GEOLOGY OF ALTERNATE ENERGY RESOURCES

HOUSTON GEOLOGICAL SOCIETY

MICHAEL D. CAMPBELL

INTRODUCTION

Oil and gas reserves are declining nationwide at an alarming rate. Alternate energy resources such as uranium, coal (including lignite), and geothermal energy must play dominant roles in the American economy in the near future. Fortunately, alternate energy resources are regionally abundant in the United States and if developed with appropriate consideration to the environment, they will serve to bridge the gap between our present petroleum-based energy systems and future solar or fusion-based energy systems (Newell, 1976). It is clear that a diversified multiple-energy base must be developed to serve our regional energy needs well into the twenty-first century (Campbell, 1976).

The south-central states were once endowed with abundant oil and natural gas resources. But, as domestic supplies begin to dwindle and as the economic incentive for producers to develop oil and natural gas deteriorates, energy consumers must now begin to seriously consider substitute sources of energy to satisfy the region's future energy requirements. However, any major industrial change-over to other energy sources will require years of planning, evaluation, research, exploration and development before they can adequately meet our energy and raw materials requirements; hence there can be no further delay.

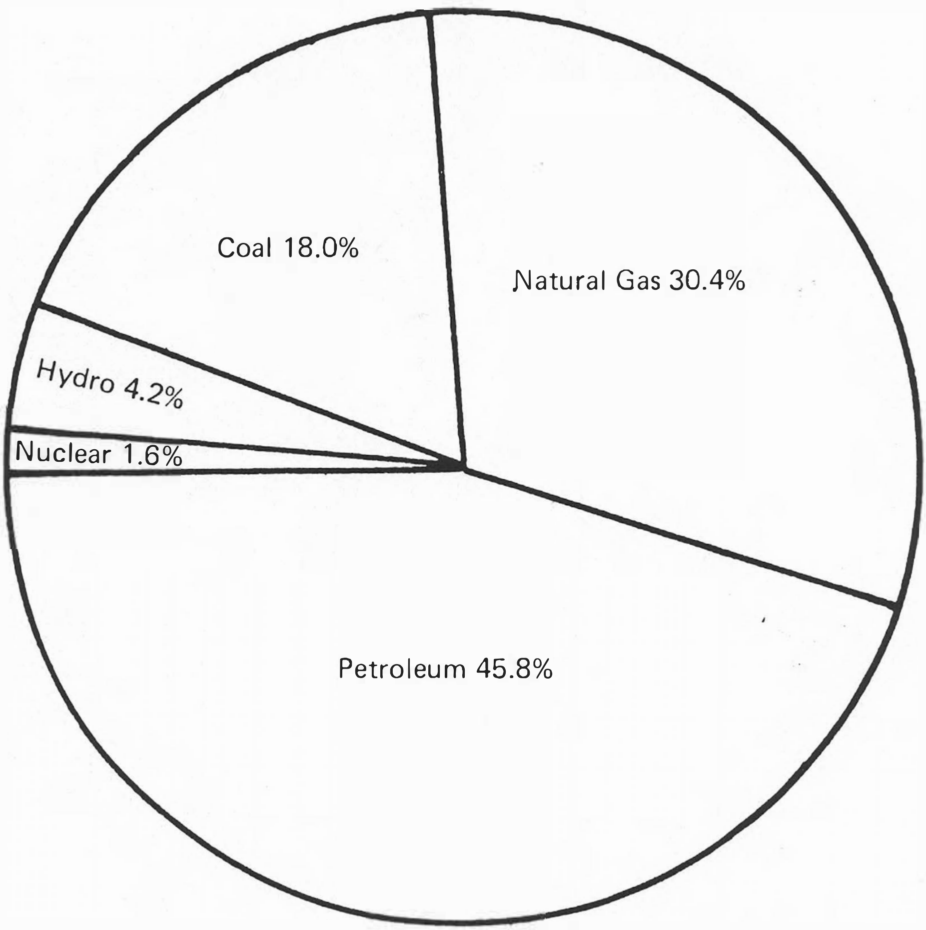
The South-Central United States is well endowed with alternate energy resources in the form of uranium, coal (lignite), and geopressured geothermal energy. This volume presents a review of what may become the region's major sources of energy in the foreseeable future, and is intended to be a state-of-the-art analysis of the total spectrum of regional energy resource assessment. Although regional in scope, the techniques of assessment and the developmental approaches explored in this text have significant application to other regions of the United States as well as to other nations.

