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A Diamond Exploration Philosophy for the 1980s

The recognition of new target rocks and tectonic settings for diamond-bearing pipes and fissures calls for a revision in exploration methods and strategy.

DAVID P. GOLD, *Professor of Geology*

This article, an update of my article on "Natural and Synthetic Diamonds and the North American Outlook" in the February 1968 issue of this bulletin,[1] deals mainly with the new "finds" and developments in exploration philosophy in the past 15 years.

During this period, Russia and Botswana have moved into the second and fourth places in diamond production,[2] the Australians and South Africans are developing new mines from their active exploration programs during the 1970s, and it is hoped that the exploration efforts of companies such as Anaconda/ARCO, Cominco, Diamex, Selco, and Superior may reap the fruits of current efforts in the development of mining operations in North America.

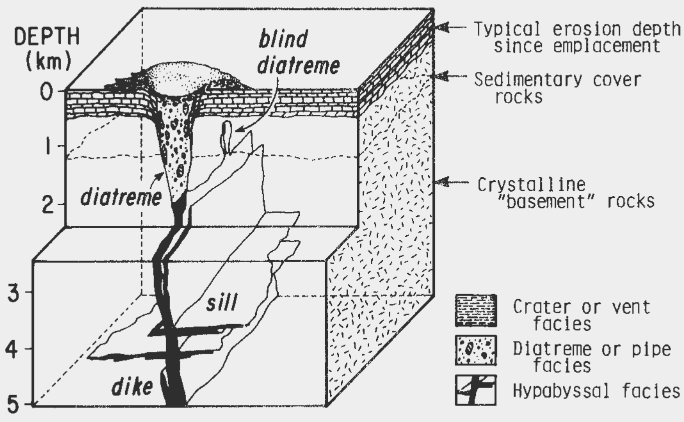

Figure 1. Model of a typical kimberlite diatreme showing bedded tuffaceous kimberlite in crater and upper vent, tuffisites and autolithic kimberlite breccia in diatreme, and massive kimberlite and kimberlite breccia in fissures and dikes of hypabyssal facies (modified after McCallum and Mabarak, ref. 14).

Diamond, the high-temperature (T) and high-pressure (P)

Continued on next page

Superconductivity and Current Research at Penn State on Type II Superconductors

Work here is directed toward a better understanding of how superconducting properties relate to the microstructure of alloys.

WILLIAM R. BITLER, *Professor of Metallurgy*

The phenomenon of superconductivity offers scientific and commercial possibilities that have intrigued scientists since its discovery just over 70 years ago. New superconducting materials and research findings hold promise for high-speed magnetic-levitation trains and nuclear magnetic resonance instruments for medical diagnosis, as well as the more obvious application in power generation and transmission.

Superconduction is the ability of certain metals, alloys, and compounds, under appropriate conditions, to conduct electricity

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Two Graduates of College Are Named Distinguished Alumni of Penn State

Two graduates of the College of Earth and Mineral Sciences were among the eight recipients of Penn State's 1984 Distinguished Alumnus Awards presented by President Bryce Jordan at a ceremony on the University Park Campus in June.

Thomas M. Krebs, 1949 metallurgy graduate, and George E. Trimble, 1942 petroleum and natural gas engineering graduate, received the award, the University's highest honor to its alumni. It recognizes those "whose personal life, professional achievements, and community service exemplify the objectives of The Pennsylvania State University."

Mr. Krebs is senior vice president and group executive of the Tubular Products Group of Babcock and Wilcox Company, a subsidiary of McDermott International, Inc. He heads a multiplant operation that is one of the world's largest manufacturers of specialty steel tubular products. Recognized as an authority on specialty steels, he is a member of the board of directors of the American Iron and Steel Institute, and, in 1981, received the McFarland Award of the Penn State Chapter of the American Society for Metals.

He has been a leader in the civic affairs of Beaver County, Pennsylvania, and an active supporter of Penn State's Beaver Campus. He has served four terms as president of the campus advisory board, and, in 1975, received the Beaver Campus Distinguished Service Award.

Mr. Trimble is president, chief executive officer, and chairman of the board of Aminoil USA, Inc., a subsidiary of R. J. Reynolds Industries, Inc. Aminoil is the nation's second largest independent petroleum ex-

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Diamond Exploration —

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polymorph of carbon, requires an environment of about 50 to 60 kb (approximately 800 thousand psi) at 1300 to 1400° C for its growth from a transition element carbide catalyst under synthetic conditions.[3] This translates to depths of about 120 to 200 km in natural regions of low geothermal gradient. Prior to 1872, when diamonds were discovered in funnel-shaped pipes and fissure-like dikes of serpentinized micaceous peridotite (kimberlite) in the Kimberley region of South Africa, all production was from alluvial deposits. Since then diamonds have been found in meteorites[4] (1880) and lamproites[5] (1977), and their natural habitat will increase substantially if reports of diamonds in alkali basalts[6] (1979), ophiolites[7] (1978-79), and andesites are substantiated.

Since the successful synthesis of diamonds in Sweden[4] (1953), industrial operations have been set up mainly by the General Electric Company (1955), De Beers Consolidated Mines (1959), and E.I. duPont de Nemours and Company (1966) to meet the shortfall in natural industrial diamond production over the current demand of some 110 million carats per year.[2] During the past 60 years, demand for industrial diamonds has increased at a steady annual rate of 9 percent—a performance record rarely equalled by other sectors of industry[8]—and this provides the incentive for exploration of new deposits.

Habitat of Diamonds

Most of the estimated 300 tons—1.5 billion carats—of diamonds[9] that have been recovered to date have come from alluvial workings. (1 carat = 0.2 gram; or 2268 carats = 1 pound). Of these, more than half (approximately 170 tons or 850 million carats) have been produced during the past quarter-century.[9] During this same period, there has been a steady increase in production from primary sources (currently about 50 percent), reflecting the higher grade of most source rocks and environmental concerns with placer mining. An appreciation of the formidable task in source rock exploration may be gained from the figures in Table 1, where grades in carats per 100 metric tons (tonnes) are listed for some of the largest kimberlite-lamproite bodies that have been sampled or mined.

Of the diamond-bearing rocks mentioned earlier, only the kimberlites and lamproites have been mined. Both of these rocks occur as volcanic pipes, fissures, and vents (rarely as sills) that are veritable windows through the crust into the lithosphere and upper mantle. A typical kimberlite setting, shown in Figure 1,[14] demonstrates a rapidly upwelling, volatile-rich magma along short-duration fissure openings in areas of tectonic tension, with escaping volatiles in the depth range of 2 to 4 kilometers. The kimberlite breccias, tuffisites, and lapilli tuff breccias are interpreted as a gas-streaming phenomenon in a fluidized bed, with bedded clastic tuffs in the upper vent or crater where the fluidized gases vented at the surface. These are unusual intrusive/volcanic events that travelled sufficiently rapidly from the source some 120 to 200 km deep to preserve fragments (xenoliths) of the wall rock as well as minerals (xenocrysts and megacrysts) unique to upper mantle environments.

The most common exploration method is tracing back to their source the characteristic and more abundant kimberlite heavy minerals that co-travel with diamond through the early part of the weathering and downstream erosion cycle. Back-tracing is a time-tested method of provenance mapping by sampling stream sediments in drainage cells to identify the typical kimberlite heavy minerals—Cr-diopside, Mg-ilmenite, and Cr-pyrope garnet.[1,4,15]

A breakthrough in exploration came in 1977, when an unusually rich diamond find in alluvial deposits at Smoke Creek in Western Australia was traced back successfully to a volcanic pipe identified not as kimberlite but as lamproite.[5,15] As a result of this discovery, it was recognized that previous exploration, restricted to a search for kimberlites, had been too narrow and that lamproites should also be identified as an important source rock for diamonds.

The lamproites are a rare group of ultrapotassic alkaline rocks, characterized by excess K_2O over Na_2O, high MgO, and the presence of leucite, or sanidine, or potassium-rich glass.[16] An attempt to categorize intrusive lamproites mineralogically is shown in Figure 2 (the silica-saturated volcanic lamproites—leucite tephrite, and leucite phonolite—have been omitted). Of these intrusive lamproites, only the "high-pressure regime" orendites carry ultramafic xenoliths and appear to be likely candidates for diamonds.[17] Their mode of emplacement is similar to kimberlites, but their setting in cratonized mobile belts, above possible fossil subduction zones, and in marginal basins may account for their diversity in composition.

Exploration Techniques

Kimberlite and kindred rocks that originated at depths in the mantle conducive to equilibrium growth of diamonds are not as rare as once suspected. However, they are difficult to find and even more difficult to identify as diamond-bearing. Of the more than five thousand kimberlite bodies known,[10] only about one in ten contains any diamonds, and only one in a hundred is likely to be exploited.

