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Geothermal Energy

RESOURCE STATUS AND ASSESSMENT

1

(DOE/ID/12850-T1)

Pre-feasibility power generation study for the Magadi Soda Company, Magadi, Kenya. (National Geothermal Association, Davis, CA (USA); GeothermEx, Inc., Richmond, CA (USA); Holt (Ben) Co., Pasadena, CA (USA)). 1989. Contract FG07-89ID12850. 102p. NTIS, PC A06/MF A01 - OSTI; GPO Dep. Order Number DE91002334.

The purpose of this report is to: (a) review the extensive published and unpublished literature on the geochemistry, hydrology and geology of Lake Magadi, Kenya, and its associated hot springs; (b) based on this review of field visits, estimate the temperature in the geothermal reservoir beneath the lake; and (c) from this, develop a plan to determine the potential for the development of geothermal electric power at Lake Magadi. 6 refs., 9 figs., 2 tabs.

2

HDR resource in south west England. Willis-Richards, J.; Thomas-Betts, A.; Sams, M.; Wheildon, J. pp. 215-223 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Numerical models of heat flow and temperature distribution in SW England have been developed independently by the Camborne School of Mines HDR Project and by the Geophysics Group at Imperial College. The thermal structure of the region is dominated by the high radiogenic heat production and large size of the Cornubian granite batholith (c 285 m y). Good constraints on the numerical models are provided by 3-D gravity survey interpretations of the space form of the batholith and by nearly 50 well determined heat flow values. These average close to 210 mW/m² on the batholith outcrop, about twice the regional value. The sensitivity

of the thermal resource to drilling and geothermal gradient cutoffs is examined. Under the land area of SW England the resource that could potentially be available for geothermal electricity generation exceeds 5×10^{20} Joules for the most conservative of criteria, and may be as much as 2×10^{21} Joules if HDR geothermal reservoirs are developed as deep as 7 km below the surface. (author).

3

Evaluation of an artificial geothermal reservoir for hot dry rock development through injection and circulation test. Kobayashi, Hideo; Tomita, Tsuneto; Okubo, Susumu; Sueyoshi, Toshihiko. pp. 447-456 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

At the Hijiori Hot-Dry-Rock Project in Japan, the temperature and pressure conditions are similar to those for a practical scale system. In the course of forming such a system, we are trying to establish the elementary technique necessary for HDR geothermal development, including the creation of an artificial geothermal reservoir, taking well logs, surveying acoustic emissions, and extracting heat from a geothermal circulation loop. In August 1988, we carried out a short term circulation test to evaluate the geothermal reservoir which has been created and stimulated previously in granodiorite. The flow rate and water temperature produced during the test were different from those we had expected. So there still remain several uncertainties that we must examine. This report discusses characteristics of the geothermal reservoir at Hijiori revealed by data from PTS logs and AE monitoring, resistivity tomography and so on, conducted during stimulation and short term circulation tests. (author).

4

A high resolution geothermal heat probe. Hudson, R.D.; Newman, D.E.;

Berod, L.D.; Eaton, G.M. pp. 1604-1609 of *Oceans '89*. Piscataway, NJ (USA); IEEE Service Center (1989). 1719p. (CONF-8909128-).

From *Oceans '89*; Seattle, WA (USA) (18-21 Sep 1989).

The design of a 16-channel heat probe capable of measuring multi-channel thermal differences as small as ± 0.0005 degrees Kelvin over a temperature range of -2 to $+30^\circ\text{C}$ is described. New low-power electronics and extensive ROM-based programs permit the instrument to be pre-programmed before deployment via a data terminal. As a result of this built-in flexibility, the instrument may be used in a variety of applications where in situ thermal gradients and/or conductivity is required.

5

Preliminary geochemical and thermodynamic assessment of the geothermal resources, Sulphur Springs area, St Lucia, W.I. D'Amore, F.; Rivera, J.R.; Giusti, D.; Rossi, R. *Applied Geochemistry (UK)*; 5: No. 5-6, 587-604 (Sep-Dec 1990).

A high-temperature geothermal resource has been located on the island of St Lucia (Windward Islands). A well drilled to a total depth of 1410 m, in the Sulphur Springs area, encountered mainly dacitic agglomerates and lava flows and a permeable zone below ≈ 1340 m, with a maximum temperature of $\approx 290^\circ\text{C}$. Well productivity decreased from an initial value close to 62 t/h to about 33 t/h under well-head pressures of 1.5 MPa after 255 h of production. Initial reservoir static pressure was 7.5 MPa. A decline in reservoir pressure of about 15% was observed at the end of the production test. During the first two days of exploitation the well produced a two-phase fluid with high steam fraction, which then developed into superheated steam with a high content of non-condensable gas exceeding 100 l/kg at standard conditions and a computed $P(\text{CO}_2)$ of 1 MPa. The average steam fraction at reservoir conditions, computed from gas composition after 120 h of production, is ≈ 0.3 . High HCl concentrations of about 300 ppm are present in the

condensate steam indicating the presence of a high concentrated boiling brine to the point of halite saturation. All data support the hypothesis of a hydrothermal hot-water system prior to drilling, that underwent a very rapid drawdown with production. (author).

GEOLOGY AND HYDROLOGY OF GEOTHERMAL SYSTEMS

6

(LA-UR-90-3442)

Three-dimensional modelling and geothermal process simulation.

Burns, K.L. (Los Alamos National Lab., NM (USA)). [1990]. Contract W-7405-ENG-36. 15p. (CONF-9010238-1). NTIS, PC A03/MF A01 - OSTI; GPO Dep. Order Number DE91002346.

From Three-dimensional computer graphics in modeling geologic structures and simulating geologic processes; Freiburg (Germany, F.R.) (7-11 Oct 1990).

The subsurface geological model or 3-D GIS is constructed from three kinds of objects, which are a lithotope (in boundary representation), a number of fault systems, and volumetric textures (vector fields). The chief task of the model is to yield an estimate of the conductance tensors (fluid permeability and thermal conductivity) throughout an array of voxels. This is input as material properties to a FEHM numerical physical process model. The main task of the FEHM process model is to distinguish regions of convective from regions of conductive heat flow, and to estimate the fluid phase, pressure and flow paths. The temperature, geochemical, and seismic data provide the physical constraints on the process. The conductance tensors in the Franciscan Complex are to be derived by the addition of two components. The isotropic component is a stochastic spatial variable due to disruption of lithologies in melange. The deviatoric component is deterministic, due to smoothness and continuity in the textural vector fields. This decomposition probably also applies to the engineering hydrogeological properties of shallow terrestrial fluvial systems. However there are differences in quantity. The isotropic component is much more variable in the Franciscan, to the point where volumetric averages are misleading, and it may be necessary to

select that component from several, discrete possible states. The deviatoric component is interpolated using a textural vector field. The Franciscan field is much more complicated, and contains internal singularities. 27 refs., 10 figs.

7

Evaluation of a hydrothermal anomaly near Ennis, Montana.

Leonard, R.B.; Wood, W.A. List 969. Alexandria, VA (USA); U.S. Geological Survey (1988). 53p. U.S. Geological Survey, 604 S Pickett Street, Alexandria, VA 22304 (USA).

USGS Technical Paper P1044-K.

Ennis Hot Spring has a temperature of about 83° C and issues from valley fill in southwestern Montana. Maps and diagrams illustrating the results of test drilling and of geophysical and geochemical studies near this spring are included in the text. Discharge from Ennis Hot Spring, and from a flowing test hole in which temperature was 94° C in fractured gneiss, consists mainly of meteoric water heated to at least 165° C during circulation in deep fracture zones.

8

The geology and remarkable thermal activity of Norris Geyser Basin, Yellowstone National Park, Wyoming. White, D.E.; Keith, T.E.C.; Hutchinson, R.A. List 956. Alexandria, VA (USA); U.S. Geological Survey (1988). 84p. U.S. Geological Survey, 604 S Pickett Street, Alexandria, VA 22304 (USA).

USGS Technical Paper P1456.

Norris Geyser Basin is adjacent to the north rim of the Yellowstone Caldera, one of the largest volcanic features of its type in the world. Hydrothermal activity may have been continuous for >100,000 years B.P. Norris Basin includes the highest erupting geyser of recent water types, colors of organisms and inorganic precipitates, frequent changes in activity and chemistry, and very high subsurface temperatures (>240° C). Norris Basin is only a part of the Norris-Mammoth Corridor that strikes north from the caldera rim to Mammoth Hot Springs. Norris Basin has a heat flow roughly 10 percent of that of the Yellowstone Caldera and requires an estimated 0.01 km³ of rhyolitic magma per year—a quantity far greater than the corridor's rate of eruption.

9

The Pannonian Basin. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p. American Association of Petroleum Geologists, P.O. Box 979, Tulsa, OK 74101 (USA).

This book contains chapters on basin evolution. Included are the following chapters: late Cenozoic tectonics of the Pannonian Basin System, some aspects of Neogene biostratigraphy in the Pannonian Basin, lithosphere and evolution of the Pannonian Basin, variations in extensional styles at depth across the Pannonian Basin System.

10

Hydrogeothermic studies in the hot dry rock project at Soultz sous Forêts. Schellschmidt, R.; Schulz, R. pp. 65-74 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Studies were carried out in the HDR-Project at Soultz sous Forêts to determine the natural temperature field of the test site and to detect water accepting zones within the borehole GPK 1. The undisturbed temperature field was measured in the borehole GPK 1 and in three oil wells in the surroundings. The virgin rock temperature is about 140° C at 2000 m depth. The temperature gradient decreases from 100 mK m⁻¹ to 30 mK m⁻¹ at about 1100 m. The heat flow density is more than 180 mW m⁻² in the Muschelkalk and about 780 mW m⁻² in the granitic section. This validates the assumption of a horizontal convective heat transfer within the aquifers. The results of a production test show that there is only one inflow zone in borehole GPK 1 at 1812 m. Three injection tests, using different injection flow rates, were conducted. A total of about 20 water accepting joints could be detected by temperature measurements. A second major outflow at 1728 m was encountered besides the one at 1812 m. About 47% of the injected water was lost at 1728 m and about 53% at 1812 m. The high resolution temperature measurements showed definitely which joints are water accepting (partly dependent on pressure) and which are not. (author).

