

Pearson New International Edition

Earth Resources and the Environment

James R. Craig David J. Vaughan

Brian J. Skinner

Fourth Edition

Pearson New International Edition

Earth Resources and the Environment
James R. Craig David J. Vaughan
Brian J. Skinner
Fourth Edition

PEARSON®

Pearson Education Limited

Edinburgh Gate
Harlow
Essex CM20 2JE
England and Associated Companies throughout the world

Visit us on the World Wide Web at: www.pearsoned.co.uk

© Pearson Education Limited 2014

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without either the prior written permission of the publisher or a licence permitting restricted copying in the United Kingdom issued by the Copyright Licensing Agency Ltd, Saffron House, 6–10 Kirby Street, London EC1N 8TS.

All trademarks used herein are the property of their respective owners. The use of any trademark in this text does not vest in the author or publisher any trademark ownership rights in such trademarks, nor does the use of such trademarks imply any affiliation with or endorsement of this book by such owners.

PEARSON®

ISBN 10: 1-292-04099-8
ISBN 13: 978-1-292-04099-8

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

Printed in the United States of America

Table of Contents

Glossary	
James R. Craig/David J. Vaughan/Brian J. Skinner	1
1. Introduction and the Origins of Resources	
James R. Craig/David J. Vaughan/Brian J. Skinner	15
2. Minerals: The Foundations of Society	
James R. Craig/David J. Vaughan/Brian J. Skinner	19
3. Plate Tectonics and the Origins of Resources	
James R. Craig/David J. Vaughan/Brian J. Skinner	35
4. History and Environmental Impact of Resource Usage	
James R. Craig/David J. Vaughan/Brian J. Skinner	57
5. Earth Resources Through History	
James R. Craig/David J. Vaughan/Brian J. Skinner	61
6. Environmental Impacts of Resource Exploitation and Use	
James R. Craig/David J. Vaughan/Brian J. Skinner	91
7. Energy	
James R. Craig/David J. Vaughan/Brian J. Skinner	137
8. Energy from Fossil Fuels	
James R. Craig/David J. Vaughan/Brian J. Skinner	143
9. Nuclear and Renewable Energy Sources	
James R. Craig/David J. Vaughan/Brian J. Skinner	203
10. Metals	
James R. Craig/David J. Vaughan/Brian J. Skinner	253
11. Abundant Metals	
James R. Craig/David J. Vaughan/Brian J. Skinner	257
12. The Geochemically Scarce Metals	
James R. Craig/David J. Vaughan/Brian J. Skinner	291

13. Fertilizer, Chemical, Construction, and Industrial Resources James R. Craig/David J. Vaughan/Brian J. Skinner	343
14. Fertilizer and Chemical Minerals James R. Craig/David J. Vaughan/Brian J. Skinner	345
15. Building Materials and Other Industrial Minerals James R. Craig/David J. Vaughan/Brian J. Skinner	371
16. Water and Soil for Life Support James R. Craig/David J. Vaughan/Brian J. Skinner	411
17. Soil as a Resource James R. Craig/David J. Vaughan/Brian J. Skinner	413
18. Water Resources James R. Craig/David J. Vaughan/Brian J. Skinner	435
19. Future Resources James R. Craig/David J. Vaughan/Brian J. Skinner	489
Appendix: Calendar of Earth Resources Events James R. Craig/David J. Vaughan/Brian J. Skinner	501
20. Units and Conversions James R. Craig/David J. Vaughan/Brian J. Skinner	509
21. Geochemical Abundances of Selected Elements in Earth's Crust James R. Craig/David J. Vaughan/Brian J. Skinner	511
22. Earth Statistics James R. Craig/David J. Vaughan/Brian J. Skinner	513
23. Geologic Time Scale James R. Craig/David J. Vaughan/Brian J. Skinner	515
24. Color Plates James R. Craig/David J. Vaughan/Brian J. Skinner	517
Index	533

GLOSSARY

abundant metals: Metals with a geochemical abundance of at least 0.1 percent in Earth's crust.

acid mine drainage: Waters issuing from an active or abandoned mine that are made strongly acid by the decomposition of sulfide minerals, usually pyrite, FeS_2 .

acid rain: Rainfall that is abnormally acid; generally attributed to the presence of nitrous and sulfur oxide pollutants in the atmosphere.

acre foot: The volume of water required to cover one acre to a depth of one foot; 325,900 gallons; 1,233,500 liters.

activated charcoal: Highly absorbent charcoal produced by heating granulated charcoal and used to absorb gases or dissolved substances, especially gold.

adit: A horizontal tunnel serving as an entrance into a mine.

age-sex pyramids: Diagrams that display the distribution of population in terms of age and sex.

aggregate: Any hard, inert construction material (e.g., sand, gravel, crushed stone) used in the preparation of concrete or as a road bed.

alchemy: The medieval science of chemistry, one objective of which was to transform base metals into gold; another was to discover a universal cure for disease and a means of indefinitely prolonging life.

Algora-type: A type of banded iron formation whose formation can be attributed to submarine volcanic exhalation.

alkali feldspars: A series of silicate minerals involving solid solution from KAlSi_3O_8 (potash feldspar, orthoclase) to $\text{NaAlSi}_3\text{O}_8$ (albite).

alkalinization: The buildup of salts of calcium, sodium, and potassium in soils due to evaporation.

alloy: A substance composed of two or more metals or a metal and a nonmetal.

alluvial fan: A low gently sloping cone-like accumulation of sediment that has been deposited where a stream issues from a mountain valley onto a plain.

alluvium: Unconsolidated sediments deposited by running water.

alpha particle: A subatomic particle, having an atomic weight of 4 and a +2 charge (equivalent to a helium nucleus), released during radioactive disintegration.

alumina: An oxide of aluminum, Al_2O_3 , which has numerous uses in the chemical industry and as an abrasive.

amalgamation: The formation of alloys of precious metals, generally gold, with mercury; usually done as a means of capturing small grains of the precious metal.

amorphous: A material without a regular crystal structure.

anaerobic digestion: The breakdown of organic material by microorganisms in the absence of oxygen.

andalusite: A mineral, composition Al_2SiO_5 ; widely used in the manufacture of ceramics and glasses.

andesite: An intermediate fine-grained igneous rock rich in plagioclase feldspar.

anhydrite: A mineral, composition CaSO_4 ; an evaporite mineral.

anion: A negatively charged atom.

annealing: The process of holding materials at high temperatures, but below their melting points, in order to change their physical properties such as brittleness and machinability by causing changes in the sizes and shapes of individual grains.

anorthosite: An igneous rock composed almost entirely of the mineral plagioclase feldspar.

anthracite: Coal of the highest rank, usually with a carbon content of 92–98 percent.

apatite: A mineral with the general formation of $\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{OH}, \text{Cl})$, that constitutes a major source of phosphorous.

aplite: A light-colored, fine-grained igneous rock consisting largely of quartz and potassium feldspar.

aqueduct: A channel built to convey water from one place to another.

aqueous: Of, or pertaining to, water.

aquifer: A rock formation that is water-bearing.

artesian well: A well in which the water level rises above the level of the water table because it is under pressure in a confined aquifer.

asbestos: A general term applied to any of a group of fibrous silicate minerals that are widely used for industrial purposes because they are incombustible, nonconducting, and chemically resistant.

asbestosis: Chronic lung inflammation caused by prolonged inhalation of asbestos particles.

asphalt: Naturally occurring thick hydrocarbon or a similar material prepared by refining petroleum and used to bond mineral fragments in blacktop road surfaces.

asphaltene: A solid, noncrystalline black hydrocarbon residual of crude oils or other bitumen.

assay: The test of the composition of an ore or numeral, usually for gold or silver.

atmosphere: The mixture of gases that surrounds Earth; composed approximately of 79 percent nitrogen, 20 percent oxygen, 1 percent argon, and 0.03 percent carbon dioxide and variable amounts of water vapor.

atmospheric inversion: The abnormal condition in which a layer of warmer air overlies a layer of cooler air.

atomic substitution: The substitution of one element for another on the lattice sites in a crystalline solid.

attapulgite: (= palygorskite); a clay mineral of composition $(\text{Mg}, \text{Al})_2\text{Si}_4\text{O}_{10}\text{OH}\cdot 4\text{H}_2\text{O}$.

azonal soil: In U.S. classification systems, one of the three soil orders that lack well-developed horizons and that resemble the parent materials.

backfill: Rock debris, usually derived from mining or mineral processing, that is placed in mined-out areas of a mine.

ball clay: A light-colored, highly plastic, organic-containing refractory clay used in making ceramics; so named because of the early English practice of rolling the clay into balls approximately 35 centimeters (14 inches) in diameter for storage and shipping.

banded iron formations: The largest iron deposits. Sedimentary rocks consisting of alternating bands of iron oxide minerals, iron silicates, and silica; also called banded jaspilite and itabirite.

banded jaspilite: A synonym for banded iron formations.

barite: A mineral, composition BaSO_4 ; a heavy, soft mineral widely used in oil drilling muds and as a filler in paints, papers, and textiles.

basalt: A dark, fine-grained igneous rock composed chiefly of plagioclase feldspar, pyroxene, and olivine.

base cation: Cations such as Ca^{2+} , Mg^{2+} , K^+ , Na^+ .

base metal: Generally any nonprecious metal, but used today to refer to the metals such as copper, lead, zinc, mercury, and tin that are neither precious nor used as ferro-alloy metals.

batholith: A large intruded mass of igneous rock generally with a surface exposure of greater than 100 square kilometers (25 square miles) and usually composed of medium- to coarse-grained rocks.

bauxite: The principal ore of aluminum; a mixture of amorphous and crystalline hydrous aluminum oxides and hydroxides.

benches: Level, shelf-like areas in open-pit mines, where ore and waste rocks are extracted.

beneficiation: The process of producing a concentrate of valuable ore minerals through the removal of valueless gangue minerals.

bentonite: A soft, plastic, porous, light-colored rock consisting of colloidal silica and clay and that has the possibility of absorbing large quantities of water; forms as a result of the weathering of volcanic ash.

beta particle: A high-energy electron released during radioactive decay.