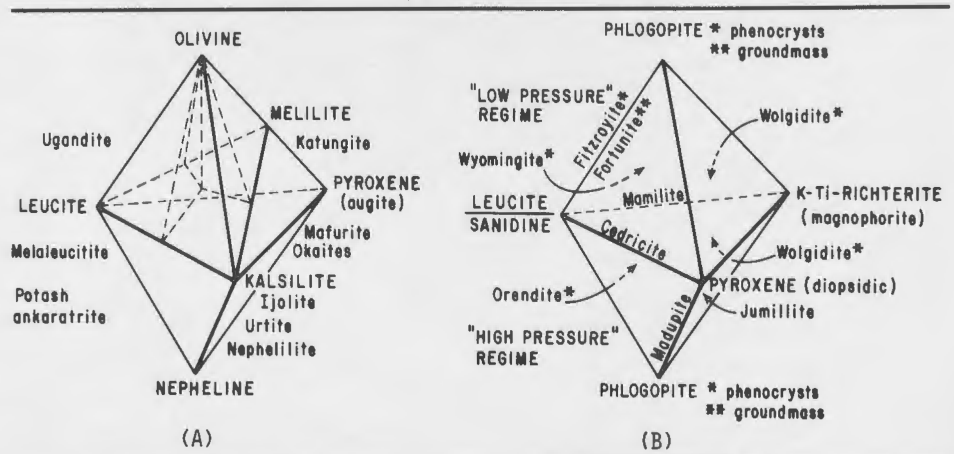

Figure 2. Mineral assemblage diagrams to illustrate the compositional fields of some lamproites. (A) Lamproites with kamafugitic affinities. (B) Lamproites with orenditic affinities for "low pressure" (top half of tetrahedron), and "high pressure" (bottom half of tetrahedron) regimes, i.e., orendites for the deep-seated equivalents of wyomingites. Madupite contains poikilitic phlogopite in a glass matrix.

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Stream sediment sampling and back-tracking the kimberlite indicator or pathfinder minerals is still the most popular exploration method.[1,4,13] Unfortunately, many fertile areas are filtered out if the lamproite pathfinder minerals (see Table 2) are not sought and if the target is not weathered and eroded sufficiently to develop a steady-state downstream dispersion train for its indicator minerals.

The recognition of depth facies (see Figure 1) for kimberlites by Hawthorne[18] is an important parameter for estimating the depth of erosion since the intrusive event. Most of the South African diamond mines represent hypabyssal and diatreme facies kimberlites in structural arches or anticlises, with 1 to 2 km of erosion since the Cretaceous (Figure 3), i.e., ideal conditions for stream sediment sampling. However, the paucity of erosion (or perhaps subsequent deposition) in the down-warped basins and syneclises is reflected in the poorly developed downstream dispersion of indicator minerals and the preservation of crater facies kimberlites and lamproites (see Figure 3). For these settings, stream sediment sampling must be replaced by the more costly technique of soil sampling on a grid basis for the indicator minerals and elements.

Some of the major "finds" of the decade (see Table 3), such as Ellendale and Mt. Abbott in the Fitzroy basin of northwestern Australia,[15] and Orapa and Jwaneng in the Kalahari basin of Botswana,[13] are well preserved crater and sub-crater facies kimberlites and lamproites adjacent to uplifted cratons. This means that a rigorous exploration program must consider tectonic setting, emplacement age, and erosion levels in the sampling scheme, with soil sampling dominating in regions where the target is barely eroded (generally basins and syneclises), and stream sediment sampling in regions where the target is deeply eroded (generally crustal arches, uplifts, and anticlises).

Most of the post-World War II exploration (in Siberia by Russian geologists, and in large tracts in Africa, Australia, and North and South America by the De Beers organization and its affiliates) was based on stream sediment sampling for kimberlites. Although these programs were successful in locating kimberlites in Brazil, eastern Australia, Siberia, and Lesotho, most of the areas covered by these earlier surveys should be re-examined using updated exploration parameters.

In the target selection stage, a closely spaced aeromagnetic survey is perhaps the most useful among geophysical methods because the ultramafic nature and magnetic content of kimberlites ensures a good magnetic contrast with the country rock. A closely-spaced ground magnetometer survey is an effective technique for tracing out the margins of a diatreme beneath a soil cover.

TABLE 1 CHARACTERISTICS OF SOME DIAMONDIFEROUS KIMBERLITES (K) AND LAMPROITES (L)

NAME/LOCATION	FACIES/TYPE	SURFACE AREA[1]	GRADE[2]	PRODUCTION[3]
Mwadui (Williamson) mine, Tanzania	crater (K)	361	22	1 million (1969)
Orapa mine, Lethakane	crater (K)	262	66.6	4.5 million (1983)
Jwaneng mine, Jwaneng cluster, Botswana	crater (K)	79	70-80	4-6 million (1985)
Letseng Le Terai, Lesotho	upper diatreme (K) subcrater	40	3-3.5	52 thousand (1979)
Finch mine, cluster 230 km WNW Kimberley South Africa	subcrater (K)	45	86-100	2.5-4.5 million (1980)
Kimberley mine, Kimberley, South Africa	deep diatreme to hypabyssal (K)	42	29-128.3 64.4 av. for mine life	14.5 million (total)
Premier mine, Transvaal, South Africa	deep diatreme (K)	76	26-33	2.46 million (1983)
Argyle AK-1, Western Australia	subcrater? (L)	111	150	20-25 million (by 1985)
Prairie Creek, Murfeesboro, AR, USA	subcrater? (L)	66	12	48 thousand (during WWII)
Sloan 1 & 2 pipes, 60 km NW Fort Collins, CO, USA	diatreme (K)	17.3	20?	none as yet
Batty K-1, Somerset Island cluster, NWT, Canada	subcrater? (K)	95	very low	none

1 acres (1 acre = 0.40468 Ha)
2 carats per 100 tonnes (1 carat = 0.2 gram)
3 peak and/or projected, in carats per year

Data for this table were compiled from references 2, 4, 8, 10, 11, 12 and 15.

Under conditions of seasonal stress, remote sensing techniques can sometimes pick up plant variations and differential moisture retention patterns over weathered kimberlites. In general, kimberlites weather to negative topographical features such as swales and swampy depressions, whereas the more resistant kimberlite breccias and lamproites can commonly be identified as small hills or ridges.

Many diatremes have been found during routine geological survey mapping projects by state and federal government agencies. Although the field report might be misleading (e.g., volcanic pipe or breccia pipe), the habit (pipe, vent, crater, dike, or fissure), and texture (porphyritic, autolith breccia, lapilli tuff, or tuff) in an alkaline igneous rock province or extensional tectonic setting (e.g., pull-apart basin, rift valley, major lineament, or flood basalt field) should alert the exploration geologist for follow-up studies by someone capable of recognizing the different types of kimberlites and lamproites, as well as their depth facies variants.

In addition to stream sediments and eluvial soils, diamonds and indicator minerals have been recovered from the terminal moraines and tills of the most recent (Wisconsin Stage) ice sheet of the Pleistocene Glacial Period. Geological reasoning suggests the source should be at the "apex of a fan formed by the glacial transport paths," somewhere to the north on the Canadian Shield.[10] Although this method has been used successfully on the Munro esker in northeastern Ontario, it can be counter-productive unless a detailed local model is developed to identify ice movements and material contamination and dispersion patterns.

Exploration Parameters and Models

A number of potential exploration guides have been listed in Table 2. Despite a probable limitation of being too restrictive in the types of diamondiferous source rocks, a critical evaluation of these parameters should help refine any site-specific exploration model. Any rapidly emplaced volcanic rock with an upper-mantle origin must be considered a candidate for exploration. Neither kimberlites nor orenditic lamproites should be the sole exploration targets; any rock that can satisfy the following criteria has potential:

—There must be a source of carbon in the magma/melt, and crystallization conditions must be within the oxidation stability field of diamond.
—For optimum growth and preservation of diamond, the magma should be the coldest possible consistent with the Simon-Berman phase boundary for diamond (i.e., $P = 7000 + 27T$ bars, for $T > 1200°$ K).[19]
—Emplacement must be rapid to preserve the metastable phases.

If these conditions are assumed to be correct, then:

(a) The preferred region for the generation of diamond-bearing magmas is at depths around 150 km and temperatures around 1000-1200° C.[14]
(b) A rapid emplacement from near the asthenosphere-lithosphere boundary requires a conduit opening in a region of plastic deformation. Brittle failure conditions that provide temporary openings into the upper mantle are feasible if a rapidly applied stress (pressure build-up and release) is superimposed on an already metastable stress region of the tectonic tension in the lithosphere plate.
(c) The age of the known kimberlite emplacement ranges from 2.5 b.y. to 30 m.y.[13] Most lamproites are younger. The peak of kimberlite activity during the Cretaceous coincides with crustal extension in the continents and the fragmentation of Gondwanaland and Laurasia.