11

In situ stress measurements in deep wells. Green, A.S.P.; Pine, R.J.;

Jupe, A. pp. 85-97 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A knowledge of the in situ stresses is essential in the development of an HDR reservoir. The stresses determine the pressures required to induce reservoir growth and the orientation of growth, whether it be by tensile fracturing or shear stimulation of existing joints. In Cornwall, the in situ stresses have been determined down to 2.5 km by hydrofracture stress measurements (HFSM) in the wells and overcoring in local mines at 790 metres. At depths down to 6-7 km, the depths at which temperatures are high enough to generate electricity in SW England, HFSM are unlikely to be practical. There are a number of other techniques that can be used. Borehole breakouts, seismic wave polarisations and microseismic fault-plane solutions may provide stress orientation but limited information on magnitude, whilst hydraulic tests and laboratory measurements of core may provide information on stress magnitudes. These alternative methods of determining the stress tensor and their applicability to deep wells will be reviewed. It will be seen that no single method is likely to provide information on the complete stress tensor at a depth of 6 km and that it will be necessary to employ a number of different techniques. (author).

12

Rock stress measurements at the HDR research site at Fjaellbacka, Sweden. Wallroth, T. pp. 98-107 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Rock stress measurements have been conducted using different techniques as part of the Swedish Hot Dry Rock research project, carried out at Fjaellbacka in the Bohus granite massif. Overcoring, hydraulic fracturing and hydraulic tests on preexisting fractures (HTPF) were used to determine the in situ stress situation. Hydraulic injection test data gave information mainly about the vertical stress component which was found to correspond to the weight of overburden at several injection

depths down to 500 m. The stress orientations are poorly constrained, but both the overcoring and hydrofracturing method indicated a major horizontal compression striking NW-SE, which was also confirmed by inversion of fault plane solution data from induced microseismicity. The stress situation proposed by the hydrofracturing results (horizontal stresses in excess of the weight of overburden down to 450-500 m) is in good agreement with the observed reservoir growth and behaviour and these results are considered as the most reliable as compared to the other measurements. (author).

13

Cenozoic tectonic history of the Carpathians. Sandulescu, M. pp. 17-26 of *The Pannonian Basin*. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

This paper discusses how the Carpathian Mountains formed during closure of the Tethys ocean during Cretaceous and Miocene convergent events. Three main shortening events occurred in the outer flysch Carpathians during Miocene time: early Miocene events (old Styrian phase, 18-20 Ma), middle Miocene events (young Styrian phase, ~ 15.5 Ma), and late Miocene events (Moldavian phase, 11-12 Ma). Early Miocene events include deformation and thrusting of the Pienides (Pieniny Klippen belt and Magura group nappes), en bloc overthrusting of the inner Dacides over the Pieniny Klippen belt, and thrusting within the most internal Moldavian nappes (Audia-Czernahora, Macla, Convolute flysch, and Dukla(?) units). Middle Miocene events include thrusting within the Moldavian nappes (Tarcau, Marginal Folds, Silesian, Skole, Subsilesian, and Waschberg units). Late Miocene events include thrusting within the outer Moldavian nappes (Marginal Folds, Tarcau, Skole, Subsilesian, and Silesian units) and the Subcarpathian nappe. Minor Pliocene-Pleistocene folding occurred in the Subcarpathian nappe in the area of the southeast Carpathian bend. All of these Pienide and Moldavian nappes consist only of sedimentary rocks, without their original crystalline basement.

14

Formation of geothermal resources at lithospheric subduction zones.

Reeder, J.W. pp. 7-18 of *Applied geothermics*. Economides, M. New

York, NY (USA); John Wiley and Sons Inc. (1987). 237p.

The known geothermal fields within subduction zones owe their existence to tectonic and magmatic processes, and to more localized geological and hydrological conditions. Such fields are associated with Quaternary volcanic or intrusive activity that was originally generated by the subduction of crust underneath the upper mantle (asthenosphere). The chemical nature of these intrusive rocks appears to reflect the type of hydrothermal resources to be expected. Such fields are also associated with a permeable host rock that contains the hydrothermal systems. The author examines the formation of geothermal resources at lithospheric subduction zones. This is done by examining the nature of the driving heat source and the nature of the hydrothermal reservoir. The purpose of such an approach is to identify the significant tectonic, magmatic, geological and hydrological environments within subduction zones that appear favourable for containing potentially exploitable hydrothermal reservoirs.

15

Evaluation of jointing in the carmenellis granite. Randall, M.M.; Nicholls, J.; Willis-Richards, J.; Lanyon, G.W. pp. 108-123 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The circulation of the Hot Dry Rock geothermal reservoir at Rosemanowes is dependent on the stimulation and manipulation of the natural joint system of the rock mass. The aim of the manipulative techniques is to enhance and manage the natural flow network. The assessment of these techniques can only effectively be done by computer based numerical modelling due to the complexity of the problem and the great number of possible permutations of operating conditions. A key parameter in this problem is the distribution and connectivity of the natural jointing flow network which has been studied by the use of conditional simulation to model observed joint properties. Observational data include surface and underground mapping, remote sensing and borehole logging, whilst indirect observation of the system is achieved through the thermal behaviour of the reservoir, its response to tracers both

natural and artificial, and through the pattern of microseismicity generated by stimulation and circulation. This paper evaluates the jointing pattern seen at the surface, in underground exposures in mines and in deep boreholes down to depths of 2.5kms and presents tentative models aimed at representing the joint network. (author).

16

European HDR project at Soultz sous Forêts. Gerard, A.; Kapfelmeyer, O. pp. 170-179 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A European Hot-Dry-Rock (HDR) project was set up in 1987 near Soultz sous Forêts in Northern Alsace, at the western rim of the Upper Rhine Graben. The site is situated close to the centre of a vast geothermal anomaly in which the geothermal gradient in the sedimentary cover of the granite base is more than twice the normal value. A 2 km deep investigation borehole has been drilled. The results of petrographic, hydraulic fracturing, stress field and seismic studies which are necessary for the planning and pre-evaluation of a HDR reservoir are summarized. At present the construction of a HDR heat exchanger is under consideration as a first step in the construction of a HDR demonstration plant. (UK).

17

Lithosphere and evolution of Pannonian basin. Meissner, R.; Stegena, L. pp. 147-152 of The Pannonian Basin. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

The Pannonian basin is an area of late Tertiary subsidence. Geophysical features such as an updoming of the mantle, a thinned lower crust, and a strong geothermal anomaly are all restricted to the basin within its geologic boundaries. Three theories are offered for the formation of the basin: a gabbro-eclogite phase transition, lithospheric stretching, or mantle diapirism. The first theory suffers serious problems in a heated environment; the second may have contributed a certain amount to the subsidence process with a possible stretching of 10-40%; the third suggestion seems to play the

most important role for the geologic development of the basin, related most probably to a back-arc situation in connection with subduction processes in the Carpathian arc. It is shown that a modification of lithospheric stretching, such as a differential stretching, and diapirism must be intimately related to each other and both are consequences of an extensional environment.

18

Preliminary sedimentological investigation of a Neogene depression in the Great Hungarian Plain. Berci, I. pp. 107-116 of The Pannonian Basin. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

The Mako-Hodmezovasarhely trench, situated in the southeastern part of Hungary, is filled with more than 7 km of thick Miocene to Holocene sedimentary rocks. Seismic profiles, stratification features in core samples, grain size distributions, and well logs in three boreholes reveal a shoaling-upward sequence within the trough. The authors have distinguished five principal depositional environments that they interpret (from bottom to top) as: coarse-grained basal turbidites; deep basin fine-grained sediments; delta front turbidites; delta slope sand, silt, and marl; and shallow lake to braided stream deposits.

19

Seismic stratigraphy and depositional framework of sedimentary rocks in the Pannonian basin in southeastern Hungary. Mattick, R.E.; Phillips, R.L.; Rumpler, J. pp. 117-146 of The Pannonian Basin. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

Seismic stratigraphic analyses and studies of core samples from three wells indicate that infilling of the Pannonian basin of Hungary resulted primarily from deltaic sedimentation from the northwest, north, and northeast. Infilling of the basin involved a single cycle of sedimentation which probably began in Sarmatian or earliest Pannonian time when water depths in the basin were >1,000 m. The subsequent history of the basin, during Pannonian and Quaternary time, reflects continuously shoaling waters. This shoaling resulted from sediment input rates that were generally higher than basin subsidence rates.

20

Potential future sites for HDR in Italy. Cappetti, G.; Luccioli, F.; Carella, R. pp. 201-212 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906142-).

From International hot dry rock (HDR) geothermal energy conference; Camborne (UK) (27-30 Jun 1989).

Research into Hot-Dry-Rock (HDR) systems is in an advanced stage of development in various countries around the world and has led to significantly increased knowledge in this field. It is recognized that HDR systems tapping very high temperature rocks (above 250°C) at a moderate depth have the best chance of being economic. Italy is among the countries where these conditions are present and where testing is planned. Wells drilled for exploratory and development purposes have produced evidence of large volumes of impermeable rock systems with temperatures of 250°-300°C at depths of 2000-2500 m at the margins of hydrothermal fields. (author).

21

Borehole geometry in the Soultz well and its implication for regional stress orientation. Mastin, L.G.; Heinemann, B.B. pp. 591-592 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The stresses in the Earth's crust produce a compressive stress concentration on the wall of a vertical borehole which is greatest at the azimuth parallel to the least compressive regional horizontal stress, and least at the azimuth perpendicular to this stress. Zones of failure and spalling ("breakouts") at the former azimuth may cause the borehole diameter to enlarge, whereas at the latter, azimuth fluid pressure in the borehole may cause vertical hydraulic fractures to form. In this paper we use logs of the four-arm caliper tool and the ultrasonic borehole televiewer to identify these features and use them to interpret the stress orientation in the vicinity of the Soultz borehole. (author).

22

Application of chemical geothermometers to some Tunisian hot springs. Dhia, H.B.; Meddeb, N. *Geothermics (International Journal of*

Geothermal Research and its Applications (UK); 19: No. 1, 87-104 (1990).