biochemical oxygen demand (BOD): The amount of oxygen required by microorganisms in natural waters of a river, stream, or lake.

biodegradation: The consumption and breakdown of lighter fractions of petroleum residue by bacteria.

biofuels: Fuels that generate energy either directly from organic materials or from secondary products made from biological materials.

biogenic gas: Gas formed as a result of bacterial action on organic matter.

biomass: The total amount of living organisms in a particular area, expressed in terms of weight or volume.

biosphere: The living sphere, encompassing all living species from the highest points on mountains to the deepest parts of the ocean.

biotite: Dark mica of composition $\text{K}(\text{Mg},\text{Fe})_3[(\text{Al},\text{Fe})\text{Si}_3\text{O}_{10}(\text{OH})_2\text{F}_2]$.

bittern: A solution, such as seawater, that has been concentrated by evaporation until salt, sodium chloride, has begun to crystallize; bitterns typically contain high magnesium contents.

bitumen: A general term applied to dark-colored liquid to plastic hydrocarbons such as petroleum and asphalts.

bituminous coal: High-rank black coal containing 75–92 percent carbon; commonly contains several percent volatile gases.

black granite: A commercial term used to describe a variety of dark colored rocks used in construction or decoration; many are not true granites.

black smoker: A sea floor vent issuing hot fluids, which on mixing with seawater precipitate very fine-grained sulfide minerals that look like black smoke.

blast furnace: A furnace in which the combustion of the fuel is intensified by a blast of air; usually used to smelt iron.

block caving: A mining method in which a large mass (block) of ore is undermined and then fractured by blasting and allowed to collapse under its own weight. The ore is removed in a series of tunnels cut beneath the ore zone.

blowout: An oil or gas well in which very high pressures encountered during drilling were sufficient to force the drill out the top of the drill hole; this usually results in the fountaining of oil, gas, and water as a gusher.

bog iron deposits: Accumulations of soft, spongy hydrous iron oxides that form in bogs, swamps, shallow lakes, and soil zones.

boghead coal: A coal composed primarily of algal debris.

borax: A mineral, composition $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$; a light-colored compound formed during the evaporation of alkaline lakes; widely used in the preparation of soaps, glasses, ceramics, and other materials.

brass: An alloy of copper with zinc.

brazing: The process of soldering with copper and zinc alloys.

breccia: A coarse-grained clastic sedimentary rock composed of angular rock fragments set in a finer-grained matrix; also said of any type of rock that has been highly fractured by igneous or tectonic processes.

breeder reactor: A nuclear reactor that produces more fissionable material than it consumes.

brimstone: A common and commercial name for sulfur.

brine: Seawater that, due to evaporation or freezing, contains more than the usual 3.5 percent dissolved salts.

British thermal unit: See BTU.

bronze: An alloy of copper with tin.

Bronze Age: The period in the development of a people or region when bronze replaced stone as the material used to make tools and weapons.

brown ores: Brown-colored iron ores consisting of a mixture of amorphous and crystalline iron hydroxides.

BTU: British thermal unit, the energy required to raise 1 pound of water 1°F.

building stone: A general term applied to any massive dense rock suitable for use in construction.

by-product: Something produced in the making of something else.

cable-tool drill: A method of drilling in which the cutting bit is attached to a long steel cable. Cutting is accomplished by the bit being raised and dropped again and again.

calcining: The roasting of limestone to drive off CO₂ to make lime, CaO.

calcite: CaCO₃; a common mineral and the principal constituent of limestone.

caliche: A layer of calcite that forms in soils in arid and semi-arid regions as a result of the evaporation of calcium-bearing groundwaters.

calorie: A unit of energy defined as the energy required to raise the temperature of 1 gram of water 1°C.

cannel coal: A compact sapropelic coal consisting primarily of spores accumulated in stagnant water.

caprock: An impervious body of anhydrite and gypsum with minor sulfur and calcite which overlies a salt dome.

capture: The process by which an atom's nucleus absorbs a high-energy particle.

carat: A common term with two meanings. First, a standard unit, 200 milligrams, for weighing precious stones; second, a term used to define the purity or fineness of gold and meaning one twenty-fourth. Pure gold is 24 carat.

carbon cycle: The cyclical movement of carbon compounds between the biosphere, lithosphere, atmosphere, and hydrosphere.

carbon footprint: The carbon dioxide generated, and usually released into the atmosphere, by the energy consumed by a person or process on a daily or yearly basis.

carbonation: A chemical weathering process in which carbon dioxide dissolved in water converts oxides of calcium, magnesium, and iron into carbonates.

carbonatite: A carbonate rock of apparent magmatic origin; commonly a host for rare-earth elements.

cartel: A combination of independent business organizations formed to regulate production, pricing, and marketing of goods by the members.

cassiterite: A mineral, composition SnO₂; the most important ore of tin.

catagenesis: Physical and chemical changes intermediate between near-surface diagenesis and deep burial metagenesis; used especially in reference to organic matter.

catalysis: Acceleration of a chemical reaction by an element or compound that is not incorporated in the reaction products.

catalyst: A substance that accelerates a chemical reaction without remaining in the reaction products.

catalytic cracking: The use of catalysts to break heavier hydrocarbons into lighter ones.

cation: A positively charged ion.

cation exchange: The exchange of one cation for another, especially by clay minerals.

cement: A binding material. *See* portland cement.

cement rock: A limestone with a sufficient clay content that it becomes cement upon calcining.

chain reaction: Where one reaction leads on to further reactions; a controlled chain reaction occurs in a nuclear reactor; an uncontrolled chain reaction occurs in a nuclear weapon.

chalcopyrite: Mineral, CuFeS₂, which is a major source of copper.

channelization: The straightening, and sometimes deepening and lining, of a stream or river channel so that the water flows more rapidly; commonly used to alleviate flooding.

chelation: The retention of a metallic ion by two or more atoms of a single organic molecule.

chemical flooding: The injection of chemicals into an oil well to promote the release of oil trapped in the rocks.

chemical weathering: The process of weathering by which chemical reactions convert the original minerals into new mineral phases.

china clay: A commercial term for kaolin used in the manufacture of chinaware.

chlorofluoromethane: Compounds such as CFC₁₃, used as propellants in aerosol cans, and which can damage the ozone layer in Earth's upper atmosphere.

chromite: A mineral, composition FeCr₂O₄; the principal ore mineral of chromium.

clastic: An adjective describing rocks or sediments composed of fragments derived from preexisting rocks.

clay: A term with two common meanings. First, a natural rock with fragments smaller in diameter than 1/256 millimeters; second, any of a group of hydrous sheet structure silicate minerals.

cleavage: The general tendency of a mineral or rock to split along natural directions of weakness.

Clinton type: A fossiliferous sedimentary iron ore rich in hematite and goethite of the Clinton or correlative formations in the Silurian sandstones of the eastern United States.

clod: A lump of soil produced by artificial breakage such as plowing. *See* ped.

coal: A combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous matter derived from accumulated plant remains.

coalification: The process by which plant material is converted into coal.

coke: A combustible material consisting of the fused ash and carbon of bituminous coal, produced by driving off the volatile matter by heating in the absence of oxygen.

col: An old British term for coal.

cold-working: Shaping of metals at room temperature by hammering or rolling; a process that hardens and strengthens the metal.

comminution: The process of crushing and grinding ores in order to break ore minerals loose from the valueless gangue minerals.

concentrate: Ground and beneficiated product that consists of one or more ore minerals that have been selectively removed from the original mixture of ore and gangue minerals.

concrete: A construction material consisting of pebbles, sand, or other fragments in a cement matrix.

conduction (of heat): The process by which heat is transferred by molecular impact without transfer of matter itself. The principal manner by which heat is transmitted through solids.

cone-of-depression: The depression in the water table that develops around a well from which water is being pumped.

confined aquifer: An aquifer bounded above and below by impermeable beds.

conglomerate: A coarse-grained clastic rock composed of coarse rounded fragments set in a finer matrix.

consumption (of water): The use of water such that it is not returned to the groundwater or surface water source from which it was drawn.

contact metamorphism: The thermal, and sometimes introduced, chemical effects occurring in a rock resulting from the intrusion of an adjacent igneous body.

continental shelf: That portion of the continental margin that lies between the shoreline and the continental slope.

convection: The movement of material, gaseous or liquid, wherein the hotter portion rises and cooler portions descend as a consequence of differences in density.

convert (metallurgical): The process of passing oxygen through a molten mass of sulfides in order to convert iron sulfides into iron oxides so that the iron may be more readily separated from the slag.

corundum: A mineral, composition Al_2O_3 ; the second hardest mineral after diamond. In clear, colored crystals, it is known as sapphire or ruby if blue or red, respectively.

cracking: The process by which heavier hydrocarbons are broken into lighter ones.

critical mass (in a nuclear reaction): The amount of uranium required to maintain a chain reaction in a nuclear reactor.

critical(ity) (in a nuclear reactor): The condition at which a nuclear reactor is maintained in order to sustain a chain reaction.

crosscut: Passageways of a mine that are cut perpendicular to the long dimension of the deposit.

crushed rock: Any rock material that has been crushed for use as fill, for road beds, or for construction aggregate.

crushing (of rock): The process of breaking rock into smaller fragments to facilitate the separation of the ore minerals from the gangue.

cupellation: The process of freeing silver or gold from base metals by using a small bone ash cup, called a cupel, and lead.

dam: A barrier built across a river or stream to hold back water.

decay (radioactive): Spontaneous, radioactive transformation of one nuclide to another.

deoxyribonucleic acid: DNA, the substance within the chromosomes of living cells that carries hereditary instructions and directs the production of proteins.

depletion allowance: A tax deduction on mineral resources initiated as an incentive for the producers to explore for new deposits to replace the present materials being depleted.

desalinization: *See* desalting.

desalting: Process by which dissolved salts are removed from water.

desertification: The expansion of desert-like conditions as a result of natural climatic changes or human-induced activities such as overgrazing or farming.

deuterium: An isotope of hydrogen containing one proton and one neutron in its nucleus.

diagenesis: Physical and chemical changes that occur in a sediment after deposition, and during and after lithification, but not including weathering or metamorphism.

diamond: A cubic form of carbon; the hardest mineral, widely used in jewelry and as an industrial abrasive.

diaspore: A mineral, composition $AlO(OH)$; a light-colored compound that occurs in bauxite.

diatomite: A rock or unconsolidated earthy material composed of accumulated siliceous tests of diatoms; single-celled marine or freshwater plants.

dimension stone: Building stone that is quarried and shaped into blocks according to specifications.

diorite: Igneous rocks generally composed of amphibole, plagioclase, pyroxene, and sometimes minor amounts of quartz.

direct shipping ore: Ore of sufficiently high grade that it can be profitably shipped to a smelter without first requiring beneficiation.

dispersed sources: Multiple widely separated sources of pollutants (e.g., automobiles).

distillation (or fractionation): The process of separating crude oil into various liquids and gases of different chemical and physical properties.

dolomite: A mineral, composition $CaMg(CO_3)_2$; a common sedimentary carbonate mineral; also commonly, but incorrectly, used to refer to a rock composed of dolomite.

dolostone: A rock composed of dolomite.

doping: The process of introducing trace amounts of an element into another element or compound to produce desirable electrical or other properties.

doré bar: The mass of gold and silver bullion recovered from the refining of ores.

dredging: The excavation of ore-bearing or waste materials by a floating barge or raft equipped to bring up and process, or transport, the materials.

