failures.

Actually, the laws of probability require that an exploration firm be able to suffer through a string of failures that is often much longer than would be indicated by the average success/failure ratio. The governing concept, known as the ‘‘law of gambler’s ruin, ” has been aptly described by Slichter:

> This rule expresses the rather serious chance of going broke when the odds for success are small, merely by a normal run of bad luck regardless of the long-run expectations of gain. The only sure way of avoiding this special risk of gambler's ruin is to have enough capital, and the will, to continue the play many times and thus ride out the inevitable runs of bad luck. For example, i f the probability of success is one in ten for each venture, there is a 35 percent chance that ten successive ventures will fail in a row. But if one has the capital to continue the play through a run of 100 failures, then the chance of gambler’s ruin is only 3 in 100,000. ”

The high cost of modern mineral activity, discussed in section C, and the low probability of success and its associated law of gambler’s ruin discussed in this section, carry obvious adverse implications for the smaller participants in mineral activities in the United States today.” Those implications will be addressed in the next section.

F. Mineral Exploration, Development, and Production: Participants

Mineral exploration, development, and production on Federal onshore land is conducted primarily by the private sector, although State and Federal geologic and mineral agencies are involved to a substantial degree in the first two stages of exploration and occasionally in later stages.

The backbone of the mineral industry during the 19th century was the mass of individual prospectors and small miners who found and worked the surface deposits. Major deposits were usually syndicated or turned over to larger firms for development and production. Even well into the 20th century, individuals using conventional prospecting techniques (see subsection C(3)) continued to discover a large proportion of the economic mineral deposits, although development and production (which involved

[53] Bailly, "Methods, Costs, Land Requirements and Organization in Regional Exploration for Base Metals," paper presented at AIME Meeting, Alaska Section, Fairbanks, Alaska, Mar. 18-21, 1964, at 18.

[54] Slichter, "The Need of a New Philosophy of Prospecting," 12 *Mining Engineering* 570 (1960).

[55] Bateman, "Exploration Program for Small Mining Companies," *Mining Congress J.*, December 1963, at 45; Going, "An Industry Analysis of Exploration Activity," in *Canadian Mineral Exploration, Resources and Outlook*, note 20, at 13.

greater costs and more complex technology) became more and more the province of the larger firms.[56] A number of the major mines still in production today were developed from discoveries by individuals or small groups prior to or during the first half of this century,[57]

Data on current exploration and mining activities, however, indicate that the roles of the individual prospector and small miner have declined sharply in recent years as a result of advancing technology, greatly increased costs, and the low grade or hidden character of most of the remaining undiscovered deposits in the onshore United States,

In order to put these data into perspective, it is necessary to have clear and reasonable definitions of terms such as "individual prospector, " "small miner, " "small firm, " and so forth. The definitions chosen for this study are:

- Individual Prospector (or Explorationist): no more than two people working together spending less than $10,000 per year on mineral exploration;
- Small Firm: no more than 50 people working together spending less than $250,000 per year;
- Medium-Sized Firm: expenditures of less than $2,500,000 per year; and
- Large Firm: expenditures of $2,500,000 or more per year.

These definitions although arbitrary appear to be reasonable, Allowing for increased costs of exploration at a serious level, but retaining the emphasis on what can be done through individual effort and finances, a limit on expenditures of $10,000 per year seems generous for the ''individual prospector.

The American Mining Congress (AMC) surveyed 41 large mining companies in 1976 to obtain data on the role of the "small miner" in mineral exploration in the United States. However, the AMC statistics, reproduced in table 2.9, are ambiguous, because the AMC definition of "small miner" would include exploration groups as large as those of some of the largest exploration firms (or exploration divisions of major firms).

The AMC defined a small miner as "an individual, partnership, or corporation which is not listed on a major stock exchange; or which has a capitalization of less than $1,000,000; or which employs fewer than 50 persons; or which produces less than [50 to 200 thousand tons annually]."[58] But 1) an exploration firm need not be, and usually is not, engaged in production, 2) the only major capital asset of an exploration firm is its land holdings, and even the land is normally not capitalized until the development stage, and 3) even the large exploration firms, including the exploration divisions of most of the 41 mining firms surveyed by the AMC, have fewer than 50 professional employees devoted to onshore mineral exploration in the United States (see table 2.8).