Each of the three alternate energy resources (uranium, coal (lignite) and geopressured geothermal energy), will be examined in terms of the four factors involved in resource assessment: 1) New (Frontier) areas of exploration, 2) Known (Trend) areas of exploration and development, 3) Resource development or utilization, and 4) Environmental considerations affecting the development of the resource. A Selected Bibliography is included to augment the technical coverage of each of the three resources examined. As an introduction to the chapters that follow, a brief summary of the present domestic energy picture is presented to emphasize the manifest need for alternate energy resources and the role that the South-Central United States can play in meeting that need.

As of 1974, the United States consumed approximately 73 quadrillion (10^{15}) Btu, of which petroleum supplied 45.8%; natural gas 30.4%; coal (including lignite) 18.0%; hydropower and geothermal energy 4.2%; and nuclear power 1.6% (Figure 1). Energy consumption is growing domestically at an average rate of approximately 5.0% per year, but the growth rate is expected to decline slowly to approximately 3.0% per year in the next few decades. The Federal Energy Administration (FEA) conservatively estimates that the nation's total energy needs 16 years

ENERGY CONSUMED IN THE UNITED STATES BY SOURCE IN 1974

(Consumption 73.1 quadrillion Btu)



U.S. Department of Interior News Release, April 3, 1975

FIGURE 1.

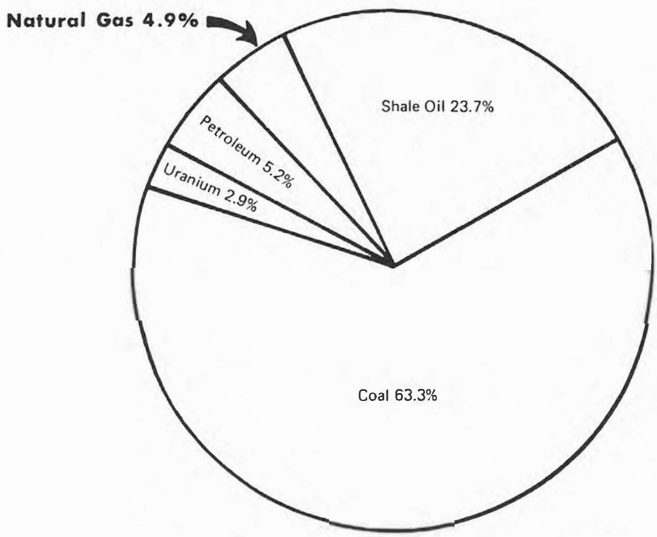
hence (1990) will increase to 112 quadrillion Btu, or about 53% more than the Btu consumed in 1974 (U.S. Dept. Interior, 1975). Presumably, this estimate assumes no change in standards of living or present levels of energy waste.

Federal estimates, in an attempt to place these requirements in perspective, have suggested that the total energy *available* from domestic fossil and nuclear fuels is approximately 55.6 quintillion (10^{18}) Btu (Figure 2). These estimates, however, although based on the most reliable data available at the time, included only a conservative view of available energy from conventional sources. As will be indicated in this text, the potential for additional energy resources (in the South-Central United States, at least) is excellent.

The Federal estimates show that domestic reserves of coal (not including the full potential of available lignite) contribute more than 60% of the potentially available energy. If used solely for energy production, coal alone could supply energy for more than 300 years at the 1990 Btu consumption rate. Ranking second in Federal estimates of potential is oil shale and sands, although no significant production has yet been achieved because of technical problems (Pforzheimer, 1976). Such resources have an uncertain role in the overall energy picture, although the Federal government has supported a reasonable research and development effort over the past five years.

Sources Of Energy For Future Needs In The United States

Total available energy is estimated at 55.6 x 10^{18} Btu



Federal Power Commission "National Gas Survey," 1974

FIGURE 2.

Placed in the above framework, the estimates show that petroleum and natural gas account for only 10% of the total potential energy available from fossil fuel, although together they currently supply more than 75% of the total energy consumed (compare Figures 1 and 2). It should be clear then that we are presently overutilizing our most limited resources (oil and gas) and underutilizing our most abundant immediate resources, uranium, coal (lignite) and geothermal energy.

