A GLOBAL VIEW OF GEOTHERMAL ENERGY

1 Russia. Several areas in the former Soviet republics are near plate margins. The subduction boundary at Kamchatka north of Japan is part of the "ring of fire". This is the only place in Russia with geothermal electric power (11 MWe), as well as many volcanoes and geysers. An 80 MWe plant at Mutnovsky is under construction with waste *hot water to be piped 80 km to heat a town.* Geothermal waters are used for district heating (about 673 GWh/yr), wool washing, wood drying, production of paper and concrete blocks. Geothermal water also heats 230 acres of greenhouses, some fish farms, many swimming pools and, in Siberia, thaws out frozen ground. The water is even bottled (in 84 plants) for drinking. Another plate margin passes close to **Georgia** which uses up to 65°C geothermal waters for bathing, space heating, manufacturing, greenhouses and fish farming.

2 Japan. The best known example of a volcanic country on the Pacific "ring of fire," Japan has been volcanically active over the past 20 million years. The country has cold winters and little heating, so the hot bath has been a national ritual from early times, and for this reason *Japan is the world's largest user of direct geothermal heat.* Hot water use is enormous, exceeding 8730 GWh/yr for bathing, with an additional 1940 GWh/yr used for space heating, manufacturing, agriculture and aquaculture (including raising alligators). Use of geothermal for electricity is by comparison recent with the first production (22 MWe) starting in 1966 with a dry steam plant in Matsukawa. Japanese geothermal developments are often hemmed in by national parks and spas, so areas available for drilling and the fields themselves tend to be small (40 MWe average). By 1982 seven power plants of 10 to 55 MWe were operating, and now the total on line is 528.8 MWe. Additional power plants of 20 and 3 MWe are planned. A longer range goal is the use in small communities of mass-produced 100 to 500 kW binary power plants to a projected total of 23.7 MWe.

3 Eastern China. Eastern China is not close to a plate boundary, but has hot water in sedimentary basins similar to those in northern Europe. Direct use in 1995 totaled 4717 GWh/yr. In Tianjin and Beijing, more than 400 wells provide 6000 kg/h of hot (50-70°C) water for space heating, cloth dyeing and paper processing. In rural areas hot water is used for over 300 acres of greenhouses, drying crops and fish farming (430 acres of ponds). Throughout the country hot water is used for bathing and heating. *Geothermal greenhouses in northeast China allow early starts of rice plants and an increase in production.* Small geothermal power plants of 300 and 686 kWe capacity are in use in eastern China. 80 to 100 MWe production is planned for all of China by 2000. Nearby **Taiwan** is close to a plate boundary and has a large high-temperature volcanic-geothermal field at Tatun (too acid for present use), as well as lower-temperature fields at Chingshui (3 MWe) and at Tuchang (300 kWe).

4 Himalayan Geothermal Belt. The collision of the Indian plate with the Eurasian plate resulted in the Himalayas and *one of the largest geothermal areas in the world.* The Himalayan geothermal belt, over 150 km wide, extends 3000 km through parts of **India, Tibet, Yunnan (China), Myanmar** and **Thailand.** Replete with more than 1,000 hot spring areas, the region gave birth to a myth that *at Manikaran (India) the goddess Parvati lost her earrings and struck the ground in rage, causing hot springs to gush forth carrying pearly sinter to please the goddess.* Over 150 of these areas are hot enough to generate electricity. Thailand has a binary plant which produces not only 300 kWe (from 117°C water), but also exhaust heat for crop drying, cold storage and bathing. Yangbajang, in Tibet, generates 25 MWe, providing Lhasa with about 40% of its electricity and helping to grow vegetables in this cold, dry region. In Tibet and Yunnan, an additional 7 MWe are generated in 7 small plants.