Locating a suitable source rock is only the first stage. Determining the economic potential of a kimberlite/lamproite involves detailed geological mapping for size, shape, and facies, and sampling for homogeneity and grade. The latter task is a major undertaking because at least a 50-to-100-ton sample is required in order to get a representative sample of diamonds in typical concentrations (about 1:5,000,000 at the South African Finch mine to 1:100,000,000 at Leseng Le Terai in Lesotho). The economic assessment is based more on the clarity, color, perfection, size, and quality than the absolute amount. As the diamond industry developed, the distinction in size between "macros" and "micros" has been revised downward to the currently accepted cutoff of 500 microns. Industrial diamonds include all the flawed, polycrystalline, and "aggregate" stones regardless of size, as well as all the smaller stones regardless of quality.

The following strategy may help to minimize making a wrong decision without making the financial commitment of a mini-mining operation which is associated with bulk sampling:

(1) Test for "micros" in large hand specimen samples (50 kg). Their presence establishes the deposit as diamondiferous, their absence indicates it is barren. Micros in stream sediments may be extraterrestrial in origin.
(2) Test for the presence of high-Cr, low-Ca pyrope garnets.[20]
(3) Test for the presence of ultramafic nodules, xenocrysts, and megacrysts in which the measured P and T for equilibrium mineral assemblages are close to the shield geotherm and within the diamond stability field.[14]

Conclusions

Area selection in a frontier-approach exploration that involves an extrapolation of geological reasoning to new regions is based on two main criteria. The first is provenance mapping for kimberlites/lamproites from their pathfinder minerals in stream sediments, or in strongly directional glacial deposits such as eskers. Only if alluvial diamonds can be traced back to their source rock will current biases for source rock type (kimberlite/lamproite) be circumvented.

The second criterion is based on the diatreme model and the setting for mantle volcanism, where favorable areas include:

(a) Regions of thick crust, low thermal gradient and heat flow, such as in the ancient cratons for kimberlites, or in the cratonized mobile belts marginal to these cratons, and in the adjacent younger basins for the lamproites. Whereas the carbon in the kimberlites is likely to be primitive ($\delta^{13}C$ of -6 to -8 per mille), those of the lamproite may be lighter (up to -22 per mille), reflecting crustal contamination in a fossil subduction zone.
(b) Any alkalic petrographic province where ultramafic nodules are preserved in rapidly emplaced intrusive bodies.
(c) Regions of crustal tension.

The best methods for target selection include:

(a) backtracking diamonds/pathfinder minerals to their source over anticlises (crustal arches and uplifts);
(b) soil sampling on a grid basis for diamonds/pathfinder minerals in syneclise

TABLE 2 PROPERTIES AND TECTONIC SETTING FOR DIAMOND-BEARING ROCKS

	KIMBERLITE	LAMPROITE
PETROLOGIC CONSIDERATIONS		
rock types/varieties	porphyritic alkali peridodite phlogopite (micaceous) kimberlite serpentine-kimberlite calcite (calcareous) kimberlite diopside-kimberlite monticellite-kimberlite	silica saturated Mg and K-rich lamprophyre orendite madupite
major elements	high CaO, Al_2O_3, TiO_2, K_2O, P_2O_5, CO_2, H_2O	K_2O, Na_2O, MgO, TiO_2
trace elements	high Cr, Ni, Co, Re, Os, Nb, Sr, Rb, R.E., Ba	high Ba, Rb, Sr, Pb, Th, U, Ti, Zr, Nb, R.E.
indicator minerals		
--spinel trends	Mg-Fe-Ti enrichment	chromite
--ilmentite	high MgO and Cr_2O_3	rare Ti-bearing minerals
--garnets	high Cr, low Ca pyropes	andradite, zircon
--unusual minerals	Cr-diopside	mangophorite and Ba-phlogopites priderite $(K, Ba)_{1.33}(Ti, Fe)_8O_{16}$ wadeite $(Zi_2K_4Si_6O_{18})$
xenoliths	ultramafic nodules with equilibration depth of 150-200 km and temperatures close to shield geotherm	
TECTONIC SETTING	alkalic rock provinces	ultrapotassic rock provinces
	stable cratons	cratonized mobile belts and basins marginal to old cratons
	regions of crustal tension regions of low thermal gradient zones of deep-seated fractures--major lineaments but not faults fracture intersections for near surface control linear gravity "high" (possible fossil graben) uplifted regions underlain by anomalous mantle (LVZ) (?)	
PHYSICAL RESPONSE		
relief	usually negative relief	usually positive relief
magnetic	high local magnetic anomaly over target	moderate magnetic response
gravity	negative local gravity anomaly over breccia pipes	positive gravity anomaly over pipe
resistivity	usually good resistivity (or conductivity contrast with country rock)	

TABLE 3. SUMMARY OF SOME RECENT KIMBERLITE/LAMPROITE FINDS

LOCATION/DEPOSIT	EXPLORATION METHOD	TYPE/FACIES	AGE/TECTONIC SETTING	POTENTIAL
AUSTRALIA				
King George River cluster, W. A.	stream sediments	kimberlite	eroded craton	diamonds found
Argyle cluster, W. A.	alluvial diamonds	lamproite	mobile belt	Argyle Ak-1 mine
Ellendale-Mt. Abbott cluster	stream sediments	kimb/lamp	mobile belt & Fitzroy marginal basin	diamonds found
Winning Pool cluster, W. A.	stream sediments	kimberlite	Carnarvon basin	diamonds found
SOLOMON ISLANDS				
Malaita diatremes	geologic mapping	alnoite?	thick oceanic crust beneath Ontong Jave submarine plateau	favorable P-T of xenoliths
CHINA				
Hanan Province	?	kimberlite	block faults ?	Chang Te mine
Shandong Province	alluvial diamonds	kimberlite	block faults ?	
Liaoning Province	alluvial diamonds	kimberlite	block faults ?	Tancheng mine
Guanxi Province	?	kimberlite	block faults ?	
Guizhou Province	?	kimberlite	block faults ?	
USSR				
Koryaksk Highlands	geologic mapping	dunite/wehrlite	Paleocene ophiolite; subduction zone	micros found
Almaznyy volcono, central range, Kamchatka	geologic mapping	basalt	Pliocene-Holocene volcanic in island arc	micros found
SOUTH AFRICA				
Finch mine, N Cape Province	soil sampling in known cluster	kimberlite	basinal	large producer
Venetia cluster, N Transvaal	geol. map; soil samp.	kimberlite?	Messina mobile belt	good potential
BOTSWANA				
Lethakane cluster	soil sampling	kimb./crater	Kalahari basin	Orapa mine
Jwaneng cluster	soil sampling	kimb./crater	Kalahari basin	Jwaneng mine
BRAZIL				
Redondao diatreme, Piaui state	stream seds; alluv.	kimb/hypabyssal	faulted craton	no diamonds produced
Vargem cluster, Minas Gerais	stream seds; alluv.	kimb/hypabyssal	craton	no diamonds produced
Batovi cluster, Mato Grosso/Goias	stream seds; alluv.	kimb/hypabyssal	craton	no diamonds produced
UNITED STATES				
state line region of Colorado/Wyoming	geol. map/stream seds.	kimb/hypabyssal?	uplifted/faulted craton	12 of some 100 diatremes contain diamonds
Prairie Creek, Arkansas	geologic mapping	lamproite	Mississippi embayment	subeconomic
Missouri Breaks, Montana	geologic mapping	4 kimb/37 alnoites?		favorable P-T in xenoliths
Haystack Butte, Montana	geologic mapping	lamproite?		?
Lake Ellen, Michigan	geologic mapping	kimberlite	glaciated craton	favorable P-T in xenoliths
Sherman Hill, Michigan	geologic mapping	diatreme?		
Limestone Mt., Michigan	geologic mapping	diatreme?		
Brule River, Michigan/Wisconsin	geologic mapping	diatreme?		
Glover Bluff, Wisconsin	geologic mapping	diatreme?		
Coyote Peak, California	geologic mapping	alnoite?	subduction zone	unlikely
Raton, New Mexico	geologic mapping	3 small kimb. vents	continental 'hot spot'	untested
CANADA				
Upper Canada mine & Michaud Twshp., Ontario	heavy minerals in Munro esker	hypabyssal fissures?	craton	untested
Sextant & Coral Rapids area, Ont.	diamond in esker	lamp. dikes	craton	untested
Picton & Varty Lake, Ontario	geologic mapping	lamp/kimb dikes	craton arch	favorable P-T in xenoliths
Crossing Creek, Elkton, B.C.	stream sediments	kimb diatreme	back arc rift	favorable
Bear & Mt diatremes, Mackenzie River, N.W.T.	geologic mapping	kimb diatremes	basinal	favorable
Somerset Island, N.W.T.	geologic mapping	19 kimb diatremes	basinal	4 diamond-bearing pipes sampled
Lac Castignon cluster, Quebec	geologic mapping	carbonatitic diatr.	Labrador trough	untested
Arvada, Quebec	geologic mapping	kimb/carb dikes	Saguenay graben	untested
Aillik Bay, Labrador	geologic mapping	kim/lamp/carb dikes	Labrador sea rift	untested
Big Island, Saglik Bay, Labrador	geologic mapping	5 big diatreme pipes	Labrador sea rift	untested
GREENLAND				
Sissimiut area, west central	geologic mapping	kimb/lamp dikes	Labrador sea rift	untested
Holsteinsborg, central west	geologic mapping	kimb/lamp dikes	Labrador sea rift	untested