The overemphasis on oil and gas as the most important forms of energy evolved from the economically sound choice of those resources that were most easily converted to Btu. However, disproportionate utilization of resources has not only caused overdevelopment of our own and foreign prime energy resources (oil and gas), it has also made us increasingly dependent on foreign oil-producing countries for a substantial part of our energy needs. Any change in industrial and societal habits is difficult, especially in terms of our use of energy, and we are presently beginning to experience the normal effects of an open, capitalistic economic system. What we pay for energy depends on supply and demand. If the supply of a particular energy source is short, not only will the price be relatively high but there will also be no assurance that it will continue to be supplied, especially if we resist, via the media and our representatives in Washington, paying the price of either domestically or foreign-produced energy. If there is no alternative, there is also no choice.

Superimposed on this assumed natural system of supply and demand economics is the significant political influence which has strongly affected the development and over-exploitation of our prime energy source and has prevented the development of alternate energy sources. Although Washington "politics" have been responsible for creating many of the obstacles and restraints to the natural development of an open supply-and-demand system (Winger & Nielsen, 1976), the energy industry has, in the course of pursuing the free enterprise system, naturally attempted to maximize profit potential by developing the most economic source of energy. If a demand is present, industry will endeavor to meet that demand at a price that the energy consumer will pay; however, because of past governmental restraints on prices, energy consumers are presently faced with prices they are unwilling to but must pay because they have no present alternative in their consumption patterns. The development of alternate energy sources has not been considered a viable economic venture until recently. As energy prices escalate, new sources of energy naturally become economically viable. A source once economically unattractive to develop may become feasible, if an economic advantage is defined. The early signs of industrial diversification of interest in a multiple-energy base have been apparent for the past few years (see Figure 3). This is a natural development, although since we have failed to diversify earlier, the interim period of industrial and societal adjustment will be plagued with short supplies of conventional energy and relatively high prices, which will continue to rise.

The role of government in this period of diversification should be two-fold. First, in an attempt to assist the industrial sector, the government should foster cooperative research and development of all potential alternate energy sources. At present industry does not have the economic incentive to evaluate or develop a particular potential energy source because of unclear governmental requirements. Secondly, government, in representing the consumer, should also protect society against industrial abuses of the environment and bring into balance