- drifts:** The passageways of a mine that are cut parallel to the long dimension of a deposit.
- dry steam:** Natural geothermal systems dominated by water vapor (steam) with little or no liquid in the system.
- dunite:** A rock composed nearly entirely of olivine.
- electroplating:** The process using electrical current to deposit a coating of a metal on another substance.
- emery:** A granular mixture of corundum and varying amounts of iron oxides (magnetite or hematite); used as an abrasive.
- energy:** The capacity to do work.
- equivalent rainfall:** The amount of water, including rainfall and runoff, to which an area of land is subjected.
- erosion:** Removal of material by chemical or physical processes.
- eutrophication:** The process by which waters become deficient in oxygen, due to an increased abundance of dissolved nutrients and decaying plant matter.
- evaporation:** The process by which water is converted from a liquid to a vapor.
- evaporite:** Sedimentary rocks that form as a result of the evaporation of saline solutions.
- evapotranspiration:** The transfer of water in the ground to water vapor in the atmosphere through the combined processes of evaporation and transpiration.
- exchange:** The process by which a mineral, especially a clay, gives up one cation bound to its lattice for another cation in solution.
- exchange capacity:** The quantitative ability of a mineral to exchange ions with a solution.
- exfoliation:** The process by which thin concentric shells or flat layers of a rock or mineral are successively broken from the outer surface of a larger rock.
- face:** The wall in a mine where ore is being extracted. To remove the ore, holes are drilled into the face; those are filled with explosives and detonated to break the rock so that it can be removed.
- fast breeder reactor:** A nuclear reactor in which fuel is made or "bred" in a blanket of ^{238}U wrapped around the core.
- fast reactor:** Nuclear reactor that utilizes high-velocity neutrons to maintain the chain reaction in enriched fuel rods.
- fault:** A surface or zone of rock fracture along which there has been displacement.
- feldspar:** A group of abundant rock-forming minerals of the general formula $\text{MAl}(\text{Al,Si})_3\text{O}_8$, where M is K, Na, Ca, Ba, Rb, Sr.
- feldspathoid:** A group of aluminosilicate minerals of sodium, potassium, or calcium and having too little silica to form feldspar.
- ferric:** Referring to the oxidized form of iron, Fe^{3+} .
- ferro-alloy metal:** Any metal that can be alloyed with iron to produce a metal with special properties.
- ferromagnesian mineral:** Iron- and magnesium-containing minerals.
- ferromanganese:** An alloy of iron and manganese used in iron smelting.
- ferromanganese nodules:** Rounded, concentrically laminated masses of iron and manganese oxides and hydroxides that form on the floors of oceans and some lakes.
- ferrosilicon:** A synthetic phase FeSi used in the steel industry as a means of removing oxygen from iron and steel during smelting.
- ferrous:** Referring to the reduced form of iron, Fe^{2+} .
- fertilizer:** Natural or synthetic substances used to promote plant growth.
- filler:** A mineral substance added to a product to increase the bulk or weight, to dilute expensive materials, or to improve the product.
- fire clay:** A siliceous clay, rich in hydrous aluminum silicates, capable of withstanding high temperatures without deforming; hence, used in the manufacture of refractory cements.
- fission (nuclear):** The process by which a heavy nuclide is split into two or more lighter nuclides by the addition of a neutron to the nucleus.
- fissure:** A surface or fracture in rock along which there has been distinct separation.
- flint:** A dense, fine-grained form of silica, SiO_2 , that was commonly used in the making of stone tools and weapons.
- fluid inclusion:** Small droplet of fluid trapped within a crystal during initial growth or during recrystallization.
- fluorite:** A mineral, composition CaF_2 ; a common and variably colored substance widely used in the preparation of glasses, the manufacture of hydrofluoric acid, and the smelting of aluminum.
- fluorspar:** An alternate name for fluorite.
- flux:** Any substance that serves to promote a chemical reaction; also, the number of radioactive particles in a given volume of space multiplied by their mean velocity.
- fly ash:** Fine particulates that are formed during the burning of fossil fuels, especially coal.
- forsterite:** A mineral, composition Mg_2SiO_4 ; a member of the olivine series of minerals.
- fossil fuel:** A general term for any hydrocarbon deposit that may be used for fuel—petroleum, natural gas, coal, tar, or oil shale.
- fractional crystallization:** Crystallization process in igneous rocks that results in progressive changes in the composition of the remaining magma.
- fractionation:** See distillation.
- Frasch process:** A method of sulfur mining in which superheated water is forced down a well to melt sulfur that is then pumped to the surface for recovery.
- fuel element (or fuel rod):** The long rod-like assemblies that contain the U_3O_8 pellets used as fuel in a nuclear fission reactor.
- fulgerite:** Sand fused by a lightning strike.
- fuller's earth:** A fine-grained earthy substance (usually a clay) possessing a high-absorptive capacity; originally used

in fulling woolen fabrics, the shrinking and thickening by application of moisture.

fulling: The process of removing grease from organic fibers.

fusion (nuclear): The combination of two light nuclei to form a heavier nucleus; a reaction accompanied by the release of large amounts of energy.

gabbro: A dark-colored, coarse-grained igneous rock composed primarily of plagioclase feldspar, pyroxene, and olivine.

galena: A mineral, PbS, that serves as the major source of lead.

galvanizing: The coating of zinc placed on iron or steel to prevent rusting.

gangue: A general term for the nonuseful minerals and rocks intermixed with valuable ore minerals.

garnet: A group of minerals of general formula $A_3B_2(SiO_4)_3$, where A = Ca, Mg, Fe^{2+} , and Mn^{2+} and B = Al, Fe^{3+} , Mn^{3+} , and Cr.

garnierite: Low grade nickel ore formed by the weathering of nickel-bearing igneous rocks.

gasohol: A mixture of gasoline and alcohol used as a fuel for automobiles.

geochemical balance: The distribution of chemical elements and chemical compounds among various types of rocks, waters, and the atmosphere.

geochemical cycling: The cyclical movement of chemical elements through Earth's lithosphere, hydrosphere, and atmosphere.

geopressured zone: A rock unit in which the fluid pressure is greater than that of normal hydrostatic pressure.

geothermal energy: Useful heat energy that can be extracted from naturally occurring steam, or hot rocks or waters.

geothermal field: An area where there is the development, or potential development, of geothermal energy.

geothermal gradient: The rate of increase in temperature in the earth as a function of depth; the average is 25°C per kilometer.

geyser: A natural hot spring that intermittently ejects water or steam.

glass: Solid supercooled liquid that does not contain a regular structure.

Global 2000 Report to the President: A large report on the status of the world's resources, population, and environment from 1975 to 2000 prepared for President Carter in 1980.

gneiss: A coarse-grained, layered metamorphic rock.

goethite: The hydrated ferric oxide mineral, $FeO\cdot OH$.

gossan: The iron oxides and hydroxides that form when iron sulfides are exposed to weathering at or near Earth's surface.

grade: The content of a metal or a mineral in a rock; usually expressed as a percentage by weight for most ores.

granite: A coarse-grained igneous rock consisting mainly of quartz and potassium feldspar, usually accompanied by mica, either muscovite or biotite.

granodiorite: A coarse-grained igneous rock consisting mainly of quartz, potassium feldspar, plagioclase, and biotite.

graphite: A mineral, composition C; a soft, black compound with a pronounced cleavage, widely used as a lubricant.

gravel: A general term for both naturally occurring and artificial ground rock particles in the size range 2–20 millimeters in diameter.

greenhouse effect: The warming of Earth's atmosphere brought about by an increase in the CO_2 content.

greensand: A foundry sand consisting of a mixture of silica, clay, and water.

guano: Accumulated bird or bat excrement; mined locally as a source of fertilizer.

gusher: An oil or gas well in which the high pressures encountered during drilling are sufficient to cause fountaining of the oil, gas, and accompanying water at the surface.

gypsum: A mineral, composition $CaSO_4\cdot 2H_2O$; formed by evaporation of seawater and used to make plaster of Paris.

Haber-Bosch process: A process perfected in Germany in the early 1900s in which nitrogen from Earth's atmosphere is fixed into ammonia so that it can be used in fertilizers and chemicals.

half-life (of an isotope): The time required for half of the quantity of a naturally radioactive isotope to decay to a daughter product.

halite: A mineral, NaCl, and the most abundant material dissolved in seawater.

heap leaching: A process by which a solvent, such as a cyanide solution or an acid, is allowed to percolate through a pile (or heap) of crushed rock to dissolve out a valuable mineral resource (such as gold or copper).

hectorite: A calcium, sodium, magnesium, lithium clay mineral formed as a result of the weathering of volcanic rock.

heliostat: An assemblage of mirrors programmed to automatically track the Sun in order to constantly focus the sunlight on a central receiver.

hematite: A mineral, composition Fe_2O_3 ; an important ore mineral used as a source of iron, as a polishing powder, and a cosmetic (rouge).

high-level waste: Radioactive waste that is more than one million times more radioactive than the level considered environmentally acceptable.

high-quality energy: Energy derived from solar radiation where the temperature is more than 100°C .

homogeneous reactor: A nuclear reactor in which the fuel and moderator are intimately mixed.

horsepower: A unit for measuring power, originally derived from the pulling power of a horse. The rate at which energy must be expended in order to raise 55 pounds at a rate of one foot per second.

hot dry rock: Potential geothermal area in which rocks near Earth's surface are hot enough to yield useful heat energy, but where there are no natural fluids to bring the heat to the surface.

humic coals: Coal derived from peat by the breakdown of plant matter by organic acids.