[redacted] for this table are available from Dr. Gold basinal areas, or regions of disrupted or poorly integrated drainage systems; and

(c) closely spaced aeromagnetic surveying, followed by ground magnetometer and resistivity surveys over specific targets.

In the target evaluation and characterization stage, the decision to follow up with a bulk sampling and drilling program should be positive if, after the initial mapping for size and sampling for petrographic and facies characterization, (a) "micros" totalling aproximately 0.01 carat or including at least one stone greater than 500 microns are recovered from a 50-kg large hand specimen sample;[21] (b) the host is a deep-seated variety of lamproite, such as orendite or madupite with sanidine rather than leucite as a primary phase; (c) xenoliths, xenocrysts, and megacrysts in the host contain mineral assemblages with equilibration T and P close to the shield geotherm at a depth (pressure) within the diamond stability field; and (d) Group 10, high-Cr, low-Ca pyrope garnets are present.

There remains no viable substitute to "bulk sampling" a prospect in order to determine its grade, the distribution and quality of any diamonds present, and its economic potential.

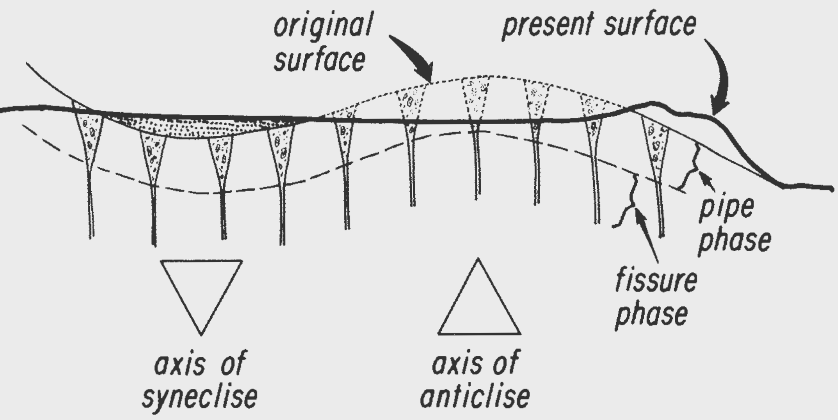

Figure 3. Model showing the relationships of kimberlite depth facies to erosion level over crustal arches (anticlises) and synclises. Stream sediment sampling for the kimberlite "sputnik" minerals (pyrope garnet, Mg-ilmenite, and chrome diopside) is an effective exploration tool only over the anticlises; it is unlikely that any alluvial diamonds in synclisal areas would have a provenance in the subjacent pipes. Fossil anticlises may be recognized as the hinge zones between basins or by gentle wedge-out unconformities.

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The Author

In addition to teaching courses in structural and economic geology in the Department of Geosciences, Dr. David P. Gold carries out research into the emplacement mechanisms and tectonic settings of alkaline rocks, kimberlites, and carbonatites. These interests stem from his undergraduate studies at the University of Natal, South Africa, and graduate work on carbonatites at McGill University in Montreal, Canada. This article represents a brief summary and the conclusion of a longer paper being prepared for a "Symposium on Diamond Exploration Methods and Strategies, with Case Histories of Recent Finds" planned for fall 1985. More information may be obtained from Dr. Gold, 307 Deike Bldg, University Park, PA 16802; phone (814) 865-3934.

Superconductivity —

Continued from first page

without the energy loss associated with the natural resistance of the material. When a superconductor is cooled to very low temperatures, it offers zero resistance to the flow of electricity and is capable of excluding magnetic fields of limited magnitude from its interior.

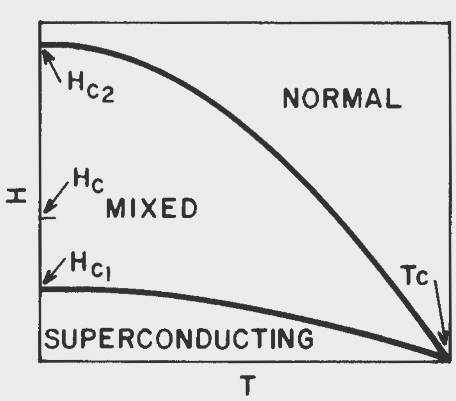

Figure 1. Type I superconductor. H_c is in the range of 10 to 10,000 oersteds; T_c is in the range of 0 to 10 K.

The History of Superconduction

Superconduction was first observed by H. Kamerlingh-Onnes[1] in 1911 just three years after he first liquefied helium, a necessary prerequisite to low temperature studies at or near 4.2 K (−269° C), the boiling point of liquid helium. He found that the electrical resistance of mercury, rather than decreasing continuously as the temperature was lowered, dropped abruptly to zero at 4.2 K, the superconducting critical temperature, T_c, of mercury. Further work showed that lead and tin lost their resistivity and became superconductors at their respective critical temperatures of 7.19 K and 3.72 K.

For some time, it was believed that superconductors differed from normal metals only in their lack of electrical resistance. Then, in 1933, Meissner and Ochsenfeld[2] found that a solid cylinder of lead in the presence of a uniform magnetic field, H, expelled the magnetic field when the sample was cooled below its critical temperature. This observation eventually led to a correct thermodynamic description of superconduction and the recognition that a phase change was occurring at T_c. Figure 1 shows a typical phase diagram for this situation. In fact, superconduction was found to be a magnetic phenomenon for which the intensive thermodynamic variables are the magnetic field, H, and the temperature, T.

In 1934, a paper by F. and H. London[3] gave an electromagnetic description of superconductors in terms of macroscopic variables—equations using variables averaged over volumes containing many atoms, as in thermodynamics. Although much effort was devoted to theoretical and experimental studies, a successful microscopic theory, in terms of individual ions and electrons, eluded researchers until 1957.

Two key observations were made in the

1950s. By measuring the T_c for different isotopes of mercury, B. Serin et al.[4] detected the dependence on mass of a superconductor's critical temperature. This indicated that the lattice structure of the superconductor was intimately involved with its electronic properties. In 1956, W. S. Corak et al.[5] carried out investigations with vanadium that indicated the existence of some type of low-temperature bound or paired state for the conduction electrons. This conclusion was based on the specific heat measurements of the vanadium in both its normal and superconducting states below the critical temperature.

In 1957, J. Bardeen, L. N. Cooper, and J. R. Schrieffer[6] published an epic paper on superconduction. For the first time, they presented a successful microscopic theory whose predictions were in reasonable agreement with the known properties of superconductors, an effort that won the 1972 Nobel prize for physics.

Type II Superconductors

All the early observations were concerned with what are now known as type I superconductors, characterized by critical temperatures in the range of 0 to 10 K and critical magnetic fields, H_c, in the range of 10 to 1000 oersteds (0.001 to 0.1 tesla). In the 1960s, superconductors were discovered that supported greater current densities and much larger magnetic fields, and these became known as type II superconductors. D. E. Kunzler et al.,[7] for example, observed superconduction in an alloy, Nb_3Sn, with current densities of up to 10^5 amperes/cm² in the presence of magnetic fields as large as 88 kilo-oersteds (8.8 tesla).