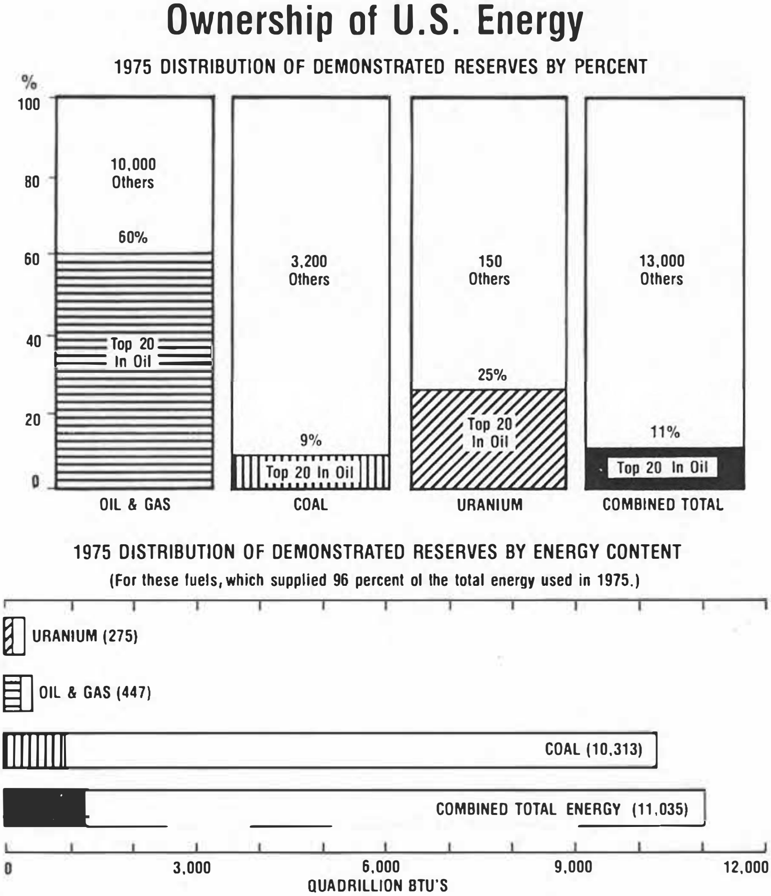


FIGURE 3. Distribution of ownership of energy reserves by percent and by energy content showing role of the top twenty petroleum companies as of 1975 in the energy field, including oil and gas, coal and uranium. (After U. S. Dept. Interior, *Energy Perspectives 2,* 1976; U. S. Bureau Mines; Keystone Coal Industry Manual, U. S. Coal Production by Company, 1975; Society of Petroleum Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers.)

environmental costs and benefits. In addition, society should be protected against possible violations of antitrust laws that undermine the natural, free enterprise system of supply and demand. Rapid industrial development has provided jobs and opportunities to produce the greatest economic growth and highest living standard in history, but this accomplishment has had its price, a price consumers have not been willing to pay; consequently, degradation of our environment and natural resources has occurred.

As has been witnessed, however, abuses of government via unreasonable environmental and pricing regulations have created an adversary relationship between government and industry in many areas. The perspective of the "happy medium" has been lost over the past few years. Government, in attempting to represent the people and the so-called objective overview, has not only grown in power, purportedly to match the powerful efforts of big industry and to protect us from ourselves, but has by doing so also dampened industrial enthusiasm to venture into new areas of energy development with innovative ideas and financial support.

Although the problems of energy development are complex, in the final analysis, industry's prime objectives are: 1) to make a profit and 2) to serve the people by anticipating their future needs. Without the collective support of the public, however, the energy industry, as we know it today, will not survive the difficult years of diversification and readjustment ahead. The arrival of plentiful, inexpensive energy from fusion or other sources may be at least 25 years in the future. The "tug and pull" of industrial development with environmental consciousness is a natural phenomenon and to be expected in a complex, open society. Although not readily apparent to some, history will surely show that progress is under way and a regionally-diversified, multiple-energy base of nuclear power, coal, and geothermal energy will be developed, and within a socially-cognizant free-enterprise system.

Nuclear Energy Potential. Nuclear power will play an increasingly significant role in nationwide electrical generation. The apparent lack of available domestic uranium resources is one of the major problems that is presently confronting the nuclear-power generating industry. If the other technical and environmental problems regarding nuclear-reactor safety (Doctor and others, 1976) and plutonium-handling (Feivesion and others, 1976, and Anonymous, 1976) are satisfactorily resolved for nuclear development (Anonymous, 1976), the present cycle of construction of light-water reactors will require substantial uranium reserves until the breeder reactor becomes operational, probably in the late 1990's (Energy Resources Council, 1976). If and when the breeder reactors become operational, they will utilize the partially consumed uranium from the light-water reactor fuel cycle to produce an additional 70 quintillion (10^{18}) Btu, or 14 quintillion Btu more that the 1974 estimates of the total *available* domestic energy and more than twice the Btu available from the present estimates of coal resources (see Figure 2).

The present need, however, is to stock the light-water reactors that are either presently in operation, under construction, or planned for the near future (see Figure 4). As mentioned earlier, the nuclear development program has proceeded cautiously over the past few years since potential environmental and technical safeguards associated with reactor safety and plutonium-handling have slowed construction in an attempt to resolve the pending questions. Voter referendums, however, on the public question of nuclear development were approved by a 2-1 margin in six states (Anonymous, 1976b). The public, therefore, has indicated that energy alternatives are necessary.

As of the present time, nuclear power has assumed approximately 9.8% of all domestic electrical production, well above previous expectations. In 1974, for example, approximately 6.0% of all electrical generation was produced by light-water nuclear power plants. Until recently, the exploration and producing companies have not had sufficient economic incentive to respond to staggering projected demands, and even now the uranium exploration and

	Thousands of Megawatts	Number of Plants
Under ERDA Enrichment Contract		
Licensed to operate	43	61
Construction permit granted	77	72
Under construction permit review	67	60
Ordered	14	12
Announced	7	6
	208	211
Not Under ERDA Enrichment Contract		
Construction permit granted	1	1
Under construction permit review	6	5
Ordered	7	6
Announced	18	15
	32	27