[56] Lacy, "Technical Developments That Should Be Considered In Drafting Mining Legislation," in University of Arizona, College of Mines, *Symposium on American Mineral Law Relating to Public Land Use* 159, 161-163 (J.C. Dotson ed. 1966).

[57] Delcour and Rees, "The Role of the Small Miner," paper presented at the 1977 American Mining Congress Convention, Sept 13, 1977, at 6 (hereinafter cited as "AMC Small Miner Survey"), citing U. S. Bureau of Mines, "Major Mines Found by Small Miners," unpublished report, 1976, See also Albers, note 32

[58] AMC Small Miner Survey" note 57, at z.

Table 2.9.—AMC Survey of Small Miner Property Submittals

‘tear	Total no. of submittals A	Submitted by individuals and small companies B		Individual and small company figures only								
				Rejected c	Examined D		Deal made E	Drilled F	Dropped G	Still under consider-at ion H	Brought into prod uction or planned I	Other d ispo-sit ion J
			% of A			% of B						
1970	2,452	2,191	89%	1,482	917	42°0	116	102	222	35	16	72
1971	2,266	1,918	85%	1,353	818	42°0	86	83	211	47	13	44
1972	2,374	1,970	83%	1,347	862	44°0	93	78	214	41	12	65
1973	2,550	2,060	81%	1,356	954	46°0	106	88	244	67	12	41
1974	2,777	2,381	86%	1,629	1,028	43%	112	92	315	95	12	54
1975	2,992	2,621	88%	1,808	1,139	43%	115	93	301	154	18	70

SOURCE Delcour and Rees, ‘The Role of the Small Miner, ” paper presented at the 1977 American Mining Congress Convent Ion, Sept 13, 1977

Thus, although the AMC definition of “small miner’” seems appropriate for firms engaged in mining (mineral production), and in fact is very similar to the OTA “small firm*’ category as applied to production activities, it is not helpful in attempting to sort out the role of various-sized individuals and groups in mineral exploration, which was the primary focus of the AMC survey.

Moreover, the meaning of the AMC statistics themselves is unclear, even assuming that the statistics primarily represent submittals by individual prospectors and small firms as defined by OTA. The terms “submittal,’” “rejected, ” “examined, ” “dropped,” and so forth were not defined, The table reproduced in table 2.9 (without statistics) was the questionnaire. Discussions with the authors of the survey indicate that the primary conclusion to be drawn from the statistics is that large firms do pay attention to “small miner”’ submittals, since 42 to 46 percent of such submittals were examined. “Examination,” however, could range from a quick check of the literature or files on the area in question (the more usual procedure) to a field trip to inspect the property, More importantly, the authors indicated there was no way of knowing whether the “submittals” were completely spontaneous offerings of mineralized property, which themselves sparked the interest of the larger firms, or rather represented reactions by holders of mining claims to expressed or known interest in an area by a larger firm based on the larger firm own geologic appraisal and targeting.

The number of ‘*submittal” properties listed by the AMC survey as having been “brought into production or planned” each year comes close to (and may even exceed) the total number of discoveries that probably were made in each year (compare table 2.3 in subsection C(3)). It is hardly likely that all U.S. discoveries resulted primarily from “small miner” submittals. In fact, the data compiled by Albers and Bailly and presented in tables 2.2 and 2.3 in subsection C(3) indicate that no significant U.S. metal mine discoveries reported since 1960 have been primarily the result of conventional prospecting, which is the stock-in-trade of the individual prospector (although the more modern individual explorationist will also use geologic inference and geochemical techniques on a limited scale). This apparent contradiction may be resolved simply by the fact that almost all mineralized or potentially mineral ground in the United States is blanketed by mining claims, so that firms wishing to explore in an area must make arrangements with the owners of those claims. If all such arrangements were counted as "submittals," almost all discoveries would be on "submittal" properties.

This was precisely the case with the Mt. Taylor uranium discovery, which is the only example cited in the AMC survey of a discovery by a small miner. The AMC survey attributes the discovery to an individual prospector, Robert H. Sayre, Jr., who "staked claims on National Forest land in New Mexico, managing to interest a small uranium firm, the Bokum Corporation, in drilling. " But information provided to OTA by Sayre and an officer of the Bokum Corporation is different. Sayre did stake claims on the land, first in 1957 and later in 1969. The "targeting" involved in selecting the land consisted simply of drawing a straight "trend" line between two known deposits and searching county land records for unclaimed land along that line, No exploration, development, or assessment work was done beyond the effort expended in staking the claims. The Bokum Corporation was interested in the area and learned that Sayre had claims on the land, so it worked out a deal with Sayre to enable it to drill the land. The first drill hole, in 1970, intersected uranium ore. At the time, the Bokum Corporation was either a large medium-sized firm or a small large firm, using the OTA definitions of firm size.