- humus:** The generally dark, more or less stable part of the organic matter of the soil so well decomposed that the original sources cannot be identified.
- hydration:** The process by which water is chemically bound in a chemical compound.
- hydraulic mining:** The use of high-pressure jets of water to dislodge unconsolidated rock or sediment so that it can be processed.
- hydroelectricity:** Electricity generated by water-driven turbines.
- hydrogenation:** A chemical process in which hydrogen is added to complex hydrocarbons to yield less complex molecules that have a higher H to C ratio.
- hydrograph:** A diagram recording the relationship between time and the quantity of water leaving a drainage basin.
- hydrolysis:** A chemical process by which a compound incorporates water into its structure.
- hydrometallurgy:** Process that makes use of aqueous solutions to extract metals.
- hydro-mulching:** The application of a soil covering to prevent evaporation and erosion by means of a high-pressure hose.
- hydro-seeding:** The application of seed to barren soil surfaces by means of a high-pressure hose.
- hydrosphere:** The waters of Earth.
- hydrothermal alteration:** Mineralogic changes in rocks resulting from interactions with hydrothermal solutions.
- hydrothermal (fluids) solutions:** Hot, aqueous solutions, some of which transport and deposit ore minerals.
- hydrothermal vein/deposit:** Mineralized zone or ore that was precipitated in a fracture or fault by hot water solutions.
- igneous:** A term applied to a rock or mineral that has solidified from magma.
- ilmenite:** A mineral, composition FeTiO_3 ; a principal ore mineral of titanium.
- impermeable:** Referring to a rock, sediment, or soil that does not permit the passage of fluids.
- inclines (in mines):** Drifts or shafts in mines that are at an angle to the horizontal.
- index of weathering:** Ratio of an element in a secondary mineral to the total amount of that element in a soil.
- industrial mineral:** Any rock, mineral, or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels, and gem stones.
- inertial confinement:** A means of confining the plasma in a fusion nuclear reactor.
- ingot:** A mass of cast metal as it comes from a mold or a crucible.
- in situ leaching:** The extraction of metals or salts by passing solutions through rocks that have been fractured but not excavated.
- intermediate level waste:** Radioactive waste that is between 1000 and 1 million times more radioactive than is considered environmentally acceptable.
- intrazonal soil:** One of the soil orders. All soils with more or less well-developed soil characteristics reflecting the dominant influence of relief, parent rock, or age over that of climate.
- ion:** Any charged atom.
- ion exchange:** The reversible replacement of certain ions by others, without change in the crystal structure.
- Iron Age:** The period that began about 1100 B.C. with the widespread use of iron for tools and weapons. It followed the Bronze Age and, in a sense, continues today.
- ironstones:** Sedimentary rocks of large lateral extent that contain significant amounts of iron oxides, hydroxides, and silicates as coatings on, and replacements of, sedimentary mineral fragments and fossils.
- irrigation:** Process of supplying water to the land to promote the growth of crops.
- isotopes:** Species of the same chemical element having the same number of protons but differing numbers of neutrons in the nucleus.
- itabirite:** A metamorphosed banded iron formation consisting of thin bands of hematite and silica.
- joule:** A unit of energy equal to 0.24 calorie, or the flow of one ampere of electrical energy for one second at a potential of one volt.
- kaolinite:** A mineral, composition $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$; a common, light-colored clay mineral.
- kerogen:** Fossilized, insoluble organic material found in sedimentary rocks. Can be converted by distillation to petroleum products.
- kiln:** An oven used to harden, burn, or dry substances; especially to convert clay products into ceramics.
- kilowatt hour:** A unit of electrical power consumption indicating the total energy developed by a power of one kilowatt acting for one hour.
- kimberlite:** The rock type in which diamonds occur; a porphyritic alkalic peridotite containing olivine, mica, and chromium-garnet.
- kyanite:** A mineral, composition $\text{Al}_2\text{Si}_2\text{O}_5$; a compound found in certain metamorphic rocks and used in the manufacture of ceramics and glass.
- lag-time diagram:** A diagram that illustrates the relationship between rainfall and surface runoff of a drainage basin in terms of time.
- Lake Superior type:** Banded iron ores of the type found and long mined in the Lake Superior district of North America.
- laterite:** A highly leached soil zone in tropical regions that is rich in iron oxides.
- leaching:** Removal of chemical elements or phases by fluids.
- leach pad:** The impermeable layer of material placed beneath a heap leach pile to allow for the collection of metal-bearing fluids.
- leachate:** A watery solution that has drained out of a landfill or a heap leach pile.
- leucoxene:** A general term for fine-grained alteration products of ilmenite, FeTiO_3 .

level (in a mine): A main underground passageway leading out from a shaft that provides access to mine workings.

liberation (of minerals): Valuable mineral particles freed from valueless gangue.

lightweight aggregate: Aggregate of appreciably lower specific gravity than normal rock or aggregate; prepared by using very lightweight clays or porous materials.

lime: The compound CaO ; usually prepared by calcining limestone.

limestone: A bedded sedimentary rock composed largely of the mineral calcite, CaCO_3 .

limonite: A general term for amorphous brown, naturally occurring hydrous ferric oxides with a general composition of approximately $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$.

lipids: Fats or fatty oils.

liquid immiscibility: The inability of two liquids to mix and form a single, homogeneous liquid. Oil and water are immiscible.

lithosphere: The rocks forming the surface of Earth to a depth of about 60 kilometers and that behave as rigid plates.

loam: A rich, permeable soil composed of a friable mixture of roughly equal proportions of clay, silt, and sand and naturally containing organic matter.

lode: Metal-bearing deposits that are mined from their original encompassing rocks—as opposed to placer deposits in which the metals have weathered out of the original rock.

low-level waste: Radioactive waste that is up to 1000 times more radioactive than is considered environmentally acceptable.

low-quality energy: Energy derived from solar radiation where the temperature is less than 100°C .

macadam road: A road made by the addition of successive layers of finer and finer pulverized rock. Named for the developer of the process, John McAdam of Scotland.

macerals: The organic components of coal. Macerals are to coal what minerals are to a rock.

mafic: A term applied to igneous rocks composed primarily of one or more ferromagnesian minerals (most mafic rocks are also basic, i.e., having SiO_2 contents less than 54 percent).

magma: Molten igneous rock that lies beneath Earth's surface.

magmatic differentiation: The changes that occur in the composition of a magma during processes of crystallization.

magnesia: The compound MgO ; the rare mineral periclase has this composition. MgO is widely used in refractories.

magnesite: A mineral, composition MgCO_3 ; an ore mineral of magnesium and of the raw material used to produce MgO .

magnetite: A mineral, composition Fe_3O_4 ; an important ore of iron.

malleability: The property of a metal that allows it to be plastically deformed under compressive stress, such as hammering.

manganese nodules: *See* ferro-manganese nodules.

mantle: That zone of Earth that lies below the crust and above the core [from approximately 10–30 kilometers (6–20 miles) to 3480 kilometers (2200 miles) deep].

marble: A coarse-grained rock composed of calcite; usually formed by metamorphism of a limestone.

marginal reserve: That part of the reserve base of a mineral resource that borders on being economically producible.

marsh gas: *See* swamp gas.

matte: A mixture of metal sulfides and oxides produced by melting ore mineral concentrates.

metagenesis: Physical and chemical changes that occur in response to the high temperatures and pressures of deep burial; used especially in reference to organic material.

metal: An element or alloy possessing high electrical and/or thermal conductivity that is malleable and ductile.

metamorphic: Pertaining to rocks in which the minerals have undergone chemical and structural changes due to changes in temperature and pressure.

metamorphism: The mineralogical and structural changes of solid rocks in response to the changes in temperature and pressure resulting from burial or adjacent igneous intrusion.

metasomatism: Change in the character of a rock as in metamorphism, but when chemical constituents are added or removed in the process.

meteoric water: Rainwater.

methane gas: A colorless, odorless, flammable gas, CH_4 ; the principal constituent of natural gas.

mica: A group of sheet silicate minerals with a general formula of $(\text{K}, \text{Na}, \text{Ca}) (\text{Mg}, \text{Fe}, \text{Li}, \text{Al})_{2-3} (\text{Al}, \text{Si})_4 \text{O}_{10} (\text{OH}, \text{F})_2$.

milling: The crushing and grinding of ores so that the useful materials can be separated from gangue materials.

mineral resource: The sum of a group of valuable minerals in a given volume of crust.

Minette type: A variety of sedimentary iron ore. The European equivalent of the North American Clinton-type ores.

mining: The process of extracting mineral substances from Earth, usually by digging holes or shafts.

Mississippi Valley type: A term applied to a class of mineral deposits widespread in the drainage basin of the Mississippi River. Zinc and/or lead sulfide ores that occur in carbonate rocks.

moderator (in a nuclear reactor): The medium, such as graphite, that moderates the flux of neutrons produced during radioactive decay.