FIGURE 4. Status of U.S. nuclear power plants as of August 31, 1976 (Parks and Thomas - 1976).

producing companies are hesitant to gear-up too rapidly because they are aware that uranium is a "political" mineral and overexpansion could be a dangerous financial risk (Anonymous, 1976). The rapidly expanding uranium market (Boyden, 1975) has helped to cause serious financial problems for one overly aggressive producer (Anonymous, 1975); other producers have become wary of increasing mining costs and of foreign uranium producers (Anonymous, 1976d; Macgregor and Vickers, 1974). The need for new uranium resources is certain and the South-Central United States may provide a significant percent of the needed uranium reserves, both from new uranium ore bodies and from mining by-products of phosphate (Ross, 1975; Anonymous, 1977).

In Part I of this text, the geological and other technical factors in uranium exploration are examined from the regional (frontier) and the local (trend) viewpoint in Chapters 1 and 2, respectively. Uranium development is explored in Chapter 3 in terms of *in situ* or subsurface solution mining, a method of growing popularity with industry and environmental regulatory agencies. Chapter 4 discusses the position of the U. S. Environmental Protection Agency with regard to the environmental impacts of uranium mining. Chapter 5 is the "Selected Uranium Bibliography." It should be noted that the selected publications appearing in Chapter 5 (and Chapters 10 and 15) do not appear in the previous chapters. The topical bibliography covers recent and background topics on uranium of possible peripheral interest.

Coal (Lignite) Energy Potential. Coal has obviously long been a conventional source of energy. Its widespread use, however, was eclipsed by oil and gas three decades ago when oil and gas became the dominant forms of energy for domestic consumption. Coal production declined, but with the early shock of short domestic supplies of oil and natural gas, coal production again began to climb. Although vast amounts of coal are presently used for steam production, a significant amount is also necessary for use in industrial processes other than energy production. Metallurgical coal is used in steel manufacturing and other industries where high-carbon materials are required.

In the past few years, coal, especially lignite, has been considered for use in the production of synthetic fuels, such as low-Btu gas, pipeline-quality gas, refinery feedstock and solvent-refined products that could be economically attractive substitutes for the decreasing supplies of oil and natural gas (Anonymous, 1976e; Hendrickson, 1975). The extent of resources of the relatively low-Btu lignite in the South-Central United States was not realized until recently, although large reserves of the resource have been known in the North-Central United States for over 40 years and have been included in Federal estimates of total available energy. South-Central resources may be capable of adding 20 quadrillion (10^{15}) Btu to the total available domestic energy reserves.

Substantial resources exist and may serve two additional functions by substituting for conventional sources of energy and by providing by-products (as energy sources for large- or small-scale power generation and as feedstocks for the chemical industry's use in the manufacture of plastic and asphaltic products). The economic viability of lignite utilization is still under study by industry but development seems to be imminent to meet either the needs of a new synthetic fuel industry, the needs of minemouth power-plant complexes (if found to be economic and environmentally cognizant) or the needs of the chemical industry.

In Part II of this text, Chapter 6 discusses the geological and other technical factors involved in regional lignite exploration and project development. Chapter 7 examines some of the local geological characteristics of lignite. Lignite utilization is discussed in Chapter 8 in terms of *in-situ* or subsurface gasification of lignite. Chapter 9 is a summary of the environmental aspects of lignite mining and related potential environmental problems of lignite utilization. Chapter 10 is the "Selected Lignite Bibliography," which includes additional publications of possible interest.

Geopressured Geothermal Energy Potential. A giant energy resource may exist that has received little attention until recently and has certainly not been included in Federal estimates of total available energy. Known western geothermal regions have experienced a slow but steady history of technological development over the past few decades. New geothermal discoveries outside the well-known Geysers area have been made recently and new geothermal electrical generating plants are in the planning stages (Keplinger, 1976).

In the South-Central United States, recent estimates have been made that suggest that the subsurface geopressured brines alone may be capable of producing 100 quadrillion (10^{15}) Btu from the heat content of the produced brine. In addition, natural gas may be in saturated solution and if present could contribute an additional 500 quadrillion (10^{15}) or more Btu of recoverable energy (Brown, 1976).