5 The Philippines. These islands have remarkable geothermal resources. Rapid subduction of the Philippine plate under the Eurasian plate results in active faulting and volcanism. Philippine geothermal fields are large (average 220 MWe) and development is active. Geothermal resources are most developed on Luzon (the population center) and on the island of Leyte. Subsea cables may soon be used to carry power between islands. Geothermal has been on a fast track here. The first plant started as recently as 1979, and electrical capacity is already at 1393 MWe with contracts for another 507 MWe to be on line by the end of 1998. *At this rate the Philippines (now #2) may well be #1 in geothermal power production by the end of the century.* In the Philippines, geothermal heat is also used directly for fish processing, salt production and drying coconuts and fruit.

6 Indonesia. *In the Indonesian islands, a great subduction plate boundary 4000 km long between the Eurasian and Australian plates has formed nearly 200 volcanoes and 100 geothermal fields.* Geothermal development started in the 1920s with the first shallow steam wells drilled at Kamojang. This field, which produced 250 kWe in 1979, has been producing 140 MWe from dry steam since 1985. The 1990s will show a great expansion. Salak (on line in 1994) now produces 110 MWe, Dieng (surrounded by ancient temples), 52 MWe and Lahendong, 2.5 MWe. Fields scheduled to start or expand by 1999 include: Kamojang (60 MWe), Dieng (95 MWe), Salak (220 MWe), Bedugul (110 MWe), and five other fields with 55 MWe or less (745 MWe total). Geothermal power in Lahendong (12.5 MWe) will encourage local industry in this remote district. 10 MWe of small (35-1000 kWe) "mini-geo" plants are planned for isolated villages. Natural steam and hot water are also used locally for cooking and bathing.

7 New Zealand. This small Pacific "ring of fire" country along the southeast subducting boundary of the Pacific plate has many hot-spring areas and several active volcanoes. In the early 1950s, with no oil and little hydropower on the North Island, geothermal development was started at the Wairakei field. By 1960 the power plant was generating 69 MWe of electricity and now produces 157 MWe. *Wairakei was the first large hot-water field ever developed.* At Kawerau 200 tons/h of geothermal steam is used directly to dry pulp in a paper mill and also generates 16 MWe of electricity. The total geothermal capacity is now 341 MWe with another 306 MWe under construction or planned. Some steam is used at Broadlands to heat a Maori tribal pool and to dry crops, and houses are heated from shallow wells in Rotorua and Taupo. Hot spring waters are widely used for bathing and greenhouses. Total direct use is about 1837 GWh/yr. **Australia** uses 29 GWh/yr for swimming pools and district heating (19,000 m^2); far more is cooled for stock watering. Test plants produce 20 and 150 kWe from hot aquifers. The great Australian aquifer, the major source of agricultural water for inland New South Wales, reaches 75°C. In Australia, hot water is also used for wool dyeing and paper making.

8 Canada. Geothermal power projects are proposed at Mount Meager in the Garibaldi volcanic belt, the extension into British Columbia of the subduction-related Cascade volcanoes. In Canada, 10-20°C groundwater is used directly or with heat pumps to heat more than 30,000 buildings, including Carleton University in Ottawa and factories in Nova Scotia (using water from the flooded Springhill coal mine of the ballad). In the Yukon geothermal keeps city water pipes from freezing.

- Electrical generation by geothermal energy (higher temperatures and down to about 100°C)
- Direct use of geothermal hot water (medium and lower temperature waters, down to about 30°C)
- Use of geothermal heat pumps and downhole heat exchangers (lower temperatures, down to about 5°C)
- Lesser use of these resources