Mohs scale: A standard of 10 minerals by which the relative hardness of a mineral can be rated. From softest to hardest, they are: talc, gypsum, calcite, fluorite, apatite, orthoclase, quartz, topaz, corundum, and diamond.

molybdenite: MoS_2 , the principal ore mineral of molybdenum.

monazite: A rare-earth phosphate mineral, $(\text{Ce}, \text{La}, \text{Nd}, \text{Th}) (\text{PO}_4, \text{SiO}_4)$.

montmorillonite: A common clay mineral with the general formula, $R_{0.33}Al_2Si_4O_{10}(OH)_2 \cdot nH_2O$ where R is Na^+ , K^+ , Mg^{2+} , Ca^{2+} .

mountaintop mining: Coal mining process in which rocks are removed from mountaintops and dumped into ravines to expose coal beds.

mullite: $Al_6Si_2O_{13}$; a rare mineral, but common synthetic material in ceramic products.

muscovite mica: White mica of composition $KAl_2[AlSi_3O_{10}(OH)_2]$.

muskeg: A bog with deep accumulations of organic material forming in poorly drained areas in northern temperate or arctic regions.

natural cement: Limestones that contain impurities of alumina and silica such that when they are calcined, they form cements when water is added.

natural gas: A mixture of hydrocarbon gases, principally methane.

nepheline syenite: An igneous rock composed essentially of plagioclase feldspar and the feldspathoid mineral nepheline, $(Na,K)AlSiO_4$.

niter: Naturally occurring potassium nitrate; saltpeter.

nitrogen: Chemical element number 7; 78 percent of Earth's atmosphere and one of the most important fertilizer elements.

noble metal: A metal with marked resistance to chemical reaction; a term often applied to gold, silver, mercury, and the platinum metal group; synonymous with precious metal.

nonferrous metal: A general term referring to metals that are not normally alloyed with iron.

nonmetallic minerals: A broadly used term for minerals that are extracted other than for use of the metals they contain or for use as fuel.

nonpoint sources: Sources of pollution that are dispersed such as farm fields, road surfaces, etc.

nonrenewable resources: Resources that are fixed in total quantity in Earth's crust.

norite: A coarse-grained igneous rock composed of plagioclase and an orthopyroxene.

nuclear fission: The breakdown of a large nucleus (e.g., of uranium) to smaller nuclei with the emission of large amounts of energy.

nuclear fuel cycle: The steps involved in the natural concentration of uranium into mineable deposits, the mining and refining of the ore, the manufacture of fuel rods, use of the fuel rods in nuclear reactors, and the ultimate disposal of the fuel rods.

nuclear fusion: The joining together of the nuclei of very light elements (hydrogen, lithium) to form heavier elements with the release of large amounts of energy.

nuclear reactor: The vessel in which nuclear fuels are reacted to generate heat, in turn used to raise steam and drive turbines.

nugget: A small solid lump, especially of gold.

obsidian: Volcanic glass; usually black, but also red, green, or brown.

ocean thermal energy conversion: A system that utilizes the differences in the temperature of surface ocean water and the temperature of deep ocean water.

oil: See petroleum.

oil mining: The process of mining oil-bearing rock so that it can be processed to extract the oil.

oil shale: A fine-grained sedimentary rock containing much bituminous organic matter incorporated when the sediment was deposited.

oil window: The set of temperature and pressure conditions, developed during burial of a sediment, which lead to the conversion of organic matter into petroleum.

olivine: A mineral, composition $(Fe,Mg)SiO_4$; an igneous mineral used in making refractories.

open-pit mining: Mining from open excavations.

ophiolite complex: A sequence of mafic and ultramafic igneous rocks including metamorphic rocks, whose origin is associated with the early phases of ocean floor rifting.

ore: Resources of metals that can now be economically and legally extracted.

ore deposit: Equals "reserve" when referring to metal-bearing concentrations.

ore mineral: Broadly used to include any mineral from which metals can be extracted.

osmotic pressure: The pressure resulting from the movement of molecules or ions in a fluid through a semipermeable membrane as they seek to establish the same concentrations on both sides of the membrane.

overburden: The valueless rock that must be removed above a near-surface ore deposit to permit open-pit mining.

oxidant: A compound or element that brings about oxidation.

oxidation: Combination with oxygen; more generally, any reaction in which there is an increase in valence resulting from a loss of electrons.

ozone: O_3 , a form of oxygen produced by lightning and by solar radiation interacting with the upper atmosphere; important in reducing the penetration of UV radiation through Earth's atmosphere.

palgorskite: A mineral, composition $(Mg,Al)_2Si_4O_{10}OH \cdot 4H_2O$; a variety of clay that is sometimes fibrous and used as asbestos.

parabolic reflector: A concave reflector so shaped that the impinging Sun's rays are focused by reflection onto a central tube that becomes heated; as a result, the tube contains a fluid that transports the heat for use elsewhere.

peat: An unconsolidated deposit of semicarbonized plant remains accumulated in a water-saturated environment such as a swamp or bog. The early stage of coal formation.

ped: A naturally formed granule, block, crumb, or aggregate of a soil. See clod.

pegmatite: An exceptionally coarse-grained igneous rock; sometimes contains rich accumulations of rare elements such

as lithium, boron, fluorine, niobium, tantalum, uranium, and rare earths.

pellets: Small, solid particles of material, especially those formed of iron oxide grains and used as a feedstock to smelt iron.

per capita: Per unit of population; for each person.

per capita use: The amount of something used by each person during a standard time period, generally per day or per year.

peridotite: A coarse-grained igneous rock composed chiefly of olivine and pyroxene.

perlite: A volcanic glass with a rhyolitic composition, a high water content, and a characteristic cracked pattern.

permeable: A rock, sediment, or soil with the capacity of transmitting a fluid.

petroleum: A naturally occurring complex liquid hydrocarbon that after distillation yields a range of combustible fuels, petrochemicals, and lubricants.

pH: A measure of acidity expressed numerically from 0 to 14; neutral is 7, with lower values representing more acid conditions. Specifically, the negative logarithm of the H^+ concentration.

Phanerozoic type: A type of iron ore deposit formed during the Phanerozoic Eon.

phosphate(s): Compounds, including some minerals, containing phosphorus in the form of the phosphate (PO_4) anion.

phosphorus: Chemical element number 15; one of the most important fertilizer elements.

photocell: A layered chemical cell that produces electricity directly from light energy.

photochemical conversion: A chemical conversion that proceeds by the addition of energy in the form of electromagnetic radiation.

photochemical reaction: A chemical reaction promoted by the presence of electromagnetic radiation.

photochemical smog: Intense smoke or fog intensified by sunlight.

photoelectrochemical conversion: The chemical process active in a photogalvanic cell.

photogalvanic: A term used for a chemical reaction in which solar energy is converted directly into electrical energy.

photosynthesis: The process by which green plants use the radiant energy from the Sun to create hydrocarbons and release oxygen.

photovoltaic cell: *See* photocell.

pickling (of metals): The use of an acid bath to cleanse the surface of metal castings, sheet metal, etc.

pig iron: The raw iron produced during the smelting of iron ore.

pigment: A coloring agent.

pitchblende: A massive, brown to black, fine-grained variety of uraninite, UO_2 ; a term commonly applied to any black uranium ore.

placer: A surficial mineral deposit formed by mechanical concentration of mineral particles from weathered debris.

plagioclase feldspars: A series of silicate minerals involving a solid solution from $CaAl_2Si_2O_8$ (anorthite) to $NaAlSi_3O_8$ (albite).

plasma: A fourth state of matter (solid, liquid, gas, plasma) capable of conducting magnetic force, usually generated by application of extremely high temperatures.

plasterboard: Large panels made from gypsum and commonly used in construction.

plaster of Paris: Partially dehydrated gypsum, $CaSO_4 \cdot \frac{1}{2} H_2O$.

podiform: Referring to ore bodies with an elongate lenticular shape; especially some chromite ores.

point source: A single point, such as a smokestack or pipe, from which pollution emanates.

pollution: The presence of abnormal substances or abnormally high concentrations of normal substances in the natural environment.

polyhalite: Complex hydrated sulfate salt containing calcium, magnesium, and potassium.

polymorph: One form of a mineral that is known to exist in more than one crystallographic form; e.g., graphite and diamond are polymorphs of carbon.

polypedon: A three-dimensional body of soil consisting of more than one recognizable soil type.

porosity: The property of containing many holes.

porphyrin: A class of organic compounds that are capable of complexing with metals such as vanadium.

porphyry: An igneous rock that contains large crystals embedded in a fine-grained groundmass.

porphyry copper deposit: A large low grade copper-bearing deposit usually associated with the intrusion of a porphyry.

portland cement: A calcium aluminosilicate produced by calcining limestone and clay; this finely ground product will recrystallize and set when water is added.

potable water: Water that is safe for human use.

potash: A term locally used for potassium oxide or potassium hydroxide or to define the potassium oxide content of minerals.

potassium: Chemical element number 19; one of the most important fertilizer elements.

pot line: Large vats used in the production of aluminum.

power: The measure of energy produced or used as a function of time. *See* horsepower.

pozzolan cement: A cement formed by grinding together hydrated lime and pozzolana, a natural volcanic glass capable of reacting with the lime at ordinary temperatures to form cement compounds.

precious metal: The scarce metals that have high value—traditionally, gold, silver, and the platinum group metals.

primary mineral: A mineral formed at the same time as the rock enclosing it, usually by igneous or hydrothermal processes.

primary recovery: Petroleum production that occurs as a result of natural flow or pumping.

prior appropriation (of water): The law that permits the buying and selling of specified amounts of water from a

stream for beneficial use. The appropriations are honored in order of the oldest first.

pumice: A light-colored, vesicular, glassy rock formed by the eruption of gas-rich lava from a volcano.

pumped-water storage system: Hydroelectric power systems in which excess electricity at low demand times is used to pump water into a storage dam so that it can subsequently be used to generate electricity.

pyrite: A mineral, FeS_2 ; "fools gold."

pyrolysis: Chemical decomposition by the action of heat.

pyrometallurgy: The metallurgical process involved in separating and refining metals where heat is used, as in roasting and smelting.

pyroxene: A group of silicate minerals of general formula WSiO_3 (or XYSi_2O_6), where $W = \text{Mg, Fe}$; $XY = \text{Mg, Ca, Fe, Na, Li}$, etc.

pyroxenite: A rock composed primarily of pyroxene.

pyrrhotite: A mineral, composition Fe_{1-x}S ; a common iron sulfide compound.

quarry: An open surface working usually dug for the extraction of building stone.

quartz: A mineral, composition SiO_2 ; a very common compound that is hard, lacks cleavage, and does not weather rapidly.

quartzite: A metamorphic rock derived from sandstone and composed primarily of quartz.

quick silver: A term for mercury, Hg.