Forty-five Tunisian hot springs are studied as geothermal indicators. Several chemical geothermometers are applied in this sedimentary geological environment. Hot springs are selected among 70 existing within the country. Selection is based on complete water analyses with a good ionic balance. Measured temperature ranges from 21 to 73°C and discharge rates range from 0.1 to 40 l/s. Studied springs show mainly chloride type waters. Geothermometers applied are: silica, Na/K, Na-K-Ca, Na-K-Ca-Mg, Na/Li and Mg/Li. Temperatures estimated by those geothermometers are plotted against the measured values to evaluate the applicability of the geothermometers used. The Na/K and Na/Li geothermometers appear to give unreliable results, as water composition seems to be greatly affected by interaction with the evaporitic and dolomitic rocks that are ubiquitous in Tunisia. The Na-K-Ca-Mg, Mg/Li and silica geothermometers seem to give plausible values, emphasizing the role played by Mg and its importance for Tunisian hot waters.

23

The Fuzhou geothermal system (People's Republic of China): Modelling study of a low temperature fracture-zone system. Hochstein, M.P.; Zhongke, Y.; Ehara, S. *Geothermics (International Journal of Geothermal Research and its Applications)* (UK); 19: No. 1, 43-60 (1990).

A conceptual model is presented which explains the likely heat and mass transfer of the Fuzhou system in both the natural and exploited states. The model was extended to 7 km depth to simulate a deep heat sweep of naturally convecting meteoric waters in a granitic crust. The permeability structure was obtained by numerical modelling, using observed well temperatures, the overall pressure response of the reservoir induced by production, and inferred natural heat loss (≈ 5 MW) as matching parameters. Modelling has shown that the Fuzhou system can be simulated as a large natural convection cell which sweeps heat from upper crustal levels (≥ 5 km depth) into segments of a deep-reaching fracture-zone of small cross-sectional extent. The system is driven by the crustal heat flow (about 70 mW/m²) and terrain-induced forced convection. A period of about 2×10^6 yr is required for convection to get established and to

extend to the surface. The secular fluid movements at and above the resource base reduce significantly the heat flow in the upper 5 km of the crust over an area of at least 400 km².

24

Geothermal pre-feasibility study in the Phetchabun area of northern Thailand. Ramingwong, T.; Suvagondha, F.; Uttamo, W.; Lerdthusanee, S.; Wattananikorn, K.; Jurasai, L.; Singhasene, C. *Nippon Chinetsu Gakkaishi (Japan)*; 12: No. 3, 229-237 (25 Jul 1990).

Four hot spring areas are located in Phetchabun province, approximately 350 km northeast of Bangkok, Thailand. The surface temperatures range from 35 to 47 °C and the discharges are generally small. Geological, geophysical, and geochemical surveys were carried out in order to select exploratory drilling spots for the geothermal energy system. Field mapping and compilation of a geological map and cross-sections, petrologic studies and fracture analyses, resistivity prospecting, and quality examination of hot spring and ground water were carried out. They concluded that the Phetchabun geothermal system is principally a fracture-controlled system and a low enthalpy system with subsurface temperatures of around 120 °C. They consider that the Pu Khan hot spring is the most viable for exploration drilling. The exploratory drilling is considered to encounter hot water upflowing along fractures at a depth of not more than 100 m. The potential uses of this geothermal resource will depend on the temperature and discharge quantity of the upflowing hot water. 9 refs., 7 figs., 2 tabs.

25

Microseismic activity beneath active fumarolic areas.: Case study at Kuju-ioyama in central Kyushu, Japan. Ehara, S.; Bito, T.; Oi, T.; Kasai, H. *Nippon Chinetsu Gakkaishi (Japan)*; 12: No. 3, 263-281 (25 Jul 1990). (In Japanese).

This report shows the results of the microseismic observation which was performed at Kuju-iwoyama situated in an explosion crater of Kuju Volcano in Central Kyushu. This region is the most active fumarolic area. The natural heat discharge is estimated as about 100 MW, and most of it (more than 95 percent) are from steaming grounds and fumaroles. The temperatures of the fumaroles exceed 200 °C and the

maximum temperature is 480 °C. A temporary seismic observation net was installed around the fumarolic area, and the investigation of microseismic activity was carried out. As a result, a high microearthquake activity zone was detected just beneath the fumarolic area down to about 1.5 km below the surface. Lower P wave velocity and low Poisson's ratio also obtained in this zone. They inferred that there are a relationship between such characteristics of high microearthquake activity and structure, and the existence of the two-phase reservoir beneath the fumarolic area. They consider that such microseismic observation is a useful technique to define geothermal reservoirs with high pore fluid pressure beneath fumarolic regions. 21 refs., 17 figs., 1 tab.

GEOTHERMAL EXPLORATION AND EXPLORATION TECHNOLOGY

26

(USGS-OFR-88-471)

Chemical and hydrologic data for selected thermal-water wells and nonthermal springs in the Boise area, southwestern Idaho. Young, H.W.; Parlman, D.J.; Mariner, R.H. (Geological Survey, Boise, ID (USA)). 1988. 41p. OSTI; NTIS; GPO Dep.; USGS, Books and Open-File Reports, Federal Center, Bldg. 810, Box 25425, Denver, CO 80225. Order Number DE91005009.

This report presents data collected during January to July 1988 from 37 thermal-water wells and 3 nonthermal springs in the Boise area, southwestern Idaho. Included are well and spring locations; well-construction, water-level, and water-use information; hydrographs of water levels in 3 wells; chemical and isotopic analyses of water from 18 thermal-water wells and 3 nonthermal springs; and drillers' logs from 23 wells. The purpose of the report is to make these data conveniently available to the public. 5 figs., 3 tabs.

27

Mineral resources of the Eagletail Mountains Wilderness Study Area, La Paz, Maricopa, and Yuma counties, Arizona. Miller, R.J.; Gvay, F.; Hassemer, J.R.; Hanna, W.F.; Pitkin,

J.A.; Hornberger, M.L.; Jones, S.L.; Lane, M.E. List 976. Alexandria, VA (USA); U.S. Geological Survey (1989). 18p. U.S. Geological Survey, 604 S Pickett Street, Alexandria, VA 22304 (USA).

USGS Bulletin B1702-G.

The Eagletail Mountains Wilderness Study Area is located in southwestern Arizona. There are no identified resources in this study area. An area near and extending into the northwest corner of this study area has a moderate potential for gold, silver, lead, zinc, and copper; a surrounding area has a low potential for these same commodities. An area northeast of Cemetery Ridge and extending along the southern boundary of this study area has a low potential for gold, silver, lead, zinc, copper, manganese, barium, and molybdenum. Along Cemetery Ridge, which crosses the southern boundary of this study area, is an area with a moderate potential for gold and lead and a low potential for gold, barium, copper, manganese, molybdenum, and zinc.

28

Mineral resources of the Henry's Lake Wilderness Study Area, Fremont County, Idaho. Tysdal, R.G.; Peters, T.J. List 963. Alexandria, VA (USA); U.S. Geological Survey (1988). 16p. U.S. Geological Survey, 604 S Pickett Street, Alexandria, VA 22304 (USA).

USGS Bulletin B 1718D.

The authors report on the 350-acre Henry's Lake Wilderness Study Area in the southern part of the Madison Range. Fremont County, Idaho, and is about 17 miles north of the hamlet of Islan Park. The southwestern part of the wilderness study area, along the Madison Range Fault, is rated as having a moderate energy resource potential for geothermal water, and the remainder of the study area has a low potential for this resource.

29

Solute geochemistry of the Snake River plain regional aquifer system, Idaho and eastern Oregon. Wood, W.W.; Low, W.H. List 963. Alexandria, VA (USA); U.S. Geological Survey (1988). 79p. U.S. Geological Survey, 604 S Pickett Street, Alexandria, VA 22304 (USA).

USGS Technical Paper P1408-D.

The authors report that proposed geochemical reactions controlling solutes in the Snake River plain aquifer

system are precipitation of calcite and silica; dissolution of olivine, pyroxene, pyrite, and and-hydrate; and weathering of plagioclase. About 20 percent of solutes are from aquifer framework weathering. The remaining solutes are from tributary drainage basins. Proposed geochemical reactions in the geothermal system are dissolution of fluorite, anhydrite, calcite, and feldspars; oxidation of pyrite; and ion exchange. Geothermal water residence time is about 17,700 years.

30

Mineral resources of the Silver Peak Range Wilderness Study Area, Esmeralda County, Nevada. Keith, W.J.; Turner, R.L.; Blakely, R.; Ehmann, W.J.; Close, T.J. List 956. Alexandria, VA (USA); U.S. Geological Survey (1988). 20p. U.S. Geological Survey, 604 S Pickett Street, Alexandria, VA 22304 (USA).

USGS Bulletin B1731-C.

The Silver Peak Range Wilderness Study Area, which includes approximately 17,850 acres, is underlain largely by volcanic rocks, and associated sediments of Tertiary age. Propylitic, argillic, and silicic alteration is widespread. No resources were identified in the study area, but the entire study area has high to low potential for epithermal gold and silver resources. One small area has low potential for marble resources, and the entire area has low potential for geothermal and oil and gas resources.

31

Mineral resources of the Tunnison Mountains Wilderness Study Area, Lassen County, California. Peterson, J.A.; Friskin, J.G.; Plouff, D.; Goeldner, C.A.; Muntz, S.R. List 955. Alexandria, VA (USA); U.S. Geological Survey (1988). 11p. U.S. Geological Survey, 604 S Pickett Street, Alexandria, VA 22304 (USA).

USGS Bulletin B1706-A.

The part of the Tunnison Mountain Wilderness Study Area requested for mineral surveys encompasses 8,445 acres in northeastern California. The area contains Tertiary pyroclastic rocks, basaltic andesite flows, and basalt flows. There are no identified resources and it is unlikely that metallic minerals or oil and gas are present. Geothermal areas south and southwest of the study area suggest that the area may have potential for geothermal energy sources. Therefore, it has been

assigned low potential for such resources; however, the mountainous geologic terrane differs from the sediment-filled valleys where the known resources are located.

32

Mineral resources of the Gila Lower Box Wilderness Study Area, Grant and Hualapai counties, New Mexico. Richter, D.H.; Lawrence, V.A.; Barton, H.; Hanna, W.; Duval, J.S.; Ryan, G.S. List 955. Alexandria, VA (USA); U.S. Geological Survey (1988). 13p. U.S. Geological Survey, 604 S Pickett Street, Alexandria, VA 22304 (USA).