Subsequent investigations showed that, between the normal and superconducting phases, type II superconductors have a two-phase region, called the mixed state, which allows superconduction to take place in the presence of magnetic fields much above the thermodynamic limit, H_c (see Figure 2). In

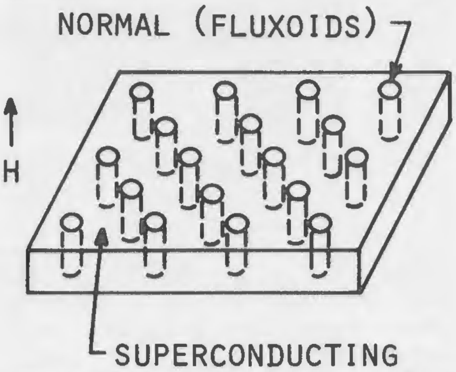

Figure 3. Type II superconductor in mixed state. Magnetic field uniform and in the vertical direction.

this region, beginning at H_{c1}, are small-diameter cylinders called fluxoids, through each of which a field of H_{c2} penetrates the superconducting material. As the magnetic field increases above H_{c1}, the number of fluxoids increases until they completely fill the sample at H_{c2}.

One might note in passing that the phase diagram of a type II superconductor apparently contradicts the Gibbs phase rule. The fluxoids of the mixed state are present because of the negative surface energy of the normal-superconductor interface. It is the presence of this negative surface energy which distinguishes type II from the type I superconductors and permits the relaxation of the Gibbs phase rule. In the mixed state, the reduction in energy of the system should be enhanced as the diameter of the fluxoids is decreased, thus increasing the surface-to-volume ratio of the fluxoids. Quantum limitations put a lower limit on the fluxoid diameter.

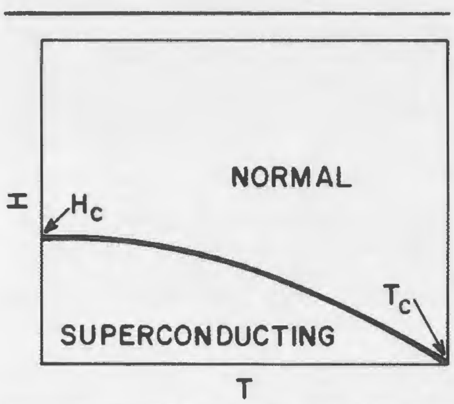

Figure 2. Type II superconductor, H_{c1} is less than H_c; H_{c2} is much greater than H_c. Maximum known H_{c2} is about 600,000 oersteds; maximum known T_c is about 23 K.

When current flows in a mixed state region penetrated by fluxoids, it can avoid the fluxoids and flow with no resistance, provided the fluxoids are stationary. However, in the presence of a magnetic field and flowing current, fluxoids are subject to a Lorenz-like force that can cause them to move and thus impede the current, leading to voltage drops and power losses. The "Lorenz" force is resisted when fluxoids interact with defects in the crystal lattice of the material such as dislocations, grain boundaries, and precipitates. This stabilizing interaction, which prevents fluxoid movement, is known as pinning. Hard type II superconductors are materials that have this fluxoid-pinning ability and thus can carry large currents, even at high magnetic fields. The critical current density is the maximum current that can be supported without raising the "Lorenz" force to a value that overcomes fluxoid-pinning stabilization.

Beyond the critical current density, the fluxoids move and although the material is still superconducting, power losses are experienced. When fluxoids move, the flowing electrons cannot avoid them; in passing through the fluxoids, which are normal regions, the usual IR voltage drop with associated I^2R joule loss occurs.

Research at Penn State

The purpose of our research here at Penn State is to learn more about the pinning mechanism in order to be able to predict the microstructure that will provide the highest resistanceless current-carrying capability.

Initially, we studied the model system of vanadium and vanadium plus vanadium-carbide in which the precipitated carbides provide the fluxoid pinning.[8,9,10] Figure 5 is a transmission electron micrograph (TEM) of pure annealed vanadium, and Figure 6 is a TEM of vanadium that has been carburized. The critical current densities are compared in Figure 7. It is obvious that the samples containing carbide can sustain much larger resistanceless currents. Our research was concerned with the detailed relationship between the critical current density, J_c, and the size and number of carbide precipitates.

More recently, our work has been directed at niobium and the niobium-zirconium alloy system in which compositions within the mixed state can be caused to react spinodally if first homogenized at high temperature.[11] This type of solid-solid reaction causes a phase separation on a scale comparable to the sizes of the fluxoids. We surmised, and later demonstrated, that such a fine microstructure provides a very effective pinning of the fluxoid lattice.

In the course of the investigation, we learned that it is very difficult to avoid oxygen contamination of the samples, and that such contamination is injurious to the superconducting properties. However, if contamination can be avoided and the alloys properly heat-treated, superior superconducting properties are achieved.

Nb-Zr was at one time used as a commercial alloy, but its use was discon-

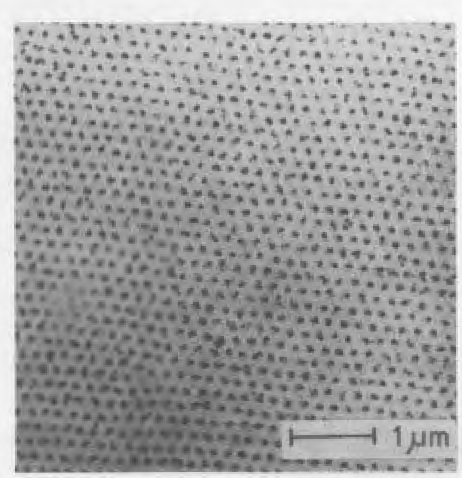

Figure 4. Surface of a superconductor in the mixed state decorated with very small iron particles to show the location of the fluxoids. (This is the analog of the familiar iron filing experiment to show the magnetic field from a permanent magnet).

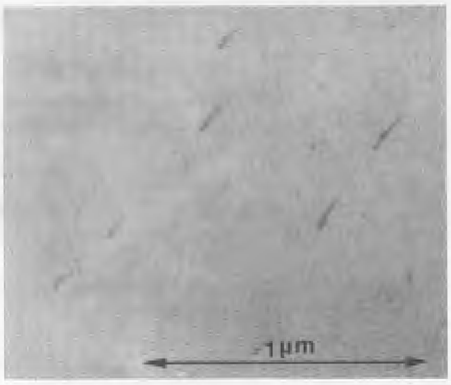

Figure 5. The annealed vanadium microstructure.

tinued, probably because of its poor workability. Our work shows that appropriate processing can improve the workability of the Nb-Zr alloys, and that proper heat treatment will produce a material with better superconducting properties than previously realized.

Many people have been involved in our studies, including Dr. R. W. Reed, a former member of Penn State's physics faculty now with United Technology Corporation, as well as several former graduate students, R. L. Schuyler III,[8,10] A. J. Marker III,[9,10] and P. J. Javier,[12] and two current graduate students, K. P. Moll and J. P. Heh.

Advantages and Disadvantages of Superconductors

The advent of type II superconductors opened the way for devices requiring high currents or the high magnetic fields obtainable from such currents.

Today, a number of superconducting type II alloys suitable for fabricating high current devices are commercially available, and superconducting magnets capable of producing fields in excess of 100,000 oersteds (10 tesla) are shelf items.

The use of superconductors in place of normal conductors has both advantages and disadvantages. The debit side is obvious and easily stated. To use superconductors, the material must be cooled down to below T_c and maintained at this low temperature. This requires capital investment in a cooling system or, as is more often the case with laboratory superconducting magnets, purchasing liquid helium needed to attain and maintain the requisite low temperature. With liquid helium costing about $5 per liter, this is not a trivial item. In one of our typical runs lasting 3 to 4 days, 100 liters—about $500 worth—of liquid helium are used.

The advantages of superconductors require a lengthier discussion. A superconductor generates no joule heat—the heat that results from resistance to the flow of an electric current. In a large electromagnet with normal conductor windings, the cooling that must be provided to remove the joule heat generated by the windings is a significant design feature and operating cost; in effect you pay for the electricity to activate the electromagnet, and then pay again for removal of the heat produced. A superconducting magnet, once excited, requires no power input to maintain the magnetic field and no heat is generated.

Because of the high current densities possible with superconductors and their lack of joule heating, many devices can be significantly reduced in size when constructed from superconductors. This can be an important advantage, as, for example, in electric motors and generators for use in ships.

The magnetic fields produced by superconductor air-core magnets are comparable in magnitude to those generated by normal conductor electromagnets with iron cores. Air-core magnets can be varied with time more readily and are easier to design so that their magnitude varies in a prescribed manner as a function of position. Thus, superconductor magnets are ideal for producing the dipole and quadrupole magnetic fields used in focusing charged-particle beams.

Superconductor Applications

In most accelerators used for high-energy physics research, the particles being accelerated are confined to their orbits in the accelerating machines by appropriate magnetic fields. An example is Fermi National Accelerator Laboratory's first high-energy superconducting synchrotron, christened the Tevatron.[13] In July 1983, it accelerated protons to an energy of 512 GeV (512×10^9 eV). As its name implies, its ultimate goal is 1 TeV (10^{12} eV) protons.