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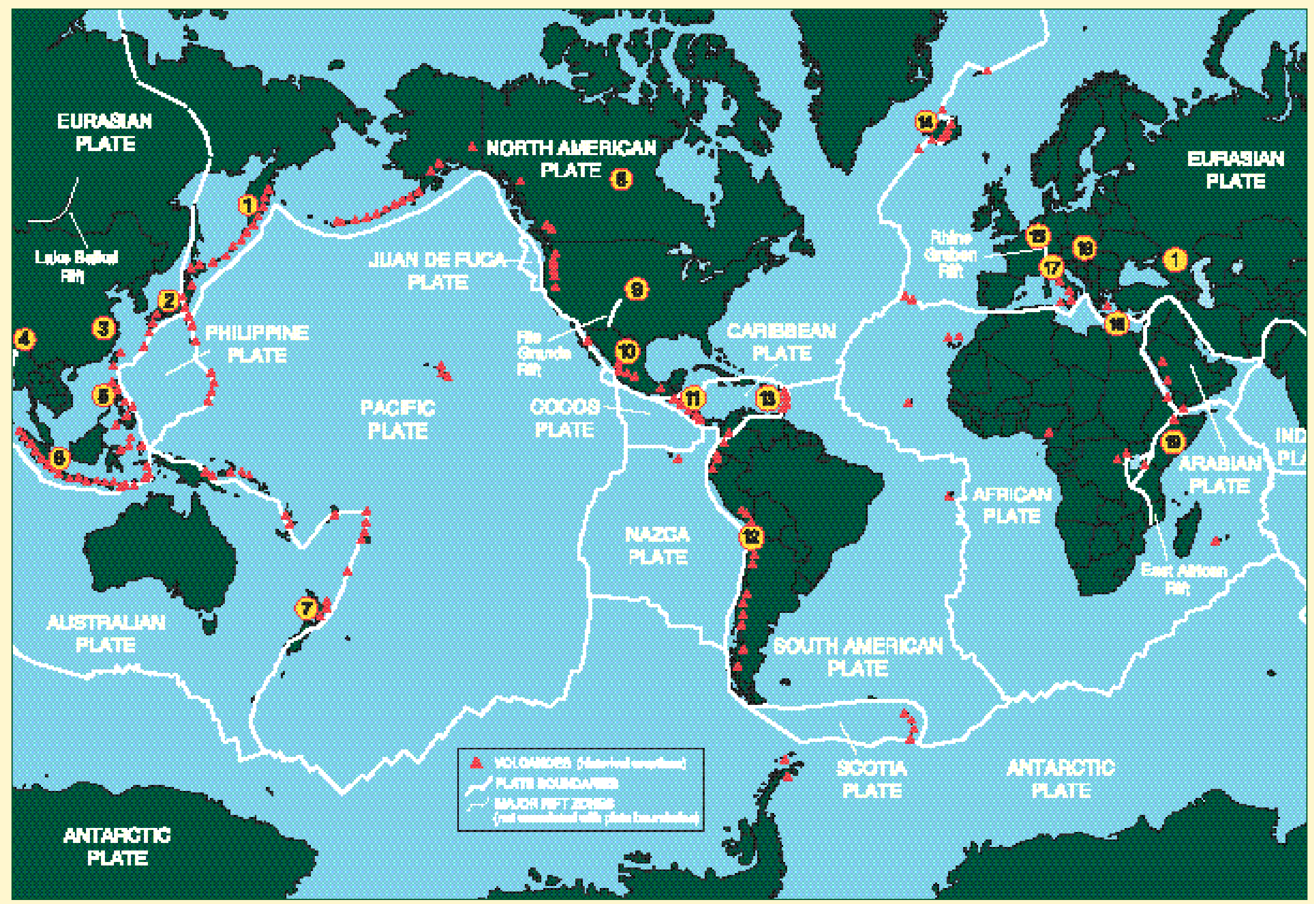
9 United States. The west coast boundary between the North American and Pacific plates is "sliding" along the San Andreas fault (many earthquakes but few volcanoes) from the Gulf of California up to northern California and subducting from the Cascade volcanoes north through the Aleutians. There are also volcanic hot spots under Yellowstone and Hawaii and intra-plate extension with hot springs in the Great Basin. California generates the most geothermal electricity with about 824 MWe at the Geysers (much less than its capacity, but still the world's largest developed field and one of the most successful renewable energy projects in history), 490 MWe in the Imperial Valley, 260 MWe at Coso, and 59 MWe at smaller plants. An additional 242 MWe are planned for operation by 2000. There are also power plants in Nevada (196 MWe now, 205 MWe more planned), Utah (31 MWe), and Hawaii (25 MWe). 75 MWe are planned in other states. Due to environmental advantages and low capital and operating costs, direct use of geothermal energy has skyrocketed to 3858 GWh/yr, including 300,000 geothermal heat pumps. In the western United States, hundreds of buildings are heated individually and through district heating projects (Klamath Falls, Oregon; Boise, Idaho; San Bernardino, California; and soon Mammoth Lakes and Bridgeport, California). Large greenhouse and aquaculture facilities in Arizona, Idaho, New Mexico, and Utah use low-temperature geothermal waters, and onions and garlic are dried geothermally in Nevada.