radiation: Electromagnetic energy transmitted in the form of waves or photons.

radioactivity: See decay (radioactive).

raise (in a mine): A vertical opening connecting two levels of a mine.

rank: A coal classification based upon physical, chemical, and thermal properties.

rare-earth elements: The 15 elements from atomic numbers 57 to 71, including, for example, lanthanum (La), cerium (Ce), neodymium (Nd), and europium (Eu).

recycling: The reuse of metals or other materials.

refining: Metallurgically: the process of extracting pure metals from their mineralogical forms; petroleum: the process of distilling and cracking crude oil in order to produce a wide variety of separate hydrocarbon liquids and gases.

refractory: A term used for unreactive materials with high melting points used to line the furnaces in which metals are smelted.

regolith: A general term for the surface layer of loose material that forms as a result of the weathering of rock.

renewable resources: Resources that are naturally replenished by processes active in or on Earth's crust.

reserve (of minerals): Mineral resources that can now be economically and legally extracted.

reserve base: That part of an identified resource that meets certain minimum physical and chemical criteria to present economic potential and that has a reasonable potential for becoming economic within planning horizons.

reservoir rock: Any rock with adequate porosity and that contains liquid or gaseous hydrocarbons.

resource: Naturally occurring concentrations of liquids, gases, or solids in or on Earth's crust in such form and amount that economic extraction of a commodity is currently or potentially feasible.

retort: A furnace-like chamber used to distill volatile materials or to carry out the destructive distillation of coal or oil shale. Heat is usually applied externally, and the decomposition products are collected by cooling the gases so that different compounds condense at different temperatures.

return flow: Water that reaches a ground—or surface—water source after release from the point of use and thus becomes available for further use.

reverse osmosis: Process utilizing pressure to separate freshwater from saltwater by forcing it through a semipermeable membrane.

rhyolite: A fine-grained extrusive igneous rock consisting largely of quartz and potassium feldspar.

ribonucleic acid: RNA, a substance similar to DNA. It carries out DNA's instructions for making proteins.

Richter Scale: A scale used in the quantitative evaluation of the energy released by earthquakes.

riparian: Pertaining to the shoreline areas of a body of water. Riparian law allows landowners to draw from a lake or stream adjacent to their property if their use does not harm other users.

roasting: Heating of an ore to bring about some change, usually oxidation, of the sulfide or other minerals.

rock cycle: The cyclical progression of rocks from sedimentary to metamorphic as a result of increased temperature and pressure, to igneous as a result of melting, and back to sedimentary as a result of weathering and erosion.

rock salt: Coarsely crystalline halite, naturally occurring or synthetically prepared.

room and pillar mining: A mining method in which rock, coal, or ore is removed from a series of openings with a series of intervening columns (pillars) left to support the overlying rocks.

rotary drills: The most common method of drilling; a hydraulic process in which a hard-toothed drill bit is attached to a rotating drill pipe. As the pipe turns, the bit grinds into the rock; the loose pieces are carried to the surface by fluid circulated down the center of the pipe.

rutile: A mineral, composition TiO_2 . The principal ore of titanium; used as a white paint pigment.

saline water: Water that contains 1000 or more milligrams of dissolved solids per liter, especially NaCl.

salinization: The buildup of salts, usually NaCl, in soils as a result of evaporation.

salt dome: Dome or pinnacle-like structure of rock salt, halite, which has risen through sediments above a bed of salt due to differences in densities.

salt peter: Naturally occurring potassium nitrate; niter.

saltwater intrusion: The movement of saltwater into an aquifer, usually as a result of excessive extraction of freshwater near coastal areas.

sand: Detrital rock fragments 1/16 to 2 millimeters in diameter; natural sands are composed almost entirely of quartz.

sandstone: A medium-grained, clastic sedimentary rock composed of sand-sized particles (commonly quartz).

saponite: A mineral, composition $(Ca/2,Na)_{0.33}(Mg,Fe)_3(Si_{3.67},Al_{0.33})O_{10}(OH)_2 \cdot 4H_2O$; a soft, soapy light-colored clay.

sapropelic coal: Coal derived from organic residues (finely divided plant debris, spores, and algae) in stagnant or standing bodies of water.

scarce metals: Metals whose average crustal abundance is less than 0.1 percent.

secondary enrichment: A zone of minerals formed later than the enclosing rock and usually at the expense of earlier formed primary minerals.

secondary recovery: Oil production resulting from procedures, such as the injection of water, steam, or chemical compounds into a reservoir in order to increase oil production beyond primary production.

sedimentary: Pertaining to rocks formed from the accumulation of fragments weathered from preexisting rocks, or by precipitation of materials in solution in lakes or seawater.

seismograph: An instrument that records Earth's vibrations, especially those from earthquakes.

sepiolite: A mineral, composition $Mg_4(Si_2O_5)_3(OH)_2 \cdot 6H_2O$; a common clay that is widely used for ornamental carvings; also known as meerschau.

sequestration: The trapping of carbon dioxide in underground formations to prevent its release into the atmosphere.

serpentine: A group of minerals, general composition $(Mg,Fe)_3Si_2O_5(OH)_4$; widely formed in metamorphism with varieties including gems (jade) and asbestos (chrysotile).

serpentinite: A rock composed primarily of serpentine group minerals and formed through the alteration of preexisting ferromagnesian minerals such as olivine and pyroxene.

shaft (of a mine): A vertical entrance into a mine.

shale: A fine-grained, indurated, detrital sedimentary rock formed by the compaction of clay, silt, or mud and with a partially developed rock cleavage.

silane: Silicon-hydrogen compounds.

silicon chip: A chip of silicon metal to which trace amounts of other elements have been added in order to affect the electronic properties.

sillimanite: A mineral, composition $Al_2Si_2O_5$; a compound found in metamorphic rocks and used in the manufacture of ceramics and glass.

skarn: An assemblage of lime-bearing silicates derived from limestones and dolomites by the introduction of silicon, iron, and magnesium, usually adjacent to an igneous intrusion.

slag: The nonmetallic top layer that separates during the smelting of ores; it is usually rich in silica, alumina, lime, and any other materials used to flux the smelting.

slate: A compact, fine-grained metamorphic rock formed from shale; it possesses the property of rock cleavage whereby it can be readily parted along parallel planes.

smectite: A term applied to the montmorillonite group of clay minerals.

smelting: The process of melting ore minerals to separate the metals from the nonvaluable phases.

smog: Fog that has become mixed and polluted with smoke.

soda ash: Sodium carbonate.

soil: The unconsolidated earthy material that overlies bedrock and that is a complex mixture of inorganic and organic compounds; the natural medium to support the growth of plants.

soil order: One of ten major subdivisions in the "Comprehensive Soil Classification System."

soil profile: A vertical section through a soil that reveals the different physical and chemical zones that are present.

soil temperature regime: The changes in temperature experienced by a soil in a normal annual cycle.

soil water regime: The changes in the amounts of water present in a soil during a normal annual cycle.

solar cell: Electronic device which yields an electric current when exposed to light.

solar energy: The total energy in the Sun's radiation.

solder: Metal alloy that melts at low temperature and that is used to bond metals together.

solid solution: A solid crystalline phase in which the composition may vary by one or more elements replacing others, e.g., Fe replacing Mg in the olivine minerals Mg_2SiO_4 - Fe_2SiO_4 .

solution mining: The extraction of resources by solutions instead of conventional mining procedures.

soot: A black substance consisting mainly of carbon from the smoke of wood or coal.

sour gas: Hydrogen sulfide, H_2S , that commonly occurs in minor quantities with petroleum or natural gas.

source rocks: Sedimentary rocks containing the organic matter that under heat, pressure, and time is transformed into liquid or gaseous hydrocarbons.

special metal: Metals such as tantalum and beryllium that are used increasingly because of unusual properties important to industry.

sphalerite: A mineral, ZnS , that serves as the principal ore of zinc.

spinel: A mineral, composition $MgAl_2O_4$; a common accessory mineral in many rocks; also refers to a crystal structure, common to some ore minerals, in which the external shape of an octahedron is often seen.

spot market: The buying and selling of commodities for immediate delivery at a price agreed upon at the time of sale.

stainless steel: An iron-based alloy containing enough chromium to confer a superior corrosion resistance.