The instrument contains 774 dipole and 216 quadrupole magnets plus 204 correction coils. These all make use of superconducting windings fabricated from a niobium-titanium alloy kept at 4.8 K when in operation. Fifty tons of Nb-Ti alloy were used to fabricate the windings at a cost of $25 million.

The alloy was first formed into 1-meter-long rods 3 mm in diameter; each rod was then inserted into a hexagonal copper tube, and 2,100 of these tubes were combined into a copper cylinder with an external wall 2.54 cm thick. The cylinder was

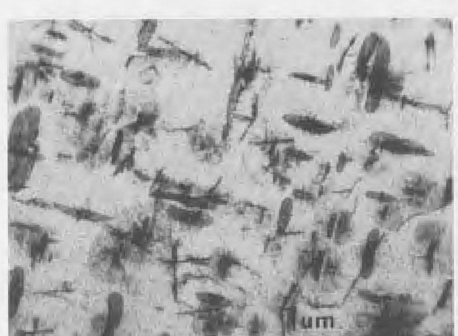

Figure 6. The microstructure observed in a radiation-cooled vanadium sample containing 0.3 atomic percent carbon.

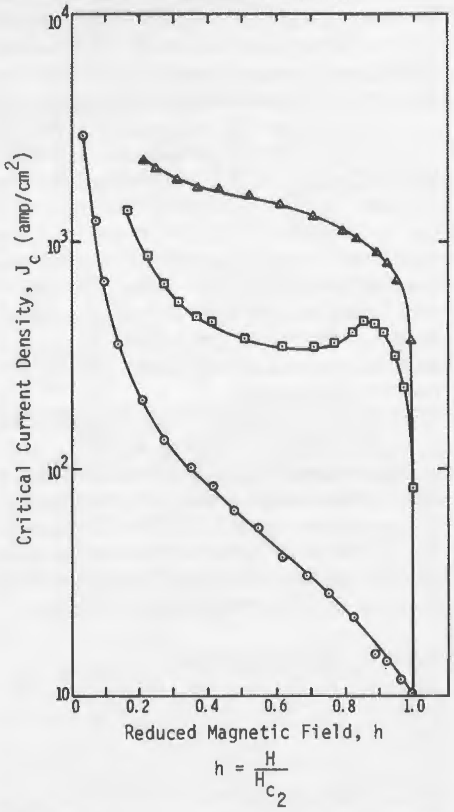

Figure 7. Critical current density as a function of reduced magnetic field for three specimens: circle — data for an annealed vanadium sample; square — data for a radiation-cooled vanadium sample containing 0.3 atomic percent carbon; and triangle — data for a radiation-cooled vanadium sample containing 0.3 atomic percent carbon which had been aged for 120 minutes at 350° C.

heated, extruded, and then drawn down to a strand 0.07 cm in diameter; each of the 2100 Nb-Ti rods became a filament about 10 µm (0.00039 inch) in diameter. Twenty-three of the strands were then twisted into the cable that was used to wind the magnets.

Other superconducting devices are being developed for electric power generation, transmission, and utilization. Efforts are under way to devise a means for using superconductors to transmit electricity over long distances with as little power loss as possible. Studies here and abroad have resulted in prototype cable systems with ac or dc capability that have already been constructed and tested. In Austria, such a system is in use in an operating power grid.[14]

Several countries, including the U.S., Germany, Japan, and the USSR, have programs aimed at developing synchronous superconductor generators. The components for both 30-MVA and 50-MVA superconducting generators have been tested in Japan and the assembled generators should be tested within the next two years.[15] In this country, General Electric Corporation has assembled and successfully tested a 20-MVA superconducting generator at its rated capacity. However, its feasibility for commercial power generation is yet to be determined by long-term continuous-operation tests.[16] GE has also designed and built a 3,000-horsepower superconducting homopolar motor for the U.S. Navy.[17]

The Bonneville Power Administration is installing a 30-MJ (8.4-kWh) superconducting magnet to smooth out low-frequency oscillations in its long-distance distribution system.[18]

A more novel application of magnetic fields generated by superconductors is the magnetic levitation of trains, which provides an almost noiseless and frictionless suspension system. Japan is probably most advanced in this area and Japanese test vehicles have already achieved speeds of up to 317 miles per hour.[19]

The use of nuclear magnetic resonance (NMR) to obtain biological measurements is an area that holds great promise for the application of superconductor alloys. NMR instruments capable of providing information similar to that obtained with the familiar CAT scan instrument have been developed. The NMR device, which subjects the patient to a magnetic field produced by a superconducting magnet, offers improved resolution over that achieved by the CAT scan.[20]

While there is not yet a large market for superconducting materials, so many applications are on the verge of becoming economically feasible that it is fairly safe to say there will be a significant market for them in the near future. With that market will come competitive pressure to develop improved superconductor alloys. As described earlier, work already in progress here at Penn State is directed toward a better understanding of the relationships between superconducting properties and the microstructure of the alloys, so that in the future the composition and processing of type II alloys can be tailored to maximize their superconducting properties.

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The Author

Dr. William R. Bitler received his B.S., M.S., and Ph.D. in physics from Carnegie-Mellon University and taught metallurgy there for several years before joining the Penn State metallurgy faculty in 1962. From 1969 to 1973, he served as chairman of the metallurgy section in the then Department of Material Sciences. His interests are in the areas of magnetic and superconducting materials, diffusion, the structure and thermodynamics of interfaces, electron microscopy, and the mechanism and kinetics of phase transformations.

The Atlas of Pennsylvania

If we are to understand America, we must understand Pennsylvania. This new publication will cover virtually every significant Pennsylvania topic that is mappable.

WILBUR ZELINSKY, *Professor of Geography*

There is an exciting new book in Pennsylvania's future! Work on the *Atlas of Pennsylvania* is already under way. Like the first-rate geographical atlases available in a handful of other states, this will be a virtual encyclopedia in graphic form — probably the single most extensive collection of information on the Commonwealth ever assembled in one publication.

The great majority of maps appearing in this volume will depict the entire state at a variety of scales and thus with varying degrees of detail. In addition, there will be a number of plates covering the Northeast or the entire country in order to show certain relationships between Pennsylvania, surrounding states, and the nation, as well as some finely-detailed maps presenting data for Philadelphia, Pittsburgh, and other metropolitan areas.

The atlas will be a single large volume containing about 280 pages, 15.5 by 13.25 inches in size. Maps, almost all in full color, will claim much of this space, but there will also be many graphs, diagrams, and tables, some photographs and remotely-sensed images, an adequate amount of text, many references, and a detailed index. Most of the drawings will be original items, compiled and designed for this project; many are to be generated on the computer using state-of-the art methods that will enable us to produce plates that are not only visually arresting, but also aesthetically pleasing and easily legible.

However handsome the packaging, it's the contents that really matter. The atlas will cover every significant Pennsylvania topic that is mappable and for which usable data can be found. The four largest sections will deal with: Pennsylvania's physical habitat; historical topics; people, society, and culture; and livelihood patterns.

The Most Comprehensive State Atlas

With its depiction of some 500 subjects, this volume will be more comprehensive than any other state atlas, including, as it will, many important, interesting topics never mapped previously in Pennsylvania, or in any state for that matter. Just a few random examples will suffice in this brief article: rural water supply and use; percentage of high school graduates who intend to enter college, by school district; location of a broad range of social services; foreign-language periodicals and radio programs; solar energy potential; cable TV territories; state and local festivals; sport stadia; zones of fan loyalty to professional teams; party registration and 1984 voting patterns by minor civil division; per-capita sales of wine and liquor; office space; solid waste dumps; registered motor vehicles by type and make; membership in voluntary organizations; industrial parks; convention halls and hotels; selected chain and franchise operations; and harvests of deer and bear.

Such innovations (and many more) are in addition to such standard subjects as energy, geology, mineral resources, climate, soils, hydrology, population traits, medical and educational facilities, housing, ethnicity, language, religion, communications, transport, agriculture, forestry, mining, wholesale and retail activity, manufacturing, land use, banking and finance, income, employment, politics, and recreation.

Five-man Editorial Committee

Work has begun on this unprecedented volume at three leading universities under the direction of a five-man editorial committee: Wilbur Zelinsky and Ronald F. Abler (Penn State); William J. Young and David J. Cuff (Temple); and Edward K. Muller (Pittsburgh). We are being assisted by a large corps of specialists who are volunteering their expertise and assembling information not available in standard sources.

Virtually every program in the College of Earth and Mineral Sciences will be contributing material to the atlas. Especially important for the project is its advisory council, 32 distinguished Pennsylvanians drawn from the worlds of business, government, labor, education and other professions, the arts, and sports.