USGS Bulletin B1735-A.

This report presents an investigation to appraise the identified resources and to assess the potential for undiscovered resources of the Gila Lower Box Wilderness Study Area, southwestern New Mexico. Identified resources of manganese occur within 0.25 mi of the study area boundary, but none are known within the study area. The eastern part of the study area has a high mineral resource potential for manganese, and the western part has a moderate mineral resource potential for manganese. The entire study area has a low mineral and energy resource potential for other metals, gemstone, geothermal energy, oil and gas.

33

Assessing the energy potential of geothermal fields by means of environmental isotopes. Gonfiantini, R. (International Atomic Energy Agency, Vienna (Austria)). pp. 51-69 of Applications of nuclear techniques and research 1990. Vienna (Austria); IAEA (1990). 81p.

This article describes the major features of geothermal energy resources, how they may occur in nature and how they can be assessed with geochemical methods, including those based on environmental isotopes variations. Applications of isotopes to geothermal exploration are included in the IAEA programme dedicated to water resources assessment, water being the major component of geothermal fluids. 10 figs, 1 tab.

34

A method for lithogenetic subdivision of Pannonian (s.l.) sedimentary rocks. Szalay, A.; Szentgyorgyi, K. pp. 89-96 of The Pannonian Basin. Royden, L.H. Tulsa, OK

(USA); American Mining Congress (1988). 390p.

A method is presented for subdividing the Neogene sedimentary rocks of the Pannonian basin based on the fact that these Neogene sediments are made up almost exclusively of pelite and psammite. The alternation of pelitic and psammitic layers and their thicknesses are known from geophysical well logs. The authors construct lithologic trend diagrams for several drill holes, and for each drill hole we obtain a characteristic trend diagram. Changes in lithologic trends can be used to define lithogenetic units, which may be used as a basis for subdividing the Pannonian strata. Similar lithologic trend diagrams from neighboring boreholes allow for local correlation of lithogenetic units. This correlation has been extended to a regional system of lithogenetic units through analysis of many lithogenetic trend curves and reflection seismic sections.

35

Correlation of central Paratethys, eastern Paratethys, and Mediterranean Neogene stages. Steininger, F.F.; Muller, C. pp. 79-88 of The Pannonian Basin. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

The most important biostratigraphic datum planes and radiometric and paleomagnetic events are given for the correlation of the European Neogene stage systems of the circum-Mediterranean area.

36

Contribution of seismic reflection data to chronostratigraphy of the Pannonian basin. Horvath, F.; Pogacsas, G. pp. 97-106 of The Pannonian Basin. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

Available magnetostratigraphic and radiometric age data for Neogene sedimentary rocks within the Great Hungarian Plain can be shown to be consistent with each other if primary seismic reflectors are interpreted as geological time lines. Using this premise, the authors argue that the boundary between the lower and upper Pannonian (s.l.) units is diachronous and varies from 9 Ma to about 7 Ma. Lithogenetic units, determined by analyzing the trend of lithologic development in drill holes, and the correlation of these units by reflection seismic data provide

a means of dividing the lower Pannonian into three subunits (Pa_1^{1a} , Pa_1^{1b} , and Pa_1^{2}). By combining age data with these correlations, the unconformity between synrift and postrift sediments can be shown to represent a time gap of one to several million years in many places in the Pannonian basin.

37

Determination of petrographic and tectonic characteristics at Soultz borehole (Bas-Rhin, France) using wire logging, SABIS borehole televiewer, cutting and core analysis. Tenzer, H.; Heinemann, B.; Traineau, H.; Jung, R.; Schulz, R.; Mastin, L.; Cautru, J.P.; Genter, A.; Schellschmidt, R. pp. 124-135 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Well logging with the Acoustic High Temperature Borehole Televiewer (BHTV; SABIS-System) provides a continuous recording of the natural planar discontinuities at the borehole wall and sampling data about the borehole geometry. The orientation of strike and dip directions of the planar discontinuities is obtained by the evaluation of the televiewer logs. The orientation of natural joint systems in the basement, which can be hydraulically activated, and their relationship to the local stress field are investigated by comparing the televiewer data with the results of the hydraulic tests and stress measurements. The newly developed SABIS-Borehole Televiewer was tested in the HDR-borehole Urach 3 by logging tests and prepared for well logging in the exploratory well GPK-1 at Soultz in France. The BHTV was tested down to a depth of 3364 m. The in-situ temperature at this depth is 143°C. The electronics of the televiewer worked faultlessly up to an inside temperature of the tool of 152°C without using an additional thermal shield. (author).

38

Geochemical studies at Soultz-sous-Forêts (France). Pauwels, H.; Criaud, A.; Brach, M.; Vuataz, F.D.; Fouillac, C. pp. 136-145 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

During the past 3 years research has been conducted on the suitability for Hot-Dry-Rock (HDR) energy production of a site close to Soultz-sous-Forêts in Alsace (France). So far, a single borehole, called GPK1, of depth 2000m has been completed. The thickness of the granite is 600m, covered by several sedimentary layers. Numerous permeable joints have been recognised during drilling and hydraulic tests. A main fracture was encountered at 1820m, producing a highly saline fluid at 137°C. Further tests have indicated that this permeable zone is connected to a major reservoir. Detailed geochemical investigations have been carried out to improve the knowledge of this possible HDR site. We present here the characteristics of the formation fluid and show that the occurrence of brine in the granite provides a means of quantifying the extent of mixing and then dissolution of the granitic rocks when freshwater is injected. Secondly, results from the use of chemical tracers and the problems associated with a crystalline environment and at a temperature 140°C are discussed with special emphasis on a thermally reactive ester. (author).

39

A trend of NEDO's hot dry rock project. Hirakawa, Seiichi; Tomita, Tsuneto; Kuriyagawa, Michio; Sueyoshi, Toshihiko. pp. 180-189 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The trends in Japanese (NEDO's) Hot Dry Rock Research Projects are described. These include the Yakedake Project, the Joint Fenton Hill Project in the USA and the Hijiori Project. The emphasis is on hot dry rock engineering. (author).

40

Variations in extensional styles at depth across the Pannonian basin system. Royden, L.H.; Dovenyi, P. pp. 235-256 of The Pannonian Basin. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

This paper reports extensional styles at depth beneath five basins within the

Pannonian basin system (Vienna, Danube, Zala, and Transcarpathian basins and Great Hungarian Plain) evaluated by applying a simple graphical technique to subsidence and heat flow data from wells in each basin. The average rate of thermal subsidence in each basin, excluding the Transcarpathian basin, indicates the same rate of cooling of the lithosphere as does the surface heat flow measured in the same basin. Thermal subsidence rates, heat flow, and effective mantle thinning or (heating) show a systematic increase with increasing distance from the Carpathian thrust front. Initial subsidence and crustal thinning show little to no correlation with distance from the thrust front. These results are consistent with thin-skinned extension (involving only crustal rocks) beneath the Vienna basin, which is located near the thrust front.

41

The use of VSP and cross-hole seismic surveys in the development of HDR reservoirs. Stewart, R.C.; Jones, R.H. pp. 509-519 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A number of active seismic surveys have been carried out at the Camborne School of Mines hot dry rock geothermal energy project since 1982. The purpose of these has been to detect any changes in the geothermal reservoir caused by stimulation of the reservoir or by the long-term circulation of water. Cross-hole seismic surveys reveal large changes during long-term water circulation and clearly have potential for mapping fractured regions that have contracted due to cooling and thus contain a high proportion of water. Vertical seismic profiles (VSPs) are also sensitive to such regions. However, VSPs are most useful in assessing the effects of stimulations: the analysis of tube waves seen in VSP surveys provides a means of mapping sizeable fractures that are intersected by a borehole. (author).

42

The potential of electrical resistivity methods to detect hydraulically connected fractures. Jackson, P.D.; Busby, J.P.; Rainsbury, M.; Mooney, P.; Reece, G. pp. 520-532 of *Hot dry*

rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Electrical resistivity modelling has been used to assess the contribution electrical resistivity methods could make to fracture mapping and circulation assessment within a Hot Dry Rock (HDR) reservoir. It is shown that enhanced resolution arrays could provide additional information on the near borehole zone which provides the majority of resistance to flow, and that cross-hole arrays can provide information on the interborehole structure. The results can be dramatically enhanced if conductive fluid is injected in one borehole enabling hydraulic connections to be identified as changes in cross borehole electrical impedance. Impedances can be monitored immediately after tracer injection and a scheme is proposed to infer the tracer movement prior to breakthrough in the recovery well. (author).

43

A study of the applicability of geotomography to rock investigations. Saito, H.; Shima, H. pp. 533-546 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

To study the applicability of geotomography to rock investigation, experiments using seismic tomography and resistivity tomography were conducted at a dam site. Numerical trials of both tomographic methods were conducted to demonstrate the appropriateness of a reconstruction algorithm developed by the authors, expecting that it will be effective in rock investigation. The site consists mainly of granodiorite, with a complex pattern of weathering and fault zones. Using seismic tomography, weathered layers and fault zones were identified as low velocity zones. Using resistivity tomography, a weathered layer near the surface and deeply located fresh rock were identified as high resistivity zones and fault zones as low resistivity zones. Beside these experiments, before and after the injection test by salt water, resistivity tomography was carried out. The results showed that resistivity tomography is

effective in evaluating the continuity of fault zones. The authors believe seismic tomography can be used not only for mapping of fault and fracture zones within geothermal zones, but also to provide valuable information for improving accuracy with which the source of seismic events can be located. Resistivity tomography in combination with a tracer injection test can also be quite an effective method for evaluating fault and fracture zones. (author).

44

Application of tracers to the determination of the geometry of the Mayet de Montagne heat exchanger. Cordier, E.; Goblet, P.; Bigot, S.; Chupeau, J.; Treuil, M.; Toulhoat, P. pp. 575-588 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Tracer tests are used to estimate the exchange surface of a geothermal doublet in fractured rock. Several tracers are used simultaneously for three different series of measurements. From the non-sorbed or weakly sorbed tracer curves, a picture of the reservoir consisting of at least two independent major conductive zones emerges. The flow rates in each channel are in good agreement with independent estimations. Values for the surface of an equivalent parallel single fracture are obtained for each channel. (author).