Other sources of data on the role of various groups in current onshore mineral exploration invariably cite the drastically reduced role of the individual prospector. For example, Simon Strauss, Vice Chairman of ASARCO and one of the leading officials in the AMC, recently observed:

> Those who like to remember the good old days will hark back to the period a hundred years or so ago when the great, wide, open spaces of the West were being explored and populated by the white man, when the rich bonanza discoveries of California, Arizona, Montana, Idaho, Colorado and Nevada brought overnight wealth to the skilled or lucky prospector. Mines were opened from the grassroots then and the number of individual operations was very large. Why can't it be like that now?
>
> For the obvious reason that the surface of this country—and most others for that matter—has been scoured by professionals. The chances of finding a rich surface outcrop are minimal. This is not to say that new finds are not being made—on the contrary , . . . But these discoveries are of deposits that for the most part are hidden from the naked eye. They have been made as a result of tenacious geological deductions—and at great expense. The lone prospector with burro and pick ax is unlikely to spot them, although the rare exception does occur. Today, exploration is a team effort using the tools of modern man—costly tools.'"

Strauss' statement is confirmed by the data presented in subsection B(3), which demonstrate that conventional prospecting for surface outcrops and other surface "expressions' of economic mineralization now plays a very small and declining role in U.S. mineral exploration, at least outside Alaska. (Conventional prospecting may con-

Strauss, "Competition in the Nonferrous Metal Markets, *Mining Congress. J.*, June 1977, at 49; accord, U.S. Geological Survey, *Mineral Resource Perspectives 1975*, Prof. Paper 940, at 7 (1975); Bailly, "Mineral Exploration Trends and Prospects," paper presented at the Semicentennial Seminar on Exploration Geophysics, Colorado School of Mines, Nov. 18, 1976, at 5, 8, 21-22, 24; *Anatomy of a Mine*, note 16, at 21, 23.

tinue for a while to be important in Alaska, because of its less thoroughly explored state. On the other hand, the remoteness of much of Alaska and the high cost of doing anything there may independently lead to a reduced role for the individual prospector, as the less remote areas become more thoroughly explored.’)”)

Canada generally falls somewhere between the lower 48 States and Alaska in terms of the thoroughness with which it has been explored for surface expressions of economic mineral deposits. Yet, even in Canada the role of conventional prospecting has diminished radically in recent years, as shown by Derry’s data, which are presented in table 2.4 in subsection C(3).

Paul Bailly has combined exploration budget data with Derry’s data on Canadian discoveries to show the role played in such discoveries by various-sized exploration groups. Bailly’s results are shown in table 2.10. They indicate that none of the commercial metallic mineral discoveries reported by Derry for 1958 through 1973 were made by individual prospectors or small firms [using the OTA expenditure-based definitions), even though individual prospectors and small firms accounted for 50 percent of the firms actively exploring from 1968 through 1973.

At OTA’S request, six of the larger U.S. mining and mineral exploration firms and one major oil and gas company estimated industry-wide ranges for costs, acreages, and times involved in exploration for and development and production of 32 different mineral occurrence types (which include almost all the nonconstruction mineral occurrence types for which exploration is currently being undertaken). The completed forms, which are collected in appendix C, include estimates of the percentage of total domestic onshore activity undertaken today by individual prospectors, small firms, medium-sized firms, and large firms in each of the six stages of mineral activity for

Table 2.10.—Commercial Metallic Mineral Discoveries in Canada According to Canadian Exploration Budget of Discoverer During Discovery Year

Canadian exploration budget of firm (1971 dollars), including land costs	Percentage of firms with given budget out of al I firms act ively exploring in 1968-73	Discoveries during 1958-67		Discoveries during 1968-73	
		Number	%	Number	%
5 to 10 million		1	4%	2	10%
2.5 to **5** million	10%	3	11%	1	5%
1 to **2,5** million		**8**	30%	7	35%
0.5 to 1 million	10%	10	37%	8	40%
0,25 to 0.5 million	30%	5	18%	2	10%
0.0 to **0.25** million	50%	0	0%	0	0%
Total	100?40	**27**	10070	20	100°/'0

SOURCE Bailly, “ Mineral Exploration Trends and Prospect s.” paper presented at the Semi centennial Seminar on Exploration Geophysics, Colorado School of Mines, Nov. 18, 1976, figure 4.