10 Mexico. A huge hot-water (280-360°C) geothermal system occurs at Cerro Prieto along an offshore segment of the East Pacific Rise which bounds the North American and Pacific plates. This field now produces 720 MWe from reservoirs up to 4000 m deep. In the Central Mexican Volcanic Belt, where the Cocos Plate is subducting under the North American Plate, Los Azufres produces 88 MWe and Los Humeros, 35 MWe. 65 MWe more geothermal power is planned. Mexico has over 1,500 hot springs: *one Mexican state is named Aguascalientes (hot waters).* Direct uses of geothermal heat in Mexico include industrial laundries, refrigeration, district and greenhouse heating, and fruit and wood drying.

11 Central American Volcanic Belt. Central American volcanoes extend along a subducting plate boundary through **Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica** and into **Panama.** This area, replete with active and recently active volcanoes, has many geothermal systems, most still undrilled. Development is most advanced in El Salvador, with a total of 105 MWe at Ahuachapan and Berlin. *At one time Ahuachapan provided almost half of El Salvador's electrical power.* Nicaragua has 70 MWe at its Momotombo field. Miravalles, Costa Rica, generates 70 MWe and will add 55 MWe more by December 1997. A 24 MWe plant is under construction at Zunil, Guatemala, and several other areas in Central America are being considered for development.



GLOSSARY

Aquifer - a porous or fractured body of rock carrying cold or hot water.

Basin or **Sedimentary basin** - a bowl-shaped depression in the earth filled with sedimentary rocks (rocks usually formed in water such as sandstone, limestone, etc.).

Fault - a break in the earth's crust which extends a considerable distance (horizontally and vertically) along which relative (sliding) movement occurs.

Fumarole - a flow of steam from the ground. Fumaroles can be weak or strong, noisy and superheated (temperature above boiling).

Hot spot - a relatively small area of a plate heated by a rising plume of magma from deep within the mantle which produces local volcanic activity over a long time period.

Plate - a rigid part of the earth's crust that moves relative to other plates. The map shows eight major plates and several minor ones.

Plate boundary - where two plates meet. When plates move apart they form a *rift boundary* (e.g. the North American and Eurasian plates). When they move together they can bump to form a collision boundary (e.g. the Indian and Eurasian plates) or one can slide under the other to form a *subduction boundary* (e.g. the Nazca and South American plates). Sometimes plates just slide past each other along a *fault boundary* (e.g. the San Andreas fault between the North American and Pacific Plates). Some boundaries (e.g. through Siberia) are poorly defined.

Rift - a part of the crust that has been pulled apart, usually bordered by faults. A **rift zone** is a rift with bordering faults. When rifting occurs, magma can move near the surface, forming volcanoes and geothermal systems. Rift zones may become plate boundaries.

Sinter - a white or gray surface deposit from a hot spring or geyser consisting of silica (SiO_2). Travertine is a similar deposit consisting of carbonate (usually $CaCO_3$).

ENERGY UNITS

GWh - gigawatt hour thermal. A unit of heat energy for non-electrical uses equal to 1000 megawatt hours (MWh). A GWh can heat 860 thousand tons of water one degree centigrade (or bring about 9 million quarts of freezing water to a boil).