45

A geothermal field model based on geophysical and thermal prospectings in Nea Kessani (NE Greece). Thabassoulas, C.; Tsokas, G.N. *Geothermics (International Journal of Geothermal Research and its Applications)* (UK); 19: No. 1, 77-86 (1990).

This study deals with geophysical exploration for geothermal resources in Nea Kessani area, NE Greece. The results of some deep electrical sounding (AB = 6000 m) with the interpretation of a gravity profile crossing the investigated area are considered together with thermal investigations. All subsequent information are used to highlight a subsurface geothermal field model.

46

A survey of geothermal reservoir properties. Bjornsson, G.; Bodvarsson, G. *Geothermics (International Journal of Geothermal Research and*

its Applications) (UK); 19: No. 1, 17-28 (1990).

This paper presents results of a literature survey on thermal, hydrological and chemical characteristics of geothermal reservoirs. The data are presented in a table summarizing important fluid and rock parameters. The primary parameters of interest are the permeability, permeability-thickness, porosity, reservoir temperature and concentration of dissolved solids and non-condensable gases. Some preliminary correlations between these parameters are given.

47

Geophysical structure of the Broadlands-Ohaaki geothermal field (New Zealand). Henrys, S.A.; Hochstein, M.P. *Geothermics (International Journal of Geothermal Research and its Applications)* (UK); 19: No. 2, 129-150 (1990).

This paper reports on a retrofitting study of the geophysical anomalies of the Broadlands-Ohaaki field undertaken after production drilling had been completed in 1984. This study uses all relevant information from earlier (1965-1970) geophysical exploration surveys, results from detailed seismic reflection and airborne magnetic surveys made in 1984, and information from 44 exploration and production wells. The seismic reflection survey (12 fold CMP) shows that reflections from the top and the bottom of concealed Quaternary volcanic extrusions and pyroclastic flows can be obtained inside a hot-water system down to about 1 km depth. Processing of the data yields a detailed seismic velocity structure showing significant horizontal and vertical velocity changes inside and outside the field which, in turn, allowed reinterpretation of earlier seismic refraction profiles.

48

The thermal and geochemical structure of the Broadlands-Ohaaki geothermal system, New Zealand. Hedenquist, J.W. *Geothermics (International Journal of Geothermal Research and its Applications)* (UK); 19: No. 2, 151-186 (1990).

Fifty two wells have been drilled into the Broadlands-Ohaaki geothermal system, New Zealand, in the course of its development. Fluid samples collected from these wells and measured temperatures indicate that boiling is common within the East and West Bank production zones, speared at the

surface by the Waikato River. Steam-heated waters form over the top of the system, above zones of boiling, and are present on the margins of the system. They are CO₂-rich, and are responsible for dilution of the deep chloride fluids, particularly on the margins of the system. Thermal inversions are common on the margins of the system, associated with the steam-heat waters. The eastern portion of the East Bank and margins of the West Bank have cooled since peak thermal conditions, possible due to dilution, as indicated by comparing fluid inclusion data with temperatures now present. However, fluid inclusion Th and Tm data indicate that boiling and dilution patterns similar to those now present have existed since inclusion formation. The hydrothermal alteration of the silicic volcanic comprises an assemblage of quartz-albite-illite-adularia-calcite-chlorite-pyrite; epidote and pyrrhotite, sphalerite, and pyrrhotite, sphalerite and galena are generally confined to the margins of the system.

49

Thermal gradients of deep wells and their terrestrial heat flows (2). Nishimura, S. *Nippon Chinetsu Gakkaishi (Japan)*; 12: No. 3, 283-293 (25 Jul 1990). (In Japanese).

This report shows the results of the observation of temperature gradient and the estimation of terrestrial heat flow which have been carried out on 8 deep wells drilled in the Kinki district since 1986. The author makes some considerations on the distribution of terrestrial heat flows in the Kinki district, connecting with the data of the previous paper (Nishimura, et al., 1986). Measurements were carried out by his own making thermistor thermometer whose errors lie within 1 ° C. The wells have 650-1500 m depths, and all of them are the hot spring wells drilled recently except a few wells. They are the wells at Kami-cho, Tojocho, Hidaka-cho, Toyooka City, Hyogo Prefecture; Nodagawa-cho, Amino-cho, Kyoto Prefecture; and Otsu City, Shiga Prefecture, and their thermal gradients are measured as 2.35, 2.03, 6.01, 3.01, 2.90, 2.82, 3.91, 2.20 (degree per 100 m), and 60, 56, 163, 82, 79, 79, 105, 62 (mW per 1 square meter), respectively. 4 refs., 10 figs., 1 tab.

ECONOMIC AND FINANCIAL ASPECTS

50

Hot dry rock geothermal energy cost modelling: drilling and stimulation results. Mortimer, N.D.; Minett, S.T. pp. 224-244 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Work began on the development of a HDR geothermal energy system cost model in the United Kingdom in October 1986. Modelling of the cost of reservoir creation, by drilling and stimulation, has been conducted at Sheffield City Polytechnic, whilst modelling of the cost of surface plant and the performance of the complete HDR geothermal energy system has been undertaken at Sunderland Polytechnic. The model which is formulated as a spreadsheet programme written on SMART software for an Olivetti M24 personal computer, can either be run as an integrated package or as individual components. Although preliminary versions of the cost model have been completed, development will continue until June 1990. (author).

51

HDR cost modelling. Harrison, R.; Doherty, P.; Coulson, I. pp. 245-261 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

In order to assist it in its future assessment of HDR technology, the UK Department of Energy has funded a study to develop a full engineering cost model of electricity producing HDR systems which includes all surface and subsurface systems and components. Sunderland Polytechnic are the main contractors for this work and Sheffield City Polytechnic are subcontractors working on the costs of drilling and reservoir creation. The development of the main model is close to completion and although work will continue enhancing the model and investigating sensitivities it is possible to report progress at this stage. As no complete operating HDR system exists, the

model is based upon a conceptual design of such a working system. This conceptual design summarises the best understanding which can be formed to date, of the likely form which commercial HDR technology will take. This is in turn based upon experience from the experiments which have been carried out for the geothermal energy project at the Camborne School of Mines. (author).

52

Economical analysis of HDR for space heating in France. Iris, P. pp. 262-267 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

This paper summarizes the results of a study to evaluate the HDR potential for space heating in France in relation with the existing space heating urban networks. The objective of this work is to answer the following main questions on the assumption of technical success for HDR technology: (1) what would be an estimate of the cost of the HDR delivered heat? (2) what is the potential market using the existing district heating networks in France? (3) in the case of an experimental doublet in Soultz-sous-Forêt in Alsace, is it possible to distribute heat to meet local needs? (author).

53

Economic appraisal of HDR power plants. Smolka, K.; Kappelmeyer, O. pp. 268-277 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Within the framework of the Soultz Hot-Dry-Rock (HDR) Project, a cost benefit model for the economic appraisal of industrial electricity producing HDR power plants has been developed. In this model, the costs for construction and operation of the HDR system and the power station are determined and considered against the revenues received from the sale of the electricity produced. The economic approach comprises comprehensive modelling of the performance of the HDR reservoir as well as a detailed economic cost evaluation. The model is realized in the computer program

HDREC (HDR Economic Cost evaluation program). This program is an excellent tool for sensitivity analyses of the energy production costs. It can be used for an evaluation of cost limits and a definition of research goals for an improvement of the economic performance of HDR systems as well as for the exploration of suitable natural conditions underground. In this paper it is applied to a preliminary economic appraisal of a HDR power plant in Soultz sous Forets. (author).

54

Geothermal energy in the world energy scenario. Barbier, E. pp. 476-488 of *Workshop on materials science and the physics of non-conventional energy sources*. Furlan, G.; Nobili, D.; Sayigh, A.M.; Seraphin, B.O. Teaneck, NJ (USA); World Scientific Pub. Co. (1989). 550p. (CONF-8708295-).

From *Workshop on materials science and physics of non-conventional energy sources*; Trieste (Italy) (26 Aug - 18 Sep 1987).

This paper reports on the world energy consumption between 1960 and 1984 from primary energy-sources (coal, natural gas, oil, hydropower, nuclear energy) and the same in percentages from 1925. This highlights the diminishing role of coal and the increased consumption of gas and oil. The latter has stabilized around 42% of the total after the drop in demand resulting from the oil crisis of 1973. The world energy consumption has then been divided into industrialized and developing countries. It appears that the latter, with a population equal to 68% of the total world population, consumed 24% of the world energy in 1982. Furthermore, the consumption figures show that the demand for domestic energy is much smaller in developing countries, and it is well-known that domestic energy consumed is one of the parameters used to assess standard of living. The total installed electric capacity throughout the world is then reported, divided between developed and developing countries, showing that the latter consumed 11% of all the electricity generated in the world in 1981. The world installed electric power of geothermal origin at the end of 1985 is shown, along with estimated for 1990. Geothermal energy represents 0.2% of the world electric power.

ENVIRONMENTAL ASPECTS AND WASTE DISPOSAL

55

(NEDO-P-8911-Vol.1)

Review of methods for long term monitoring of the environmental effects of geothermal development (hot spring). part 1. (New Energy Development Organization, Tokyo (Japan)). Mar 1990. 83p. NTIS (US Sales Only), PC A05/MF A01. Order Number DE91727686.

Pertaining to the geothermal development, literature review was made to establish environmental monitoring system. Examples for the geothermal power generation development to influence hot spring do not exist in Japan, but are reported to do overseas, which existence is in case that reservoir with derivation of hot spring and extrusive steam is directly developed or that hydrothermal reduction is not made. Factors which may influence it comprise discharge flow rate, quality and temperature of hot spring, while those on the side of geothermal power generation plant do production of steam and hydrothermal reduction. Those, apart from the geothermal development, do change in heat source and excessive development of hot spring due to rainfall quantity, underground water level, volcanic activity, etc. Many geothermal power generation plants in operation observe the temperature and discharge flow rate of hot spring, while its chemical content is also measured by some of them. Though there are few reports of monitoring method, were introduced to presume/predict, from geothermal system model, featuring hot spring aquifer and geothermal reservoir, the fluid fluidization and change in hot spring. However, they have not been established firm yet and are expected to be put to practical use with necessary continuation of review/study and simplification in method. 141 refs., 13 figs., 11 tabs.