[10] See the data in Hawley and Whitney, note 22, at 3-12 to 3-14

each mineral occurrence type. These estimates are compiled in table 2.11. The estimates indicate that individual prospectors play a minimal active role in the first three stages of exploration for all but a few mineral occurrence types (placers, marine evaporates, carbonate stratiform, and certain vein deposits), and almost no role in the more expensive stages of detailed physical exploration, development, and production. Small firms are more active in the first three stages, but their role drops substantially during the last three stages.

Table 2.1 1.—Estimated Percentage of Total Domestic Onshore Activity Undertaken by Various-Sized Groups in Each of the Six Stages of Mineral Activity

Mineral occurrence type	Indiv. prospector						Small firm						Medium firm						Large firm					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SURFICIAL																								
1. Aluminous Clay & Laterite	5	5	5	1	1	1	5	10	5	4	2	2	15	25	5	20	5	5	75	60	85	75	92	92
2. Laterites: Nickel	0	0	0	0	0	—	0	0	0	0	0	—	0	0	0	0	0	—	X	X	X	X	X	—
3. Stream Placer: Gold, Tin	X	—	X	0	0	—	X	—	X	X	X	—	X	—	X	X	X	—	0	—	0	0	0	—
4. Coastal Placer: Titanium	0	10	20	0	0	0	33	30	20	0	0	0	33	30	30	50	50	50	34	30	30	50	50	50
5. Residual Deposit: Phosphate	0	0	0	0	—	—	10	10	10	0	—	—	30	30	30	35	—	—	60	60	60	65	—	—
6. Brines in Evaporites	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7. Supergene: Base & Precious	9	2	0	0	0	0	9	8	8	0	0	0	32	25	30	12	5	5	50	65	62	88	95	95
8. Supergene: Silver	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X	X	X
STRATABOUND—EXTENSIVE																								
1. Precambrian: Gold, Uranium	3	1	0	0	—	—	20	20	20	10	—	—	35	35	35	40	—	—	42	44	45	50	—	—
2. Marine Sedim.: Phosphate	0	0	0	0	—	—	10	10	5	0	—	—	40	40	10	40	—	—	50	50	85	60	—	—
3. Marine Evaporite: Potash	15	15	15	2	0	—	25	25	20	10	2	—	30	30	35	38	38	—	30	30	35	50	60	—
4. Continental Sed.: Coal	12	20	0	0	0	—	20	23	10	10	10	—	33	28	45	45	45	—	35	29	45	45	45	—
5. Stratiform Igneous: Metals	0	0	0	0	—	—	0	0	0	0	—	—	0	0	0	0	—	—	X	X	X	X	—	—
STRATABOUND—DISCRETE																								
1. Marine Sedim.: Oil & Gas	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2. Continental Sed.: Uranium	0	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X	X	X	0	0	0	0	0	0
3. Lacustrine Evaporites	0	0	0	0	—	—	10	10	5	0	—	—	30	30	30	30	—	—	60	60	65	70	—	—
4. Fossil Laterite & Clay	2	5	5	1	1	1	3	10	5	4	2	2	15	25	15	20	5	5	80	60	75	75	92	92
5. Shale Mass. Sulfide: Cu	0	0	0	0	0	0	10	10	10	5	0	0	30	30	30	20	20	20	60	60	60	75	80	80
6. Shale Mass. Sulfide: Pb-Zn	0	0	0	0	0	—	0	0	0	0	0	—	0	X	X	X	0	—	X	X	X	X	X	—
7. Carbonate Stratiform: Ba-F	8	8	9	4	2	—	17	17	25	20	22	—	28	31	33	37	38	—	47	44	33	39	38	—
8. Carbonate Strat.: Pb-Zn-Cu	6	7	4	0	0	0	14	14	14	13	14	10	30	25	40	42	43	45	50	55	42	45	43	45
9. Volc. Mass. Sulfide: Metals	0	0	0	0	0	—	30	30	30	10	0	—	30	30	30	35	30	—	40	40	40	55	70	—
10. Metamorphic: Graphite, etc.	0	0	0	0	0	—	50	50	50	50	30	—	40	40	40	40	50	—	10	10	10	10	20	—
DISCORDANT																								
1. Breccia Pipes: Metals	0	0	X	—	—	—	X	X	X	—	—	—	X	X	X	—	—	—	X	X	X	—	—	—
2. Porphyries: Copper, Moly.	0	0	0	0	—	—	0	0	0	0	—	—	0	0	0	0	—	—	X	X	X	X	—	—
3. Replacement Deposit: Sulfur	0	0	0	0	0	—	10	10	0	0	0	—	30	30	40	40	30	—	60	60	60	60	70	—
4. Vein-Replacement: Silver-Cu	25	25	26	0	0	—	25	25	28	10	10	—	25	25	23	45	45	—	25	25	23	45	45	—
5. Mass. Sulfide Pipes: Metals	5	4	1	1	—	—	10	16	10	10	—	—	30	30	25	30	—	—	55	50	64	59	—	—
6. Mafic-Ultramafic: Ni-Cu	0	0	0	0	0	—	20	20	20	10	0	—	40	40	40	40	30	—	40	40	40	50	70	—
7. Anorthosite: Iron, Vanadium	0	0	0	0	0	—	20	20	10	0	0	—	30	30	30	25	10	—	50	50	60	75	90	—
8. Vein Ultramafic: Asbestos	0	0	0	0	0	—	5	4	5	0	0	—	10	9	10	10	10	—	85	87	85	90	90	—
9. Vein Meta. Dolomite: Talc	40	45	20	5	0	0	40	40	50	45	40	40	20	15	30	50	60	60	0	0	0	0	0	0
10. Carbonatite-Alkalic	0	0	0	0	0	—	20	10	10	5	0	—	40	45	45	40	50	—	40	45	45	55	50	—