- stannite:** A mineral, composition $\text{Cu}_2\text{FeSnS}_4$; an ore of tin.
- steam flooding:** The injection of superheated steam down an oil well in order to promote the release of oil trapped in the rocks.
- steel:** An iron-based alloy; other metals or substances are alloyed with the iron to impart specific properties such as hardness or strength.
- stock:** Exposure of plutonic igneous rock over an area of less than 40 square miles.
- stockworks:** Closely spaced intertwined veins that serve as feeder zones of ore deposits.
- Stone Age:** The period in human culture when stone was used for the making of tools. It began with the first humans and ended at various times in different places (e.g., about 3000 B.C. in Egypt and Mesopotamia) when bronze was used to make tools.
- stope:** The room-like area in a mine where ores are extracted.
- stratification:** The layer-like nature of a sedimentary rock.
- stratiform:** Referring to an ore deposit that is layered and parallel to the enclosing strata.
- stratigraphic traps:** Sedimentary units such as sandstone lenses into which oil migrates and is prevented from further movement by surrounding impermeable layers.
- strip mining:** The removal of coal or other commodities by surface mining methods in which extraction is carried out in successive strips of land.
- structural traps:** Folded or faulted rocks into which oil migrates and from which further migration is prevented.
- subduction:** The process in which one crustal plate descends beneath another.
- subeconomic resource:** That part of identified resources not meeting the economic criteria of reserves or marginal reserves.
- subsidence:** The naturally or artificially induced dropping of the land surface resulting from the removal of the underlying rocks either by mining or groundwater solution.
- superalloy:** Mixture of metals that exhibits one or more properties that is greater than either of the metals being used.
- superphosphate:** A soluble mixture of calcium phosphates produced by reaction of phosphate rock with sulfuric acid; used as fertilizer.
- surface runoff:** The water that flows directly off the land surface and the water that, after infiltrating into the ground, is discharged into the surface.
- swamp gas:** Methane, CH_4 , produced during the decay of organic matter in stagnant water.
- syenite:** An igneous rock composed largely of potassium feldspar, any of the feldspathoid minerals, and an amphibole. Quartz is rare or absent.
- SYNROC:** Synthetic rock-like material used to incorporate radioactive waste.
- taconite:** A term used in the Lake Superior district for laminated iron ores consisting of iron oxides and silica or iron silicates.
- tactite:** An alternate name for skarn.
- tailings:** The valueless materials discarded from mining operations.
- talc:** A mineral, composition $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$; it is extremely soft, making it a valuable lubricant and cosmetic ingredient.
- tar:** A dark, oily, viscous mass of hydrocarbons.
- tar sand:** Sand deposits in which the interstices of the grains are filled with viscous hydrocarbons.
- tectonism:** Movement of a portion of Earth's crust, usually related to mountain building.
- thermal cracking:** The application of heat to break heavier hydrocarbons into lighter ones.
- thermal maturation:** The progressive change in organic matter in sedimentary rocks resulting from increasing temperature as the depth of burial increases.
- thermal pollution:** Abnormal heating of the environment, usually rivers, caused by the combustion of fossil fuels, by nuclear power generation, or industrial processing.
- thermogenic gas:** Gas formed as a result of the thermal breakdown of organic matter.
- thermosetting plastics and resins:** Plastics and resins that require heating in order to become solidified.
- tidal energy:** Energy derived from the movement of water during the rise and fall of the tides.
- transpiration:** The release of water vapor by plants during their normal respiration.
- traps:** Rock structures or beds in which oil accumulates and is prevented from further migration.
- tritium:** A synthetic isotope of hydrogen containing one proton and two neutrons in its nucleus; its half-life is 12.5 years.
- tuff:** A compacted deposit of volcanic ash.
- ultramafic:** Said of igneous rocks composed chiefly of one ferromagnesian mineral (most ultramafic rocks are also ultrabasic, i.e., having SiO_2 contents less than about 44 percent).
- Uranium District:** Mining district spanning the Colorado-Utah boundary and that was mined primarily for ores of uranium and vanadium.
- vadose:** Referring to water in the uppermost soil, the zone in which most intergranular interstices are air filled.
- vein:** A sheet-like infilling of a fracture by hydrothermally deposited minerals often containing ore minerals.
- vermiculite:** A group of clay minerals characterized by the tendency to undergo extreme expansion when heated above 150°C ; widely used as an insulator and as a component in lightweight construction materials.
- vesicles:** Cavities in a lava formed by the evolution of gas during the rapid cooling of a molten lava.
- vitrification:** The formation of a glassy or noncrystalline substance.
- volcanic glass:** Natural glass formed in volcanic eruptions when lava cools quickly; commonly called obsidian.

Glossary

volcanogenic massive sulfide: Ore deposit containing more than 50 percent ore minerals and formed as a result of precipitation of the ore minerals from hydrothermal fluids on the sea floor.

Wabana type: A regional name applied to some iron ore deposits in North America.

water flooding: The injection of water into an oil well to promote the release of oil trapped in the rock.

water glass: A water soluble form of sodium silicate.

waterlogging: The situation where irrigation raises the water table such that it covers the roots of crops and either reduces productivity or kills the plants.

water rights: The right to draw and use (and sometimes sell) water drawn from a lake, river, or underground source.

water table: The surface in a soil or rock below which all the voids are water filled.

watt: A unit of power equal to work done at a rate of one joule per second; approximately equal to 1/746 horsepower.

weatherability: The rate at which weathering affects the physical and chemical nature of a rock or mineral.

weathering: The progressive breakdown of rocks, physically and chemically, in response to exposure at or near Earth's surface.

wet steam: Natural geothermal systems dominated by hot waters with associated steam.

wind farm: An array of windmills used to generate electricity.

winze: A vertical opening connecting two levels of a mine. The same as a raise.

withdrawal: The extraction of water from a surface or groundwater source.

work: Usually the result of applied force, defined as the product of the force and the displacement. Usually expressed in foot-pounds, joules, or kilowatt-hours.

yellowcake: A general term for yellow oxidized uranium oxide arising from concentration in the mining and processing of uranium ore.

zeolite: A group of hydrous aluminosilicate minerals characterized by their easy exchange of water and cations; used as catalysts in oil refining.

zircon: A mineral, composition $ZrSiO_4$; a common accessory mineral in many rocks; the main source of zirconium.

zonal soil: One of the soil orders that have well-developed characteristics that reflect the agents of soil genesis, especially climate and the action of organisms.

Introduction and the Origins of Resources

Our entire society rests upon—and is dependent upon—our water, our land, our forests, and our minerals. How we use these resources influences our health, security, economy and well-being.

JOHN F. KENNEDY, FEBRUARY 23, 1961

MODERN SOCIETY AND EARTH RESOURCES: THE COMPLEX NETWORK

President Kennedy's words are as true today as they were years ago. Furthermore, they are as relevant to the world as they are to the United States. All of the materials needed for the well-being of humans in our complex society come from the Earth. Food and water, clothes and dwellings, automobiles, aircraft, televisions, and computers all contain materials drawn from the Earth. Even the paper on which these words are printed contains cellulose from wood, plus clay and barium sulfate to give body and an absorbent, tough surface. Almost every material we use actually employs many other materials, as well as energy, in its extraction and any subsequent processing. Now, early in the twenty-first century, we have finally come to recognize that there is much truth in the old adage that "there is no such thing as a free lunch." Almost everything that humans do impacts the world around us. In recent decades, we have become aware of the many unintended and undesired impacts on the quality of our air, water, or living space that result from resource extraction and use. In this context, we have also seen the emergence of new terms such as *greening* of society, *carbon footprint*, *global warming*, and *sea level rise*. One can envision the whole of Planet Earth as a large, interconnected network. When something disturbs it in one place, there is a reverberation throughout the entire network and, if any part is broken, the network is weakened. A disruption in one part can have unforeseen consequences elsewhere and, thus, we must proceed with caution if we are not to damage irreparably this network on which our very survival depends.

THE CHANGING WORLD

Profound changes have occurred in the fifty years since President Kennedy spoke his insightful words. The world population has more than doubled to 6.7 billion, fertilizer use has more than tripled, energy production has tripled, the number of automobiles in the world has quadrupled, and nuclear power has grown from a tiny fraction of the

energy supply to the world's second leading source of electricity. This growth has not been without consequences for the environment; since 1961, the amount of carbon dioxide in the atmosphere has risen by about 20 percent, and the world's rain forests have been reduced by one-third. We hear reports of the over-exploitation of the world's resources and, at the same time, we learn of new technologies that can enable us to discover new resources, or more efficiently exploit old ones. We hear of growing levels of atmospheric pollution, and of damage to the ozone layer that protects us from cancer-causing ultraviolet radiation, but we also hear of cleaner water in once polluted rivers. We hear reports of vanishing plant and animal species in the wild, and of new, genetically altered, and cloned species in human-made environments. In the United States, concerns about reliance on imported fossil fuels, especially petroleum from the Middle East, have provided a stimulus for the generation of domestically produced biofuels. But this created the largely unforeseen dilemma of driving up prices for food commodities as farmers diverted their efforts to grow corn for ethanol production rather than for human consumption. The end result was little change in environmental impact, insufficient ethanol production to offset much imported oil, reduced grain for exports, increased grain prices that especially hurt the world's poor and, hence, anger toward the United States, and ultimately calls to reduce the use of corn for ethanol production. It is clear that in nearly every aspect of life more changes are occurring; the rates of those changes accelerating. Such changes make it more difficult to predict future needs in terms of the nature and the amounts of resources. A general view has developed that more of everything will be needed in the future because of the increase in world population. This is true for many commodities such as petroleum, iron, aluminum, and crushed stone. However, there have been reductions in the need for commodities such as asbestos, lead, arsenic, and mercury, partly due to the development of new technologies, but mainly due to the recognition of the damage to human health and the environment caused by these materials. There is no doubt that world population will continue to grow in the twenty-first century, and may even double again to 12 billion people, which alone would drive the need for vast quantities of additional resources. The result of this growth will inevitably be to increase the extent of the human impact on our global environment.

INTERDEPENDENCE AND COMPLEXITY

Our ancestors learned long ago that the materials needed for food, clothing, dwellings, fuel, and later for commercial activities are not uniformly distributed over Earth. When demand locally exceeded supply, three options were open to our ancestors: substitutes could be developed, trading could be started with people who had ample supplies, or the people in need could move in order to find new supplies. Even where quantities were once sufficient, the demands of increasing populations would often eventually exceed the limits of supply. The result was the development of local, regional, national, and international trade routes. There is now a vast network of interdependence that becomes evermore complex. This increasing complexity, along with the increasing quantities of materials being transported around the world, has made more materials available to more people, but it has also increased the vulnerability of supply systems to disruption by both natural and human forces. It is important to remember that the availability of materials is not just a function of resources—there are also economic, social, political, and environmental considerations. The availability of a commodity may be dictated by politics more than by any other factor; examples include the prevention of sales of oil from Iran and Iraq to the United States, and the long-standing embargo of importation of a variety of goods from Cuba to America. In recent years, environmental concerns have also been ranked in importance above economics, as demonstrated by the removal of hydroelectric dams to allow salmon to migrate up the Snake River in the western United States.

THE EARTH—OUR ONLY HOME

During the latter part of the twentieth century, we humans reached out and touched the Moon and our two nearest planets, Mars and Venus; we also sent unmanned probes close to the other planets. These explorations have confirmed what we have long suspected: Earth is the only planet in our solar system that is capable of providing the resources needed to build and nurture human societies. Our ability to reach these other celestial bodies has also led to speculation that we might one day inhabit such planets and even extract valuable resources from them. But despite our extraterrestrial explorations and our advancing technology, there is no serious expectation that humans will extract resources from other planetary bodies within the next half century (and quite possibly well beyond that). We humans, for the next several generations, are Earth-bound; we must be mindful that all of the resources we shall need for the foreseeable future must be found on this planet, and that any negative environmental impact associated with the extraction and use of any resource will be in our own “backyard”. We must remember that all known life in the Universe lies on or near Earth’s surface. Furthermore, we must all understand that we are enmeshed in a complex, interdependent network where actions often have consequences far beyond the obvious, the local, and the immediate.