56

(NEDO-P-8911-Vol.2)

Review of methods for long term monitoring of the environmental effects of geothermal development (hot spring). part 2. (New Energy Development Organization, Tokyo (Japan)). Mar 1990. 151p. NTIS (US Sales Only), PC A08/MF A01. Order Number DE91727688.

Pertaining to the geothermal development, this is a data sheet collection of domestic and foreign review documentation to establish environmental monitoring system. Global chemistry and physics review comprise examples in Shikano Hot Spring in Tottori Prefecture, deep portion in Shimosuwa region, etc. Hydrologic fluidization study of geothermal water system explained Kakkonda, Matsukawa, Sengan region, Asaseishikawa fault, Tatehina highland, Hakone Yumot, Beppu, etc. Apart, simulation is being made by geothermal structure model. As for the content of hot spring water, there are review results from Noboribetsu, Izu/Hakone, Shimabara, Beppu, etc. Relation between the discharge flow rate of hot spring and rainfall quantity comprises examples in Onikobe, Kusatsu, etc. As for the influence of hot spring development, secular statistic is made of the dynamic water level, temperature and quality of hot spring in Aomori, Bunpi, etc. Influence review of power generation plant installation comprises reports from Hatchobaru, Onikobe, Onuma, Mori, etc. Regarding the geothermal development and environmental assessment, study is made of the scenery, water quality, atmospheric pollution, land subsidence, hot spring exhaustion, change in hydrothermal system, etc. Foreign examples were also explained. 121 figs., 14 tabs.

GEOTHERMAL POWER PLANTS

57

(EGG-M-90376)

Second law analysis of advanced power generation systems using variable temperature heat sources. Bliem, C.J.; Mines, G.L. (EG and G Idaho, Inc., Idaho Falls, ID (USA)). [1990]. Contract AC07-76ID01570. 8p. (CONF-901194-6). NTIS, PC A02/MF A01 - OSTI; GPO Dep. Order Number DE91001818.

From ASME winter annual meeting; Dallas, TX (USA) (25-30 Nov 1990).

Many systems produce power using variable temperature (sensible) heat sources. The Heat Cycle Research Program is currently investigating the potential improvements to such power cycles utilizing moderate temperature geothermal resources to produce electrical power. It has been shown that mixtures of saturated hydrocarbons

(alkanes) or halogenated hydrocarbons operating with a supercritical Rankine cycle gave improved performance over boiling Rankine cycles with the pure working fluids for typical applications. Recently, in addition to the supercritical Rankine Cycle, other types of cycles have been proposed for binary geothermal service. This paper explores the limits on efficiency of a feasible plant and discusses the methods used in these advanced concept plants to achieve the maximum possible efficiency. The advanced plants considered appear to be approaching the feasible limit of performance so that the designer must weigh all considerations to fine the best plant for a given service. These results would apply to power systems in other services as well as to geothermal power plants. 17 refs., 15 figs.

58

The trilateral flash cycle system for power recovery from hot dry rock.

Smith, I.K.; Martin, P.R. pp. 278-285 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

This paper describes a novel binary system developed specifically for the recovery of electrical power from liquid dominated geothermal resources and especially Hot Dry Rock. It is based on the successful development of efficient two phase expanders for organic working fluids and can yield outputs considerably higher than from the Organic Rankine Cycle or double flash steam systems. Results of a detailed design study show that for a brine flow of 75 kg/s at 200°C from Cornish Hot Dry Rock, the nett recoverable rate of electrical power is 6.75 MW_e for a total installed cost of Pound 7.35 million, corresponding to \$11.76 million at 1987 prices. (author).

59

Longevity evaluation for optimum development in a liquid dominated geothermal field: Effects of interaction of reservoir pressure and fluid temperature on steam production at operating conditions. Hanano, M.; Takahashi, M.; Hirako, Y.; Nakamura, H.; Fuwa, S.; Itoi, R. *Geothermics (International Journal of Geothermal Research and its Applications) (UK)*; 19: No. 2, 199-212 (1990).

The steam production rate of a well at fixed operating conditions in a liquid-dominated geothermal field is reduced at first by a decline in reservoir pressure and then by a decrease in fluid temperature, if reinjected water returns to the production well. In many cases, the fluid temperature decrease reduces the steam production rate more than does the reservoir pressure decline. Those effects should therefore be taken into due account in the evaluation of the longevity of an area, because sufficient longevity and recoverable electric energy are the minimum requirements for planning field development.

60

Generation of electric power from a thermal spring.: Characteristics of a small-size screw expander.

Yoshida, T.; Kurisu, M.; Kawabe, H.; Kodama, Y. *Nippon Chinetsu Gakkaishi (Japan)*; 12: No. 3, 239-261 (25 Jul 1990). (In Japanese).

This report describes the performance characteristics of small-size screw expander for the energy conversion of hot spring water. The screw expander has been recognized as an effective machine for the conversion of low temperature energy such as hot spring water. In the low temperature energy conversion cycle, organic working mediums are used usually, and the performance tests of expander under the same conditions of a practical conversion cycle are difficult. The authors produced small-size screw compressors, and carried out the compression and expansion tests with air, and expansion tests with organic working medium R 11 using natural hot spring heat, and then compare the performance from the results of these tests. The two testing screw expanders with built-in volume ratios 2.0 and 2.4 are used. They consider that if the performance of expansion with organic working mediums could be estimated by the compression tests with air, it might be an effective technique for the design of the low temperature energy conversion cycle. 11 refs., 12 figs., 1 tab.

61

Evaluation of magma energy power generation systems. Sondrup, A.J.; Boehm, R.F. *Energy Conversion and Management (UK)*; 30: No. 3, 297-313 (1990).

A study of power generation schemes for magma energy systems is

reported. In the magma energy concept thermal energy is removed from the molten region below the Earth's crust by circulation of water from the surface. The heated water is then assumed to drive a thermal cycle. Thermodynamic analyses of three general cycles are considered. In the first, the heated water is assumed to be used directly in an expander. This case is treated here with a variety of expander efficiencies to model conventional turbines as well as direct expansion devices when the entering state is liquid. A closed Rankine cycle (where the well fluid exchanges heat with the power cycle fluid) is also considered. Finally, a flashed cycle is also evaluated. The state of the input fluid to the power cycle is determined from a downhole model that represents many facets of the anticipated heat transfer and fluid flow. Power output and other results are presented as a function of mass flow rate, effective thermal conductivity of the heat exchange zone, and specific cycle parameters. Conclusions are drawn about which cycles show potential for maximizing power output. It is shown that the magma energy scheme holds great promise for economic power generation. (author).

62
Hydrothermal scheduling of a multireservoir power system with stochastic inflows. Contaxis, G.C.; Kavatzas, S.D. *IEEE Transactions on Power Systems (Institute of Electrical and Electronics Engineers) (USA)*; 5: No. 3, 766-773 (Aug 1990).

This paper presents a suboptimal optimization method for solving the annual hydrothermal scheduling problem for a multireservoir hydrothermal system. Hydrothermal scheduling is performed in order to find the optimum cost of a mixed hydrothermal system is minimized. In this paper the hydrothermal scheduling problem is formulated as a constrained optimization problem which is decomposed into three subproblems: maintenance scheduling of thermal units, dispatch of thermal units and dispatch of hydroplants. The algorithm takes into consideration the stochastic nature of the water inflows to the reservoirs and the forced outage rates of the thermal units. Results from a study case are reported.

63
Hydroelectric generation scheduling with an effective differential dynamic programming algorithm.

Chang, S.C.; Chen, H.H.; Fong, I.K.; Luh, P.B. *IEEE Transactions on Power Systems (Institute of Electrical and Electronics Engineers) (USA)*; 5: No. 3, 737-743 (Aug 1990).

This paper presents an effective multiplier method-based differential dynamic programming (DDP) algorithm for solving the hydroelectric generation scheduling problem (HSP). The algorithm is developed for solving a class of constrained dynamic optimization problems. It relaxes all constraints but the system dynamics by the multiplier method and adopts the DDP solution technique to solve the resultant unconstrained dynamic optimization problem. The authors formulate the HSP of the Taiwan power system and apply their algorithm to it. Results demonstrate the efficiency and optimality of our algorithm for this application. They also suggest some operational strategies based on these results.

64
Scale treatment facilities for geothermal power generation plant. Inoue, Y.; Yamada, H.; Tanno, O.; Tsutsumi, J.; Yaegashi, N. (to Japan Metals and Chemical Co. Ltd.). Japan Patent 2-136573. 25 May 1990. Filed date 15 Nov 1988. 4p. (In Japanese). Japan Patent Information Organization or International Patent Documentation Center.

In the conventional closed system geothermal power generation plant, low pressure steam is produced by flushing hot water for effective use in the power generation, or sensible heat is recovered by heat exchanging. As the result, the decreases in the temperature and pressure of the hot water become the cause for the deposit of dissolved silica, calcium, etc., and scale accumulates on the wall of pipe lines and other places. This invention relates to a system which has plural cooling systems for scale removal in the pipe line connecting the injection well and the steam separator which separates steam and hot water blowing out of the geothermal production well. The cooling system contracts line pipes by rapid cooling to create cracks in the scale adhered on the pipe wall to peel the scale off the wall. The peeled-off scale is collected by the closed type scale collecting device provided between the final stage cooling system and the injection well. The hot water overflowing from the scale collecting device is returned to the injection well. 4 figs.

GEOTHERMAL ENGINEERING

65
(EGG-EP-8800)

Supercritical binary geothermal cycle experiments with mixed-hydrocarbon working fluids and a near-horizontal in-tube condenser. Bliem, C.J.; Mines, G.L. (EG and G Idaho, Inc., Idaho Falls, ID (USA)). Dec 1989. Contract AC07-76ID01570. 108p. NTIS, PC A06/MF A01 - OSTI; GPO Dep. Order Number DE91001815.