Geopressured geothermal energy may indeed be a sleeping giant among alternate energy resources. Its development is directly related to petroleum engineering and technology, and with present or near-term technology, the resource may become economically recoverable. However, further evaluations must indicate favorable economics and technology. The apparent problems regarding environmental and institutional factors must also be favorably resolved.

In Part III of the text, Chapter 11 deals with the frontier or regional potential of geopressured geothermal energy and the geological factors and exploration techniques involved. Chapter 12 explores the techniques of local evaluation of prospective geopressured geothermal trend areas. Chapter 13 is a review of the potential utilization of the geopressured geothermal resource. Chapter 14 is an analysis of the environmental aspects of the development of the resource. Chapter 15 is the "Selected Geopressured Geothermal Bibliography," which also includes recent publications on the subject of additional interest.

Although many geological, engineering, environmental, and institutional problems are apparent, the development of the alternate energy resources of the South-Central United States as explored in this text could significantly add to the total available energy resource of the United States. But, before nuclear, fossil fuel or geopressured geothermal energy can be fully developed and utilized, the resources first must be located via many of the geological techniques discussed in this text. And, before the resources can be used on a broad scale, the environmental aspects must be evaluated to assure that the safety and well-being of society will not be negatively affected. This effort also involves many of the geological techniques of evaluation that are treated in the following chapters. Although the exploration and development of the three resources involve many unique approaches and techniques, all three are natural resources that first require geological assessment, hence the importance of a solid geological foundation in alternate energy development and the supporting need for *Geology of Alternate Energy Resources in the South-Central Unites States.*

March, 1977
Houston, Texas

Michael D. Campbell
Editor

REFERENCES

Anonymous, 1975, Westinghouse: The waiting period: Forbes, December 1, pp. 24-26.

Anonymous, 1976a, Efforts at nuclear disposal made: Oilweek, September 13, pp. 32, 36, 40.

Anonymous, 1976b, Can Carter debottleneck nuclear power?: Chemical Week, November 17, pp. 17-18.

Anonymous, 1976c, Overplayed hand?: Forbes, September 15, pp. 53-54.

Anonymous, 1976d, The uranium dilemma: Why prices mushroomed: Business Week, November 1, pp. 92, 97.

Anonymous, 1976e, Why coal gasification is leaving the West: Business Week, September 13, pp. 76J-76O.

Anonymous, 1977, Recovery plant go-ahead for Uncle Sam: Mining Week, January 7, pp. 5-6.

Boyden, T. A., 1975, The marketing of uranium, *In* Colorado Mining Association Yearbook, pp. 110-113.

Brown, W. M., 1976, A huge raw reserve of natural gas comes within research: Fortune, October, pp. 219-222.

Campbell, M. D., 1976, Alternate energy and mineral development: General outlook and comparative economics: A paper presented at the 1976 Keplinger Energy Seminar, University Club, New York City, November 23, 30 pp.

Doctor, R., and others, 1976, The California nuclear safeguards initiative: Sierra Club Bulletin, vol. 61, no. 5, May, pp. 4-6, 44-46.

Energy Resources Council, 1976, Uranium reserves resources and production: NTIS PB-254-896, June, 14 pp.

Feiveson, H. A., and T. B. Taylor, 1976, Security implications of alternative fission futures: Bull. Atomic Scientists, vol. 32, no. 10, December, pp. 14-17.

Hendrickson, T. A., 1975, Synthetic Fuels Data Handbook, Cameron Engineers, Inc. Colorado, pp. 161-231.

Keplinger, C. H., 1976, OPEC oil price enhances U. S. geothermal development: World Oil, August.

Macgregor, W., and E. L. Vickers, 1974, Capital and the U. S. resources crunch: Eng. Mining Journ., Reprint R-209, 6 pp.

Newell, G. 1976, Hydrogen fusion shows promise of becoming ultimate energy source: Oilweek, September 13, pp. 22, 26, 28.

Parks, J. W., and D. C. Thomas, 1976, Plans for operating enrichment plants and the effects on uranium supply: Uranium Industry Seminar, U. S. ERDA, Grand Junction, October 19-20.

Pforzheimer, H., 1976, Commercial development of oil shale: forecast goes from cloudy to bleak: Eng. Mining Journ., vol. 177, no. 8, August, pp. 81-83.