MWe - megawatt electrical. A unit of electrical power equal to 1000 kilowatts (kWe) - enough (in the U.S) for about 1000 people.

12 Andean Volcanic Belt. The Andes run the length of the west coast of South America from western **Venezuela** through **Columbia, Equador, Peru, Bolivia, Chile** and **Argentina.** Subduction of the Nazca plate under the South American plate has produced many active and recently-active volcanoes. Several high-temperature geothermal systems occur in these sparsely populated areas, but since electrical demand is low, they are not developed. The first major United Nations geothermal project (1965) was El Tatio, Chile, which could provide all of the energy needed (about 30 MWe) to run the great copper mine at Chuquicamata, 100 km to the west. There is a 670 kWe electric power plant at Copahue, Argentina, and some geothermal waters are used for bathing and district heating.

13 The Caribbean. The Lesser Antilles islands in the eastern Caribbean are associated with a small subducting plate boundary and have some active volcanoes and fumarole fields. Exploration on **Guadeloupe** began in 1969, and drilling of shallow high temperature wells has resulted in a 4.2 MWe double flash plant (on line since 1984). Exploration has also been encouraging on **Dominica, Monserrat** and **St. Lucia**, but electricity is not yet being produced.

14 Iceland and other Atlantic Islands. Iceland is a volcanic island on the Mid-Atlantic Ridge rift zone. From the earliest settlement (ninth century) crops were planted in naturally-heated ground for rapid growth and early harvest. Iceland has many high and low temperature geothermal systems, and if hydropower were not so abundant, geothermal electrical production would be far greater. Even so, geothermal energy is Iceland's second largest source of energy, with more than 5877 GWh/yr used for heating (85% of all houses!), bathing, greenhouses, soil heating, fish farming and industry, along with 49.4 MWe of electrical generation. Geothermal power stations presently under construction will more than double the present geothermal generating capacity. Reykjavik ("Bay of Steam"), the capital, with more than 145,000 people, pipes hot water to every house at a cost less than cold water. In the 1980s Iceland decreased its dependence on imported oil by increasing heating with geothermal. **The Azores**, just off the Mid-Atlantic Ridge, have volcanoes, hot springs and a 4.6 MWe power plant. Further drilling and development is underway on San Miguel to provide 40% of its electricity needs. Geothermal hot springs and fumaroles are also found on the **Canary Islands.**

15 Northern Europe. In **France** hot water (1470 GWh/yr) is used in the Paris and Aquitaine sedimentary basins (from wells up to 1800 m deep and 45-85°C) to heat over 200,000 homes. Similar basins are found in **Belgium** (28 GWh/yr), **Germany** (about 800 GWh/yr and 50% more by 2000), **Denmark** (12.5 GWh/yr), the **Netherlands** and **England,** where heating systems like those in France are being tested. Researchers have experimented with Hot Dry Rock projects in England, France and Germany to see if water pumped into hot dry rocks can be heated economically. Heat pumps are used now to extract largely geothermal heat from (5 to 10° C) groundwater in **Switzerland** (964 GWh/yr), **Sweden** (267 GWh/yr), and other northern European countries. Parts of Switzerland, Germany, France and **Austria** have alpine geothermal spas like those in Eastern Europe.

16 Eastern Europe. Warm water (to 80°C) from deep (500-2000 m) wells in sedimentary basins is used in **Hungary** (1630 GWh/yr), **Bulgaria** (220 GWh/yr), **Slovakia** (502 GWh/yr), **Romania** (360 GWh/yr), **Poland** (206 GWh/yr) and the former **Yugoslavia** (1085 GWh/yr), mostly for swimming pools, greenhouses, and health spas. Medium-temperature geothermal aquifers exist beneath almost all of Hungary, so wells can usually be located wherever heat is needed: for bathing (45%), greenhouses (42%), industry (10%) and space heating (3%). Large amounts are also cooled for drinking. In southwest Hungary, where thermal aquifers are the deepest and hottest (to 140°C), more than 80% of all greenhouses are heated by geothermal waters. In Poland and the **Czech Republic**, hot water rich in mineral salts from crystalline rocks is used for bathing and as medicine. *The famous Czech thermal spas of Carlsbad and Marienbad have been popular for 500 years.*