The projected date of publication is 1987, and we estimate the total cost for compiling, drafting, editing, and printing at around $900,000. Support is being sought, and some has already been received, from federal and state agencies, the universities, and business firms and foundations based in Pennsylvania.

Among the more obvious practical applications of the atlas will be its use in planning the location and operation of various facilities by business firms and public agencies. It could also be a potent device in educating potential tourists, retirees, and movable business executives about the attractions and livability of the state. Within the academic and professional communities, geographers, historians, sociologists, demographers, biologists, geologists, agronomists, meteorologists, students of the humanities and information sciences, and many other categories of scholars will find the atlas an invaluable resource.

The experience of publishers of the better state atlases elsewhere in the U.S. suggests that the *Atlas of Pennsylvania* will also have considerable appeal for the general public, and indeed we would like to see it in many private homes.

But beyond its obvious utility as a ready source of facts and as a strategic resource for promoting Pennsylvania's economic and social well-being, publishing the *Atlas of Pennsylvania* could very well stimulate much research. By juxtaposing a variety of phenomena within the covers of a single volume, often within the same plate, this work is likely to generate new questions and novel approaches to older questions.

A Very Special Kind of Place

Beyond all the foregoing reasons for the atlas and the purposes it will serve, there is another quite compelling motive: the very special kind of place Pennsylvania happens to be. In fact, a principal justification for the project is the pivotal role the Commonwealth has played in the evolution of the United States in terms of population, culture, economy, and technology. (More than whimsy is responsible for the coinage "Keystone State.") Pennsylvania has been the seedbed, or point of entry, for some of the most crucial developments in American agriculture, transportation, mining, manufacturing, business practice, urban design, certain important religious denominations, vernacular architecture, and basic American speech. And a large share of the folks who settled the central and southern sections of the nation were born in, or passed through, the state. Thus, if we are to understand America, we must understand Pennsylvania.

For the geographer, Pennsylvania is especially intriguing because of an immense internal variety in terms of both physical and human landscapes. Indeed the range and multiplicity of mappable phenomena is such that, in many respects, Pennsylvania is the United States in microcosm.

The Author

Dr. Wilbur Zelinsky earned his B.A. and Ph.D. in geography at the University of California at Berkeley and his M.A. at the University of Wisconsin. He taught at Wisconsin, the University of Georgia, Wayne State University, and Southern Illinois University, and worked for the Chesapeake and Ohio Rail-

R. E. Newnham Receives Faculty Scholar Medal

Dr. Robert E. Newnham, professor of solid state science, has been awarded the Faculty Scholar Medal for Outstanding Achievement. The award was established in 1980 to recognize creative excellence represented by a single achievement or a series of contributions around a coherent theme.

Dr. Newnham, chairman of the University's interdisciplinary Solid State Science graduate program was honored for his pioneering work on composite materials. Since he joined the Penn State faculty in 1970, he has carried out extensive crystallographic research and, in collaboration with Dr. L. Eric Cross, professor of electrical engineering and associate director of the Materials Research Laboratory, has made significant contributions to the field of electroceramics.

Dr. Robert E. Newnham, professor of solid state science.

Dr. Newnham's work has been praised for the soundness of its theoretical base, the elegance of its reasoning and the technical creativity demonstrated in developing new materials that have wide application in electronics. He was honored specifically for his investigations into piezoelectric materials—materials that develop an electric polarity in response to mechanical stress—and ferroelectric polycrystalline materials that can be made piezoelectric. These materials are used in piezoelectric transducers which convert mechanical or acoustic signals to electric signals, and vice versa, in electronic devices.

Transducers have traditionally used lead zirconate-titanate (PZT) as the best single-phase ferroelectric ceramic material available, but since 1975 Dr. Newnham and his co-workers have been developing innovative composite materials that overcome the limitations of homogeneous solids such as PZT. By selecting materials exhibiting the required physical and electrical properties and combining them in various ways, superior new materials have been created.

Dr. Newnham has demonstrated that in composites the manner in which the materials are interconnected (connectivity) is of major importance in controlling the electric flux pattern and mechanical stress distribution. The connectivity pattern can be relatively simple, using one-dimensional chains or fibers or two-dimensional layers of fibers within a matrix, but Dr. Newnham has shown how connectivity patterns that are essentially interconnecting three-dimensional networks within the composite will offer great improvements to component performance.

This concept has sparked a revolution in the development of new piezoelectric materials engineered for specific purposes. These include sonar materials for use in underwater hydrophones and ultrasonic transducers for electromedical equipment.

Dr. Newnham holds a bachelor's degree in mathematics from Hartwick College, a master's degree in physics from Colorado State University, a Ph.D. in physics from Penn State, and a Ph.D. in crystallography from Cambridge University. Before joining the Penn State faculty, he was a research fellow at the Cavendish Laboratory in Cambridge, and a member of the faculty of the Massachusetts Institute of Technology. He is currently serving as president-elect of the American Crystallographic Association and was recently selected to be the first invited lecturer of the Science and Technology Agency of the Japanese prime minister's office. In a three-week stay in Japan, he gave lectures at the National Institute for Research on Inorganic Materials and the Institute of Physical and Chemical Research.

way Co. before joining the Penn State faculty in 1963. He was head of the Department of Geography from 1970 to 1976, and also served as director of the university's Population Issues Research Office from 1972 to 1974. He has held a number of positions in the Association of American Geographers, including the presidency in 1972-73.

News of E&MS Alumni

Heads Goddard Space Center Section

Robert Stanley ('60 B.S., GPhys & GChem) now chief of the simulations section at NASA's Goddard Space Flight Center, reports that he and his section received special recognition last summer after it served as the operations center for simulations that ultimately became the series of maneuvers that nudged the errant Tracking and Data Relay Satellite (TDRS-A) into proper orbit. The satellite, designed to usher in a new era in space communications, was deployed from the Space Shuttle Challenger on April 4, 1983, and encountered problems that kept it from reaching its planned orbit. It took the engineers 58 days to get it where it was supposed to be.

Mr. Stanley reports that NASA has been his employer for 20 years. His experience has included serving as NASA director on the ship, Huntsville, for the Apollo 10 and 11 reentries; also he has traveled to a number of remote locations throughout the world for various space-related missions.

Pennzoil Promotes PNGE Graduate

Ralph Williams ('77 B.S., PNGE) has been promoted to supervising engineer in the Midland, Texas, district office of Pennzoil Exploration and Production Company, a division of Pennzoil Company.

Alumni Deaths

Bruce F. Trumm ('40 B.S., CerEng), former administrative manager of corporate facilities at Owens-Illinois, Inc., Toledo, Ohio, died May 11, 1984.

Other deaths: *Glenn A. Winchester* ('18 B.S., MngE), Bemus Point, N.Y., August 19, 1983; *James K. Gregg* ('39 B.S., PNGE), December 23, 1983; *Edward C. Calvert* ('41 B.S., PNGE), Willowick, Ohio, November 9, 1983; *Paul W. O'Malley* ('42 B.S., Metal), Ft. Wayne, Indiana, April 25, 1983; *Jaime Amorocho* ('46 M.S., PNGE), Davis, California, November 22, 1983.

College News Notes

Gordon Reports on Federal Study

Dr. Richard L. Gordon, professor of mineral economics, reported to a number of coal industry and other groups last spring on the recommendations made by the Commission on Fair Market Value Policy on Federal Coal Leasing of which he was a member. Also, he and other members of the commission testified before committees in both houses of Congress.

The commission, which began its work amid much-publicized controversy that led to the resignation of James Watt as Secretary of the Interior, went on, according to Dr. Gordon, "in what proved to involve a continually tumultuous process, to complete its report to the satisfaction of both the majority of the commission and numerous outside critics.

"Ultimately," he says, "the report presented strong criticism of the management of coal leasing under James Watt and his key associates in the coal leasing area. It was further suggested, for various reasons, including the need to insure that each lease offering is more carefully appraised, that coal leasing schedules for 1984 and 1985 be lower than Watt proposed.

"However, the report," he points out, "also indicated that coal leasing is 'in the national interest' and devoted most of its recommendations to suggestions that the Secretary of the Interior could take to improve the implementation of the policy."

Serves on Short Course Faculty

Dr. Earle Ryba, associate professor of metallurgy, lectured and taught both laboratory and recitation sections of 21st annual short course on X-ray powder diffraction given at the State University of New York at Albany early this summer. He serves on the permanent faculty of the short course which covers the entire range of X-ray powder diffraction principles and applications.

Roy Holds AAAS Post

Dr. Rustum Roy, professor of the solid state and director of Penn State's Materials Research Laboratory, is currently serving as chairman of the Chemistry Section of the American Association for the Advancement of Science. The AAAS, which serves as a collective professional society for the scientific community in the U.S., is organized into some dozen discipline-oriented sections and cross-disciplinary units.