X = participates, but no attempt to quantify percentage.
— = no data given in response to questionnaire,

The estimates in table 2.11 are for participation; they do not reflect the success of the various-sized groups. The other statistics cited in this section, as well as discussions with industry exploration executives, indicate that, with rare exceptions, individual prospectors and even small firms do not make actual discoveries of significant commercial mineral deposits. Nor, less clearly but still apparently true, do they often identify or delineate the targets that the larger firms then investigate for an economic deposit. Rather, it seems that the two smaller groups establish land-tenure positions on any land that is even faintly mineralized and probe the surface more or less diligently within the limits of their funding and expertise, trying to develop information that will interest the medium-sized or large firms. They serve essentially as a chamber of commerce for their piece of land and its bit of geologic and mineral information, making sure that the information is fully fed into the models and files of the larger firms, along with all the other information compiled by the larger firms from published sources and their own regional reconnaissance.’)’

The larger firms form the models and identify the targets, which may include a property submitted by, perhaps even as a result of information supplied by, an individual prospector or small firm, who may nevertheless be completely unaware of the particular mineral or information that made the property a target.

This would appear to be the primary role of individual prospectors and small firms—a role quite similar to that of the U.S. Geological Survey in its geologic mapping and survey programs, although more specific and proprietary as a result of the tie to particular tracts: namely, the development and dissemination of basic geologic and mineral information to serve as a base for the more extensive and sophisticated exploration efforts of the larger firms,[62]

Occasionally, as with the Geological Survey, f)(this basic information activity will result in identification of targets, development of models, or even actual physical discovery by an individual prospector or small mining firm, more often by those with training in modern geology and the less expensive applications of the modern techniques .“[64]

The more successful individuals and small firms in the mineral exploration business today no longer fit the image of the penniless and self-reliant prospector. They have evolved into a role similar to that of the “independents” in the oil and gas business, described below, They provide technical and consultant services to the larger exploration firms, do work on contract or “farm out” from the larger firms, or occasionally initiate their own projects with financing from the larger firms or from local investors (who are often motivated by tax writeoff possibilities as well as the prospect of success). These independent explorationists usually concentrate, for their own projects, on the smaller targets which, because of structure, overhead, raw materials requirements, and so forth, would not be of interest to the large-r firms.’)’ Their activity,

[61] Payne, *Nevada Mineral Exploration and Mine Development 1950-1972*, at 12-16 (1976) (unpublished report prepared for the U.S. President's Council on Environmental Quality).