PLATE TECTONICS AND THE FORMATION OF EARTH RESOURCES

If the Earth were homogeneous (that is, if all of the chemical elements were evenly distributed), the only two solids would be ice and an “average” rock. There would be no fossil fuels, no ores, no fertilizers, no gems, nor any of the other mineral resources that we now use in such large quantities. Fortunately, Earth is a dynamic body in which there are great cyclical movements of materials that are ever rearranging and concentrating the chemical elements and their compounds. Some cycles are relatively rapid and easily visualized; an example is the hydrologic (water) cycle in which rainfall is followed by runoff and then evaporation returning the water back into the atmosphere from which it will fall again as rain to continue the cycle. Other cycles, such as the subsurface movement of fluids that deposit metal-rich veins, are of much longer duration and are hidden from view. We do not see these moving fluids because they are deep within the Earth, but we find the veins exposed in outcrops of rock, or in mines, long after they have formed.

The most important of Earth’s cycles is the one referred to as “the plate tectonic cycle”; this involves the slow transport of large blocks, or plates, that make up Earth’s outermost solid layer. The plates are carried along atop convecting cells within the Earth’s underlying mantle. The development of plate tectonic theory in the 1960s provided the key to understanding the formation of the Earth’s crust, the expansion of ocean basins, and the movement of continental masses throughout geologic time. Earth’s internal heat provides the driving force for the large convecting cells within the mantle. The upwelling zones, such as the mid-Atlantic Ridge and the East Pacific Rise, are spreading centers where hot mantle rock rises upward to the surface, adding new material to Earth’s crust along the plate boundary. As new material is added, older rock is transported laterally away from the boundary. At spreading centers, there is much seismic activity, volcanism, and the release of hot aqueous fluids that carry dissolved metals. As the fluids are expelled into the cold ocean water, there is immediate precipitation of metal-rich sulfide deposits at hot vents called “black smokers.” Although mining of these deposits is presently impractical because of their deep-water locations, similar deposits on the continents (and which are the fossil equivalents of present-day black smokers) have been mined for hundreds of years. Elsewhere, plates collide, commonly with one plate sinking downward under another. These convergent or collision boundaries are also sites of extreme seismic activity and volcanism; there too, there is a release of hot metal-bearing fluids and the formation of even richer and more diverse types of metal ores, often intermixed with a variety of volcanic rocks.

Although many rich resources have been formed along plate boundaries, others that were formed far from the boundaries also owe their locations to plate tectonics. For example, movement of the plates has played a critical role throughout geologic history in the positioning of the continents and the formation of great sedimentary basins. This, in turn, has dramatically affected climatic conditions, and rates of erosion and sedimentation, which, in turn, have controlled the formation of many types of resources, especially oil and gas. Every type of resource forms by one or more geological processes, and every process in the Earth's crust and mantle can concentrate, alter, or disperse resources. Igneous intrusions drive fluids which concentrate and precipitate metal-rich veins. Erosion of those veins disperses the concentrations of copper, lead, gold, or silver, but can result in the subsequent concentration of gold nuggets in a river bed. Evaporation removes water but leaves behind rich salt deposits. The gradual burial of peat bogs on the land, or of marine plankton in the sea, results in the formation of coal and oil, respectively. Earth's resources are formed by myriad processes, which have been acting over vast periods of time. The result is the accumulation of large numbers of deposits of differing richness and size in various places and at various depths. The challenge of mineral exploration is to understand where resources are hidden so that we can exploit them for the sustenance of modern society.

Minerals: The Foundations of Society



Earth's resources used by humans are constantly changing in response to the technologies of particular societies. This photograph contrasts the natural stone used in the construction of the great Pyramids in Egypt more than 4000 years ago with the wide variety of special metals used in the construction of a modern U.S. Air Force B-1B bomber and its escort fighter jets. (Photograph by Staff Sgt. Jim Varhegyi; used with permission of U.S. Air Force.)

Resources are like air, of no great importance until you are not getting any.

ANONYMOUS

FOCAL POINTS

- All materials needed for modern society are derived from Earth, directly or indirectly.
- World population grew slowly until about A.D. 1500; increasingly rapid growth from around 1800 raised population to 2 billion by 1930, to 4 billion by 1975, to 6 billion by 2000, and to an expected 8 billion by 2035.
- Human population, presently exceeding 6.7 billion, is projected to rise to at least 12 billion before stabilizing by about A.D. 2100.
- The rates of population growth are much higher in less developed countries than in developed countries.
- Renewable resources, such as plants, flowing water, and sunlight, are replenished on timescales that are short compared to human life spans; nonrenewable resources, such as mineral deposits, are formed over vast timespans and are being used much faster than they are replaced. (Some resources such as tropical rain forests, while clearly renewable, are also being consumed at rates far greater than natural processes are capable of replacing them.)
- Earth's crust is like a large "machine" with energy input from Earth's interior and from the Sun; the energy fluxes result in movement of material, or *geochemical cycles*, that are constantly forming, concentrating, redistributing, and altering the mineral resources.
- "Resources" are naturally occurring concentrations of mineral substances from which economic extraction may occur.
- "Reserves" or "ores" are those concentrations of mineral substances that are presently economical to extract.

THE WORLD'S RESOURCE NEEDS

All the materials needed for the health and prosperity of human societies have come from Earth. In primitive societies, it was simply the food, water, and shelter

necessary for survival. Today, the list is much longer and includes automobiles, planes, televisions, and computers, but we are just as dependent on Earth for raw materials. The major differences are that today we

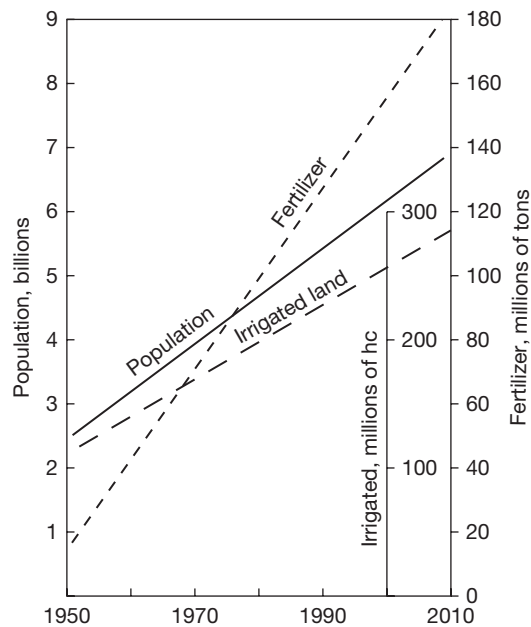


FIGURE 1 The relationships between world population, irrigated farmland, and the consumption of fertilizers needed in the second half of the twentieth century in order to produce sufficient food for the world. As world population has more than doubled, agricultural production has been able to keep pace, but this required more than a doubling of irrigated land area, and a tenfold increase in the use of fertilizers to promote crop growth. (Data from FAO of the United Nations.)

use much greater amounts than did individuals in the past; we use a greater variety of materials; we use materials from more sources; and we use many materials that we have synthesized from those raw materials. How straightforward it would be if we could consider each raw material or end-product irrespective of all the others. This is not possible because the increasing use of materials has been associated with increasing complexity in the systems needed to extract and deliver materials, and increased interdependence in the supply of materials. Our most basic need is for food, and much concern has been expressed about the world's ability to provide food for a growing population. Consider Figure 1, which addresses food production and some of its complexities. In the second half of the twentieth century, world population increased from 2.5 billion to 6 billion with food production just keeping pace. However, in order to feed the world's growing population, the need for water to irrigate crops increased at approximately the same pace, while the need for tractors manufactured using metals and many other raw materials and using fossil fuels to propel them, increased at a faster pace. Finally, it shows that need for fertilizer to produce that food increased more than four times faster than the population. Thus, the production of food depended not only on seed and soil, but also upon water, metals, fossil fuels, and fertilizers (and this is only a very simplistic view). Whether the growth in agricultural production can continue to

keep pace with increasing world population over the next century (when population will grow toward 12 billion) is not clear. What is clear is that the terrible scenes of famine in Africa, caused by disruptions in food supplies, are all too common in the newspapers and on television. Such local famines, whatever their cause, are only minor examples of what would happen on a much larger scale were the global food network to be disrupted. Because adequate food production now requires adequate mineral and energy production, minerals and energy have also become part of the foundation of all societies. If important minerals and energy sources were to run out, or for some reason be denied us, social chaos would ensue. The result could be a drastic reduction in the world's population.

POPULATION GROWTH: THE FORCE THAT DRIVES RESOURCE CONSUMPTION

Many millennia ago our ancestors were hunters and gatherers for whom nature's random production of grains, fruits, and animals were sufficient. When local population needs began to exceed the natural yield of materials, farming was developed out of the necessity to control, and thereby to increase, the production of fruits, grains, and meats. Archeologists suggest that farming began in the Middle East about 10,000 years ago. From that time onward, the world's population has not only increased, but has grown ever more dependent on the controlled production of food and clothing and, thereby, on all the other materials we draw from the Earth. As far as historians and archeologists have been able to decipher, world population grew slowly but more or less steadily to the end of the sixteenth century A.D. (Figure 2), interrupted only by occasional outbreaks of plagues, pestilences, and famines. One of the worst epidemics started in Europe when Crusaders, returning from Asia Minor in 1348, inadvertently brought back rats bearing plague-carrying fleas. Starting in Italy, the bubonic plague swept through Europe over a period of two years. Between a third and a quarter of the entire population of Europe died; the populations of some cities were reduced by half. This particular outbreak was known as the "Black Death."

Near the end of the sixteenth century, the world population began to grow rapidly. The initial causes for the increase in rate were primarily due to advances in hygiene in the cities, but a marked improvement in the diets of Europeans also occurred when potatoes and maize were introduced from the Americas. World population reached 1 billion in about A.D. 1800. One hundred and thirty years later—by 1930—the population had reached 2 billion (Figure 2). A mere 45 years was all the time it took before the population doubled again to reach 4 billion in 1975; another 2 billion people had been added by 1999, bringing the total to 6 billion.