Ross, R. C., 1975, Uranium recovery from phosphoric acid nears reality as a commercial uranium source: Eng. Mining Journ., December, pp. 80-85.

U. S. Department of Interior, 1975, Energy perspectives, February, 12 pp.

Winger, J. G., and C. A. Nielsen, 1976, Energy, the economy and jobs, *In* Energy Report from Chase, September, 8 pp.

Contributors

DONALD G. BEBOUT

Dr. Bebout received a Bachelor of Science degree (1952) from Mount Union College, Alliance, Ohio, a Master's degree (1954) in geology from the University of Wisconsin, and a Ph.D. degree (1961) from the University of Kansas. During the period 1961-1973, Dr. Bebout was employed by Exxon Production Research Company in Houston as Research Geologist. Since 1973 he has been a Research Scientist with the Bureau of Economic Geology, University of Texas at Austin and in a joint appointment with the Department of Geological Sciences, University of Texas. Dr. Bebout has conducted research and published on subsurface Cretaceous carbonates, Texas Gulf Coast geology, and geopressured geothermal potential of Tertiary rocks in the Texas Gulf Coast area. He is a member of the Geological Society of America; American Association of Petroleum Geologists; Society of Economic Paleontologists and Mineralogists, and other societies. For further information, see *American Men and Women of Science* (13th Edition).

KEVIN T. BIDDLE

Mr. Biddle received a Bachelor of Science degree (1973) in earth sciences from the University of California at Santa Cruz and a Master's degree (1976) in geology from Rice University. He is presently completing his Ph.D degree (1978) at Rice. Previous industrial experience includes a period with the U. S. Geological Survey and intermittent private consulting assignments on uranium and lignite exploration. He is a member of the Society of Economic Paleontologists and Mineralogists, the Geological Society of America and a junior member of the Society of Mining Engineers (AIME). His publications include papers on recent marginal marine sedimentation and clastic sedimentology. His areas of research interest include carbonate and clastic diagenesis and uranium genesis.

EDWARD J. CALHOUN

Mr. Calhoun received a Bachelor of Arts degree (1974) in geology from Franklin and Marshall College, Lancaster, Pennsylvania. During the period 1974-1975 he was employed by Consolidation Coal Company in Shreveport as Project Geologist and in 1975 joined General Crude Oil Company in Houston as Exploration Geologist. Mr. Calhoun is a member of the Houston Geological Society and the Geological Society of America.

MICHAEL D. CAMPBELL

Mr. Campbell received a Bachelor of Arts degree (1966) in geology from The Ohio State University and a Master's degree (1976) in geology from Rice University. Following the Bachelor's degree, Mr. Campbell worked in Australia and Southeast Asia for the Continental Oil Company (Australia) Ltd., Minerals Exploration Department, as Staff Geologist on phosphate, potash, uranium and other projects. In 1970, he joined Teton Exploration Division, United Nuclear, Inc. in Casper, Wyoming as District Geologist. During the period of 1971-1976, Mr. Campbell was a Geological Consultant based in Columbus, Ohio and as of 1973, was located at the Department of Geology, Rice University, in Houston. He has been involved in a wide range of research and international and domestic projects on strata-bound minerals (uranium, coal and lignite, and industrial minerals), and ground-water geochemistry, exploration, development, pollution control, rural-water systems engineering and subsurface waste-injection systems for private and public companies, the U. S. Environmental Protection Agency, U. S. Office of Water Resources Research, Washington, D. C. and the National Water Well Association, Columbus, Ohio. In 1976, Mr. Campbell merged his consulting practice with Keplinger and Associates, Inc. He is a Certified Professional Geological Scientist (formerly AIPG), and a member of the Society of Mining Engineers (AIME) and other societies. Mr. Campbell has presented numerous lectures and papers on clastic sedimentology and diagenesis, shallow drilling, ground water, mineral and alternate energy exploration, development and pollution control. He is a member of the Editorial Board of the journal *Ground Water*. In 1976, Mr. Campbell was appointed as a United Nations Technical Expert to review overseas ground-water and mineral exploration programs. For further information see *American Men and Women of Science* (13th Edition).

GARY F. COLLINS

Mr. Collins received a Bachelor of Science degree (1973) in geology from the University of Wyoming.