The Heat Cycle Research Program, which is being conducted for the Department of Energy, has as its objective the development of the technology for effecting improved utilization of moderate temperature geothermal resources. Testing at the Heat Cycle Research Facility which was located at the DOE Geothermal Test Facility, East Mesa, California is presently being conducted to meet this objective. The testing effort discussed in this interim report involves a supercritical vaporization and counterflow in-tube condensing system with a near horizontal tube orientation. A previous report explored the supercritical heating, supersaturated turbine expansions and the condenser performance in the vertical orientation. This report presents a description of the test facility and results from a part of the program in which the condenser was oriented in a nearly horizontal orientation. Results of the experiments for the in-tube condenser in a nearly horizontal orientation are given for both pure and mixed-hydrocarbon working fluids. Although most of the data is for a completely active condenser in countercurrent flow, some data is available for a configuration in which half of the tubes were plugged and some data for cocurrent (parallel) flow is analyzed. The horizontal-oriented condenser behavior predicted by the Heat Transfer Research Institute computer codes used for correlation of the data was not in agreement with experimental results at this orientation. Some reasons for this difference are discussed. A special series of tests, conducted with propane and up to approximately 40% isopentane concentration, indicated that a close approach to "integral" condensation has occurred as was the case with the horizontally oriented condenser (similar results were obtained for the vertical condenser). 18 refs., 37 figs., 15 tabs.

66

(LBL-29617)

Application of an expert system for analysis of geothermal well tests.

Mensch, A.; Benson, S.M. (Lawrence Berkeley Lab., CA (USA)). Mar 1990. Contract AC03-76SF00098. 8p. (CONF-900115-4). NTIS, PC A02/MF A01 - OSTI; GPO Dep. Order Number DE91004282.

From 15. workshop on geothermal reservoir engineering; Stanford, CA (USA) (23-25 Jan 1990).

WES is an expert system designed at Lawrence Berkeley Laboratory for interpreting well test data. The results of WES's analyses of two geothermal well tests are compared to those calculated using traditional methods. WES is well suited for analyzing well tests in geothermal systems because it is robust enough to carry out analyses of data sets that are noisy or incomplete. It also has a broad knowledge base that recognizes most of the hydrogeologic characteristics observed in geothermal systems, such as double-porosity, fractures, and leaky or sealed boundaries. Application of expert systems for analyzing geothermal well tests has several advantages, including: providing clear documentation of the procedures used in the analysis; providing on-site expertise to guide the testing program; providing a greater knowledge base than a single expert may have; and, greatly decreasing the time required for these analyses. Over the next decade expert systems will become an integral part of resource definition and development programs. This paper provides just one example of how expert systems can be used. 25 refs., 16 figs., 3 tabs.

67

Applied geothermics. Economides, M. New York, NY (USA); John Wiley and Sons Inc. (1987). 237p. John Wiley and Sons Inc., 605 Third Avenue, New York, NY 10150 (USA).

This book contains articles on applied geothermics. Included are the following chapters: An introduction to geothermal energy, Formation of geothermal resources at lithospheric subduction zones, Physical and thermodynamic properties of geothermal systems.

68

Hot dry rock and its relationship to existing geothermal systems.

Batchelor, A.S. pp. 13-29 of Hot dry rock: geothermal energy. Baria, Roy.

London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The HDR resource is merely a body of rock at elevated temperatures with insufficient fluids in place to enable the heat to be extracted without the need for injection wells. All of the major field experiments in HDR have shown that the natural fracture systems form the heat transfer surfaces and that it is these fractures that must be manipulated to provide viable reservoirs. The techniques developed for geothermal systems producing from naturally fractured formations provide a basis for directing the forthcoming programmes in HDR away from the procedures of massive hydraulic fracturing but, equally, they require accepting significant location constraints on HDR for the time being. This paper presents a model HDR system designed for commercial operations in the UK and uses production data from hydrothermal systems in Japan and the USA to demonstrate the reservoir performance requirements for viable operations. It is shown that these characteristics are not likely to be achieved in host rocks without significant jointing given the current understanding of the stimulation processes. However, the long term goal of artificial geothermal systems developed by systematic engineering procedures at depth may still be attained if high temperature sites with extensive fracturing are developed or exploited first. (author).

69

Drilling and associated aspects of HDR systems.

Beswick, A.J. pp. 33-52 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The principal cost in the construction of an HDR system is the drilling and completion of the injection and production wells. To date research efforts have been directed to system emplacement in crystalline rocks. From the drilling standpoint, this requirement together with the associated high temperature and rock stress environment, introduces special conditions which differ significantly from the normal demands of the petroleum and mining

industries. Although many of the individual requirements are within the current state-of-the-art of drilling and completion technology, there are some important areas which step outside current experience, particularly related to completions for multiple stimulations of fractured rock in hot, large diameter boreholes. The combination of the conditions and specifications for the wells are therefore unusual and demanding. In the last ten years, significant experience has been gained in drilling both vertical and directional boreholes in granites for a variety of purposes including three intermediate depth HDR wells in Cornwall. This provides a database for the planning of a deep prototype system and gives confidence that wells to 7000 m can be drilled and developed successfully. This background experience is reviewed in the context of HDR exploitation and areas of remaining uncertainty are highlighted. (author).

70

Role of drilling fluids in drilling HDR wells.

Lundie, P.R. pp. 53-64 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The properties and formulation of drilling fluids can significantly influence the prospect of obtaining the declared objectives of a hot dry rock reservoir. This paper examines those objectives and the required properties of the drilling fluid. The experience base from comparable projects will be reviewed and recent technical advances in drilling fluid technology will be described. Details of fluid systems that may be considered will be given. (author).

71

Determination of instantaneous shut-in pressures in hydraulic fracturing tectonic stress measurements.

Hayashi, Kazuo; Sakurai, Izumi. pp. 75-84 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A new method is presented for the determination of the instantaneous

shut-in pressures in hydraulic fracturing tectonic stress measurements. It is developed by an analysis of the closure process of the crack induced by hydraulic fracturing, based on linear theory of elasticity and fracture mechanics. The method utilizes the inverse of the rate of decrease of the downhole water pressure after shut-in. The plot of the inverse of the decrease rate vs the downhole pressure consists of two straight lines. The point of intersection of the two lines corresponds to the onset of crack tip closure, and the pressure at this point, i.e. the crack tip closure pressure (CTCP), is an excellent estimate of the tectonic stress component which is acting perpendicular to the induced crack. The new method is applied to the pressure vs time records which were obtained in field experiments. It is shown, by application to the field data, that the new method can clearly determine the crack tip closure pressure (CTCP) from all of the pressure vs time records. (author).

72

Engineering evaluation of geothermal reservoirs. Economides, M. pp. 91-110 of *Applied geothermics*. Economides, M. New York, NY (USA); John Wiley and Sons Inc. (1987). 237p.

This paper discusses how reservoir engineering has been a major tool in the exploration and production of ground-water, oil and gas reservoirs. Techniques developed in these fields have been applied to geothermal systems as well. A reservoir is an accumulation of fluid occurring in an underground trap formed by structural and/or stratigraphic features. A reservoir consists of a single hydraulically connected system. The state or phase of a fluid in any reservoir (including geothermal) changes with pressure while the temperature remains essentially constant. Hence, fluid production results in pressure decline and while the state of the fluid is altered the process is considered as isothermal. Reservoir pressure measurements and their interpretation are then important in the evaluation of geothermal fluids and their behavior.

73

The background to phase 3 of the Camborne School of Mines Geothermal Energy Project. Parker, R. pp. 159-169 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The Camborne School of Mines Hot Dry Rock (HDR) Geothermal Energy Project has been concerned mainly with development of the technology of reservoir creation in a jointed granite environment. Phases 1 and 2 of the Project are outlined. It has been demonstrated that it is possible to create a large HDR reservoir in granite at a depth which allows a significant understanding of the engineering problems associated with the creation, development and circulation of the reservoir. Phase 3A commenced in October 1988. The first objective is to investigate ways of improving the characteristics and performance of a HDR reservoir. Using the present well-documented Rosemanowes reservoir, it is intended to investigate the placement of proppants in joints close to the production wellbore, the selective stimulation of a zone of the production well which is currently not flowing, and the possibility of sealing off short circuits. The second objective is to develop instrumentation to the stage where it can be used to create and operate reservoirs at greater depths. The third objective is to participate in the conceptual design of a prototype of a commercial system. In 1990, there will be a review of the status of the technology, and a decision will be taken whether or not to construct this prototype in Phase 3B. (author).

74

Heat extraction from low-temperature fractured petrothermal resources. Dyadkin, Y.D.; Kruger, P. pp. 190-200 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A research program is underway to develop the technology for economic heat extraction from low-temperature geothermal resources located throughout the USSR. The first artificial circulation system for geothermal energy extraction in the Soviet Union is being developed in the Russkie Komarovtsy area of the Zarkapate region in the Ukrainian SSR. This experimental system will consist of an injection-production well module with three vertical hydrofractures creating flowpaths in the interval between

depths of 1900 and 2700 m. The formation consists primarily of a granodiorite intrusion at a mean temperature of 124 C. The experiment is designed to produce thermal water at a constant flowrate of 96 m³/hr at a temperature of 110°C. At an estimated thermal extraction rate of 40 GJ/hr, the resource is expected to have a useful lifetime of about 10 years. The investment in this type of module is estimated as 2.4 million rubles, providing a hot water resource at a mean cost of 1.87 ruble/GJ. The success of this experiment should provide reliable data for development of low-temperature geothermal resources in other regions of the Soviet Union. Comparison of heat extraction from the Russkie Komarovtsy field is made with the Cholpon-Ata field in Kirgizia. (author).

75

Stimulation modelling. Nicol, D.A.C.; Randall, M.M.; Hicks, T.W. pp. 289-298 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A successful Hot Dry Rock (HDR) geothermal system requires the development of a large reservoir within a rock mass of enhanced permeability. The system's structure must provide a sufficient area of heat transfer and an acceptable impedance to flow. A number of experimental reservoirs have been created by the hydraulic stimulation of natural fractures. To date, none of these systems has met the criteria for a commercial HDR geothermal system. The future success of HDR will depend on the consistent stimulation of commercial reservoirs. The development of this capability presents the major challenge currently facing HDR technology. This challenge will only be met through the understanding and control of the physical processes involved in reservoir stimulation. Numerical modelling of the fluid flow through stressed and jointed rock masses can provide much information essential in achieving this. Considerable progress has been made, both conceptually and numerically, in understanding the role of natural fractures in stimulations. The FRIP family of codes has been developed to specifically model the fluid rock interaction. In conjunction with these codes, standard oil industry fracturing models have been

used to describe processes such as complex rheology and proppant transport which the FRIP codes currently cannot handle. (author).