Dr. Roy was recently elected to the Indian National Science Academy as a Foreign Fellow.

Ramani Participates in APCOM Conference

Dr. R. V. Ramani, professor of mining engineering, participated recently in the 18th International Symposium on the Application of Computers and Mathematics in the Mineral Industries (APCOM), held at the Imperial College of Science and Technology in London, England. He is chairman of the APCOM International Council.

He directed a conference session on "Underground Mining—Underground Environment"; delivered the closing address of the symposium; and presented a paper, "Information Systems Management for Mineral Management," co-authored by R. L. Frantz, head of the Department of Mineral Engineering.

The University is a permanent member of the APCOM council and will host the 19th international symposium in 1986.

Visiting Scientist from Spain

Carmen Pascual, a research scientist with the Instituto de Ceramica y Vidrio of the Consejo Superior de Investigaciones Cientificas in Madrid, Spain, is spending two years working in the College of Earth and Mineral Sciences.

Her primary interest is in high-temperature ceramic materials, and she is conducting research with Dr. V. S. Stubican, professor of ceramic science and engineering.

The two graduates of the College of Earth and Mineral Sciences who received Penn State's Distinguished Alumnus Awards in June are shown at the conclusion of the awards ceremony with Dr. C. L. Hosler, center, dean of the college. They are Thomas M. Krebs, left, 1949 metallurgy graduate, and George E. Trimble, right, 1942 petroleum and natural gas engineering graduate.

Two E&MS Graduates Honored by University —

Continued from first page

ploration and production company with interests in natural gas and geothermal steam in addition to crude oil and petroleum products.

He joined Reynolds Industries in 1976 following a distinguished career in international operations with Exxon Corporation. For 20 years, he held management positions in Latin America and the Middle East, serving as executive vice president and board member of Exxon's Libyan affiliate, and subsequently becoming deputy general managing director of the Iranian oil consortium, the highest ranking American corporate position in Iran. He has also been active in civic and community affairs and served on the Industry Advisory Committee to the Reagan administration on a study of alternative energy sources.

A total of 29 of the college's alumni have now received Distinguished Alumnus Awards, 16 percent of the total number awarded, while E&MS alumni represent only 4 percent of the total alumni body.

Five Faculty Promoted

Five members of the E&MS faculty received promotions as of July 1. They were: *to professor* — Dr. Rodney A. Erickson, geography, and Dr. K. Osseo-Asare, metallurgy; *to associate professor* — Dr. Bruce A. Albrecht, meteorology, Dr. Tarasankar Deb Roy, metallurgy, and Dr. Mark A. Klins, petroleum and natural gas engineering.

Dean on Planning Committee

Dr. C. L. Hosler, dean of the College of Earth and Mineral Sciences, is serving on a 14-member University Planning Advisory Committee appointed by Penn State's president, Dr. Bryce Jordan, to help develop a strategic planning program for the University.

Among other tasks, the committee will set a timetable for the planning process, reexamine University goals, and prepare comprehensive planning guidelines for all teaching, research, and service units.

New Books by Faculty Members

Dr. E. Willard Miller, professor emeritus of geography and associate dean emeritus for resident instruction in the College of Earth and Mineral Sciences, and his wife, Ruby M. Miller, former map librarian at Pattee Library, are the co-authors of a four-volume bibliography, *Industrial Location and Planning*. The bibliography was prepared for the Commission on Industrial Systems of the International Geographical Union and was published by Vance Bibliographies. Both American and international sources are cited among the more than 2,500 references. The four volumes cover "Theory, Models and Factors of Localization"; "Localization, Growth and Organization"; "Regions and Countries"; and "Industries."

Dean Miller is also co-editor with Dr. S. K. Majumdar of Lafayette College, of a book, *Hazardous and Toxic Wastes: Technology, Management and Health Effects,* published by the Pennsylvania Academy of Science. Two members of the E&MS faculty were among the contributors to the book—**Dr. Richard R. Parizek** and **Dr. Robert Schmalz,** both professors of geology.

Dr. Z. T. Bieniawski, professor of mineral engineering, is the author of a textbook, *Rock Mechanics Design in Mining and Tunneling,* published this summer by A. A. Balkema, Rotterdam, Netherlands. As the first engineering design text to be developed specifically for the graduate engineer specializing in rock mechanics aspects of mining and tunneling, the book is expected to find a wide audience among mining, civil, and geological engineers at universities and in industry.

Dr. Craig F. Bohren, associate professor of meteorology, and Dr. Donald R. Huffman, professor of physics at the University of Arizona, are the authors of a book, *Absorption and Scattering of Light by Small Particles,* published recently by Wiley-Interscience. It is an interdisciplinary study approached from the perspective of the physicist, and contains examples and applications drawn from astrophysics, atmospheric physics, and biophysics. Included are three computer programs for calculating absorption and scattering by homogeneous spheres, coated spheres, and infinite cylinders.

Dr. Hans A. Panofsky, Evan Pugh professor emeritus of atmospheric sciences, and **Dr. John A. Dutton,** professor and head of the Department of Meteorology, are co-authors of *Atmospheric Turbulence—Models and Methods for Engineering Applications,* published earlier this year by John Wiley & Sons, Inc., as a Wiley-Interscience Publication. The book has two primary purposes: to serve as a summary of the current knowledge of the statistical characteristics of atmospheric turbulence, and as an introduction to methods required to apply these statistics to practical engineering problems.

Dr. Chi U. Ikoku, associate professor of petroleum and natural gas engineering from August 1982 to August 1983, is the author of a textbook, *Natural Gas Production Engineering,* published recently by John Wiley & Sons, Inc. Dr. Ikoku has returned to Nigeria to assume family responsibilities following the death of his father, and is now head of the petroleum engineering department at the University of Port Harcourt, Nigeria. His text is a systematic treatment of the technology of the production and transportation of natural gas.

C. D. Stahl Retires after 37 Years on PNGE Faculty; Turgay Ertekin Succeeds Him as Section Chairman

Dr. C. Drew Stahl, left, has retired as professor emeritus of petroleum and natural gas engineering, and has been succeeded as chairman of the PNGE Section by Dr. Turgay Ertekin, associate professor, right. Dr. Stahl joined the faculty in 1947, while Dr. Ertekin became assistant professor in 1978.

Dr. C. Drew Stahl, chairman of the Petroleum and Natural Gas Engineering Section in the Department of Mineral Engineering, retired June 30 as professor emeritus of petroleum and natural gas engineering.

Succeeding him as section chairman is Dr. Turgay Ertekin, associate professor of petroleum and natural gas engineering, a member of the faculty since 1978.

Dr. Stahl, a member of the faculty for 37 years, had headed the PNGE program since 1960 and had seen it grow from 36 students in 1962 to its present enrollment of about 400 undergraduates and 20 graduate students. He took a strong interest in undergraduate teaching, and, in 1981, received the Matthew J. and Anne C. Wilson Outstanding Teaching Award of the College of Earth and Mineral Sciences.

During his tenure, the program's course offerings more than doubled to reflect technical changes in the field, there was increasing emphasis on simulation methodology and tertiary oil recovery methods, and practical laboratory instruction greatly expanded.

His own research interests were focused on fluid flow and displacement in porous media, particularly as these relate to water-flooding recovery of oil. He was active also in research on the application of tertiary recovery methods to oil deposits in Pennsylvania.

First appointed to the University staff as a research assistant in 1947, he holds three degrees in PNGE from Penn State, having received his Ph.D. in 1954.

He always maintained close ties with PNGE alumni, and worked to foster cordial relations between the PNGE program and industry. His efforts gained considerable industry support for the program and for scholarships for its students. He will continue to be active in the cultivation of industrial support, and do some undergraduate teaching.

Dr. Ertekin received his B.S. and M.S. from the Middle East Technical University, Ankara, Turkey, and his Ph.D. at Penn State in 1978, all in petroleum and natural gas engineering. He served on the staff of the Ankara university for five years before coming to the U.S. He teaches advanced courses in reservoir modeling and analysis, and well testing and evaluation, and received the college's Wilson Outstanding Teaching Award in 1982. His main research interests are in mathematical modeling, computer simulation techniques, and tertiary oil recovery. Also, together with mining faculty members, he has carried out investigations into methane flow in coal.

He is co-author of a book, *Gas Well Testing: Theory, Practice and Regulations,* and numerous papers and articles. He has been an active member of the Society of Petroleum Engineers, was a member of the organizing committee for a NATO advanced study institute on heavy oil recovery held in Ankara, and has given lectures and short courses in Turkey and Latin America as well as the U.S.

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