[62] See "AMC Small Miner Survey," note 57, at 4, 5-6; cf. Albers, note 32, at 71.

[63] See, e.g., Miller, note 17, at 843 (North Carolina phosphate); *Mining Congress J.*, May 1977, at 13 (Utah uranium); Payne, note 61, at 36 (Nevada barite).

[64] *Anatomy of a Mine*, note 16, at 22-23; Payne, note 61, at 12-18; Bateman, note 55, at 46-47; "AMC Small Miner Survey," note 57, at 6-7.

[65] Bailly, note 59, at 8; *Anatomy of a Mine*, note 16, at 23; Payne, note 61, at 18.

however, is constrained by the extent of outside financing they can obtain during any given period,[66]

The sharp decline of the professional (full-time) individual prospector has been accompanied by a mushrooming of recreational or weekend prospectors who contribute very little to mineral discoveries but, as described in recent reports, may be a boon to the local economy at the expense of the surface environment:

> In recent years, as full-time professional prospectors have almost disappeared from the scene, amateur prospectors have become far more numerous. To many outside of the mining business it is difficult to distinguish between the two.
>
> The publicity, sometimes highly distorted, given to rushes such as the uranium boom of the 1950's, the convenience of modern off-road vehicles, and the increasing amount of leisure time available to so many, have combined to produce tens of thousands of amateur prospectors. Some of these individuals make great efforts to equip and train themselves, and they are capable of finding prospects worthy of exploration and development. However, the majority of the amateurs are poorly motivated and so lacking in the most rudimentary knowledge that they create difficulties for those seriously engaged in prospecting and exploration.
>
> The amateur's common lack of consideration for the rights of land owners, his abuse of laws and regulations, and his ill-conceived bulldozing of the surface have become so offensive that there is mounting pressure for drastic restrictions on all prospecting and exploration activities,[67]
>
> The amateur prospector does not, of course, depend upon mining as his means of livelihood, He makes a significant contribution to the local economy in his purchase of off-road vehicles, maps, supplies, and inexpensive metal detection devices of various sorts, No important mineral discovery has been made in Nevada by an amateur prospector in the post-World War II period.[68]

The role of the small production firm, like that of the individual prospector, is apparently in a state of decline, although less precipitate.[69] The AMC small-miner survey states that small miners (as defined by the AMC) contributed only 4,5 percent of the total value of U.S. hardrock mineral production during 1975, even though they operated over 75 percent of all mines, Small miners, however, account for all or much of the production of some of the more common minerals such as dimension stone, perlite, barite, feldspar, mica, gypsum, crude asbestos, graphite, kyanite, talc, and industrial garnets. Moreover, there are many more small mines than large mines, and the small mines may account for a large part of total mine employment, As in exploration, the small mining firm concentrates on deposits too small to be of interest to the larger firms, and thus produces minerals that otherwise might not be produced,[70]

One area where the small firm, though not the individual prospector, may play a substantial role is the exploration, development, and production of onshore U.S. oil and gas. Published data indicate that "independents" made 75 percent of the new-field onshore and offshore wildcat discoveries between 1969 and 1974, inclusive, whereas major companies made only 25 percent of the discoveries. The bulk of the majors' exploration occurred in the offshore Arctic and ultradeep inland drilling, where the

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[66] Payne, note 61, at 72-75,
[67] *Anatomy of a Mine*, note 16, at 23.
[68] Payne, note 61, at 12; see *Anatomy of a Mine*, note 16, at 59,
[69] Lacy, note 56, at 161-164,
[70] "AMC Small Miner Survey," note 57, at 3, 7-9,

average discovery is substantially larger and more expensive than the average independent's discovery. (The major company discoveries, even counting only the first 100 million barrels of major discoveries such as Prudhoe Bay, accounted for almost half of the oil and gas reserves, and resulted from drilling only 10 percent of the total new-field wildcat wells.) But it is impossible to draw from such data any conclusion as to the actual role of small oil and gas firms, because "independents" were defined as all but the 16 largest oil and gas companies. "

Jackson, "Independents/Majors: Their Exploratory Role," *Oil and Gas J.*, Feb. 7, 1977, at 95. See also *Oil and Gas J.*, June 14, 1976, at 34.