17 Italy. Volcanoes and geothermal fields in central Italy are related to a poorly-understood microplate connected to the African-Eurasian plate boundary. In 1904, the Larderello field in Tuscany - used by Etruscans for baths, and later for the production from condensed steam of boric acid antiseptic - *produced the world's first geothermal electricity.* Major production at Larderello began in the 1930s, and by 1970 power capacity reached 350 MWe. Since the 80s, there has been more drilling and increased power production, bringing Italy up to a total of 592.5 MWe with 149.7 MWe reserve and 87.5 under construction. The Roman legions built 57 large Roman baths using natural hot water throughout their empire (which extended from North Africa to northern England and from Spain to Turkey). They heated these buildings using hot vapor carried through hollow tiles from the thermal springs - not the first, but undoubtedly the best-organized early use of direct geothermal heating. Modern direct use projects have expanded to 1120 GWh/yr. At Castelnuovo, greenhouses and district heating use water heated by low-pressure steam; at Monte Amiata, waste heat from a geothermal plant warms a large greenhouse complex. *The fumaroles at the Campi Flegrei near Naples are said to have been so impressive they became the model for Dante's Inferno.*

18 Eastern and Southern Mediterranean. A complex plate boundary crosses **Turkey** and **Greece** where several high-temperature geothermal prospects have been found. Since 1984, the Kizildere field in western Turkey has produced 20.4 MWe, and a dry ice plant was built in the late 80s. The plant makes dry ice using CO_2 from geothermal wells, supplying a large part of the Near East market. Lower temperature hot water (552 GWh/yr) is used for heating and greenhouses at Ankara, Izmir and elsewhere. In Greece 37 GWh/yr is used directly, and on Milos a 2 MWe flash plant was operated for several years. In **Israel** and **Jordan,** at the Red Sea - Jordan Valley Rift (between the African and Arabian plates), many hot springs (to 102°C) are used for bathing and heating (332 GWh/yr in Israel). Geothermal hot water is used in **Algeria** (460 GWh/yr) and **Tunisia** (400 GWh/yr) for bathing, greenhouses, drinking and watering crops.

19 East Africa Rift System. The active East African rift (an incipient plate boundary) runs through **Zambia, Malawi, Tanzania, Uganda, Kenya, Ethiopia** and **Djibouti** and touches six other countries. Active volcanoes occur in Kenya, Ethiopia and Tanzania. An experimental 200 kWe electrical generator operates in Zambia, and at Olkaria, Kenya there is a 48 MWe geothermal power plant and an additional 64 MWe plant will be on line by 1998. Intensive exploration is under way in Kenya to increase electricity production to keep pace with population growth. In dry parts of the area, nomadic tribes condense steam from fumaroles to water sheep and goats.

Contributors: Research and text by Alfred Truesdell. Concept and additional text by Marilyn Nemzer (Geothermal Education Office). Base map by Ellen Lougee (U.S. Geological Survey) using plate boundaries from Charles DeMets (U.Wisc.). Locations of volcanoes with historical eruptions by Robert Tilling (USGS). Most energy production figures (MWe and GWh/yr) are from articles by G.W. Huttrer and D.H. Freeston in the 1995 World Geothermal Congress Proceedings. Further information is from U.N. Conferences on Geothermal Energy in 1970, and 1975, and GRC International Meetings in 1985 and 1990. The authors appreciate the data and good advice from Marnell Dickson (IIRG), John Lund (GHC), Patrick Muffler (USGS), Marcelo Lippmann (LBL), and numerous readers of the earlier printings. All readers are invited to keep the GEO informed of projects in their countries.

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A GLOBAL VIEW

GEOTHERMAL ENERGY

ABUNDANT • CLEAN • RENEWABLE