76

Stochastic modelling of fractured reservoir. Thomas, A.; Blin-Lacroix, J.L. pp. 299-308 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

In this paper, the authors present a brief review of a complete system of fractured reservoir modelling. This system was designed for three-dimensional stochastic modelling of fractured rock masses and the software has been applied to a hot dry rock geothermal site and also to fractured oil reservoirs. The main innovations are as follows: (1) digital data collection on bore profiles (either bore sample photographs, or bore geophysical measurements); (2) the analytical treatment of fracture geometry; (3) the fractal generation of stochastic models and (4) the method of spatial simulation of the fracture field. For each step of the model, examples of the results from the geothermal research site of Mayet de Montagne (France) and from various oil-reservoirs are given. (author).

77

Three-dimensional stochastic fracture network model. Cacas, M.C.; Bruel, D. pp. 309-314 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The intermediate scale of fracture in rock-masses, where the fractures form a network, seems to be of concern in HDR experiments, according to the variability of the fracture density profiles which are usually observed in deep boreholes. At this scale, the hydraulic properties of the jointed-rock are rather heterogeneous. Since this behavior is due to the connectivity of the fracture system a better understanding of the connectivity is important. To this end, a discrete-stochastic model that generates a fracture network based on the statistical properties of the real fracture network and simulates flow and mass-transport has been developed previously. One of the assumptions in

the development of this model is that the hydraulic pressures are not stress dependant. This is adequate when the water pressure field is small. However, this hypothesis may not be valid for HDR simulation and the impact of the in-situ stress regime at elevated fluid pressure has to be considered. Taking advantage of the previous flow computation, thermal effects are coupled in order to evaluate the geothermal potential of a given reservoir. (author).

78

A discrete fracture model for a hot dry rock geothermal reservoir. Robinson, B.A. pp. 315-327 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Modeling results are presented for the Fenton Hill Phase II reservoir using a two-dimensional steady state simulator of fluid flow and solute transport in fractured porous media. Fluid flow and tracer response data are simulated using a fracture flow model in which the fracture apertures are strong functions of pressure. The model is used to match the available steady state data of pressure drop versus flow rate and the tracer data. Various schemes for improving reservoir performance, such as high backpressure, chemical etching, stimulation using a viscous fluid, and the drilling of a second production wellbore, are then examined. (author).

79

Stimulation design and analysis for hot dry rock reservoirs at the Camborne School of Mines Geothermal Energy Project. Nazroo, M.F.; Pine, R.J.; Markland, J.T. pp. 328-342 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The purpose of stimulation in Hot Dry Rock (HDR) geothermal energy systems is to create a large heat transfer area, the reservoir, within a rockmass of very low permeability, which links two or more wells. Experience at the Camborne School of Mines (CSM) has shown that there are two dominant aspects to the successful creation of a HDR reservoir. Creation of

the main heat transfer area is achieved by a large volume fluid injection (stimulation). The fluid is water or a low viscosity gel which increases the permeability by dilating the natural joints. The stimulation has to be large enough to provide a heat transfer area which will last for the life of the system whilst allowing water to be circulated in commercial quantities. Following the bulk stimulation it may be necessary to create localised links into the reservoir from the wells, in particular the production well, by secondary stimulations. These are smaller stimulations using high viscosity gels which provide a low impedance connection from well to reservoir. The resulting new fracture will usually need to be held open by proppants. (author).

80

Hydraulic stimulation experiments in high temperature geothermal wells at Nigorikawa and Kakkonda Fields, Japan. Takanohashi, Morihiko; Miyazaki, Shin'ichi; Tateno, Masayuki. pp. 343-352 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The installed capacity of geothermal power stations in Japan has reached a total of 215.1 MWe. The Japan Metals and Chemicals Company (JMC) has been supplying steam amounting to a total of 122 MWe to three geothermal power plants -Matsukawa, Kakkonda Unit I and Nigorikawa (Mori) - and is currently developing another 50 MWe to be supplied to a unit designated as Kakkonda Unit II. Furthermore, a direct use project is planned in Kakkonda area by the local Iwate government. To date, JMC has drilled 21 exploration wells and 109 geothermal wells with high formation temperatures (200-340°C) at a depth of approximately 1500 m for these projects. However, in several cases insufficient natural subsurface fractures were intersected. To make these wells commercial, 47 hydraulic stimulation treatments were performed on 35 wells. 28 of these stimulations have been successful thereby improving productivity and/or injectivity. This paper first describes the geology and the results of hydraulic stimulation in several geothermal wells at the Nigorikawa and Kakkonda fields. An application of the AE technique in the evaluation of geothermal reservoirs

based on rock fracture mechanics, which is extremely useful in geothermal reservoir energy development, is then described. (author).

81

New concepts of hydrofrac stress data interpretation at GPK1, Soultz sous Forêts. Baumgaertner, J.; Rummel, F.; Hansen, J. pp. 353-362 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The state of stress in the 2 km deep geothermal research well at Soultz sous Forêts was estimated using the "Fracture Pressurization" or "FP-method". It takes into account that boreholes intersect various types of weakness planes in the rock mass which during a hydraulic fracturing experiment may open at lower pressures than those required for fracture stimulation in intact rock. The FP-method is usually based on the determination of the "far field" stress components acting across a number of arbitrarily oriented fracture planes and uses inversion techniques to calculate the principal stresses. The in situ stress measuring procedure concentrates on instantaneous shut-in pressure tests and extreme low flow-rate pumping tests to determine the normal stress components. Results from fracture pressurization tests in the Soultz borehole are discussed. The computed stress profiles characterize clearly the expected typical graben situation with a dominant normal faulting mode ($S_v > S_{Hmax} > S_{Hmin}$). This stress regime with extreme low horizontal stress components is strongly supported by long drilling induced hydraulic fractures and by the complete lack of stress induced borehole breakout zones. A simple fracture mechanics approach may be applied to estimate crustal stresses based on the information included in the total pressure record. This model will be used in future testing at Soultz to verify the information derived from conventional and FP-method data interpretations. (author).

82

Microseismics: a key to understanding reservoir growth. Baria, R.; Green, A.S.P. pp. 363-377 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific

Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The creation of a Hot Dry Rock (HDR) reservoir requires the injection of fluid (hydraulic stimulation) into a rock mass to improve the low natural permeability. At the Camborne School of Mines (CSM) HDR project, a number of hydraulic stimulations into an Hercynian granite batholith in SW England have been carried out over the past eight years. Microseismicity induced during these stimulations reveals that reservoir growth has been due predominantly to the shearing on natural joints. The interaction of the in situ stresses and jointing determine the direction of reservoir growth and the pressures required to induce growth. In addition, the influence of naturally permeable features which exist on a larger scale than the jointing also seem to play an important part in reservoir growth. Microseismicity has also been induced during periods of medium and low flow rate circulation. The analysis of these data has been used to define the optimum operating conditions for the Rosemanowes reservoir during circulation. (author).

83

Seismic monitoring on the Soultz site (France). Beauce, A.; Fabriol, H.; Le Masne, D.; Chen, X.; Cavoit, C.; Mechler, P. pp. 378-387 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

During the first phase of the French-German Hot Dry Rock geothermal energy project at Soultz/Forêts in Alsace (sponsored by the European Community), a hydraulic stimulation test has been undertaken at the bottom ($T = 140^\circ\text{C}$) of the 2000 m deep GPK1 borehole. Important faults dipping 60° West affect the thick (1400 m) sedimentary cover and the granitic horst underneath. The seismic network, set up to monitor the microseismicity induced in the granite by the stimulation, is made up of three-directional probes (especially designed to stand the rough temperature and corrosion conditions) cemented at the bottom of the three observation boreholes. Once the seismic signals are digitized in the

computing system, automatic detection and storage of the seismic events is performed in real time. To get a precise idea of the tectonic context at depth, a vertical seismic profile has been determined. During the 3-day stimulation experiment, despite a rather low water flow-rate (3.3 l/s), 58 seismic events have been recorded on the network. Results show a general trend of magnitudes decreasing with time, and a spectral content within the frequency range 50-300 Hz for geophones sited 700 to 1200 m away from the stimulated zone. Seismic activity starts 2 hours after the beginning of the stimulation. Two main focal zones are concerned and at first their activity are simultaneous; one close to the stimulated borehole, and the other one deeper than GPK1's bottom. Only the remote focal zone remains active during the whole survey. (author).

84

Fracture extension by hydraulic fracturing at Hijiori site. Sato, Y.; Kuriyagawa, M.; Yamaguchi, T.; Matsunaga, I.; Oikawa, Y.; Ito, H. pp. 388-397 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The development of hot dry rock power generation systems has been studied since 1979 at the Hijiori test site, Yamagata prefecture. Two wells, SKG-2 and HDR-1, were drilled and hydraulic fractures were created at a depth of 1,800 m. A short term circulation test was conducted in 1988. Cold water was injected into SKG-2 and hot water and steam were produced from HDR-1. In future, larger and hotter fractures will be created at the depth of 2,200 meters and water will be circulated for more than a year. Since the experiments at the Hijiori test site, we have been facing two technical issues. It was revealed that we created a reservoir which consists of natural and artificial fractures. When we model the reservoir, it is important to know the detail of the fracture system. During the course of initial circulation tests for 17 days, the water loss was about 60%. Another important problem, therefore, is how to reduce the water loss. Water has been injected more than ten times into SKG-2 since 1979 for the purpose of hydraulic fracturing, stimulation and circulation. The average permeability of

the rock around an openhole section of SKG-2 was calculated using the data on the injection volume and the well-head pressure. The permeability was increased by stimulation in SKG-2, resulting in a decrease of the impedance of the reservoir. (author).

85

The problem of channelling in hot dry rock reservoirs. Cornet, F.H.; Desroches, J. pp. 398-422 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A forced fluid flow percolation experiment has been conducted in a granite rock mass after hydraulically stimulating some preexisting fractures. The process involved initially only the injection of gel of low viscosity at flow rates of the order of 1.5 m³/min. However, for some fractures, some sand was also injected at the end of the stimulation. Only the latter proved useful in improving the production flow rate. Spinner logs showed that for large enough flow rates, some preexisting fractures are opened. However, results from tilt measurements suggest that in none of these cases were the fractures opened at large distances from the borehole. This suggests that even during hydraulic stimulations, flow occurred mostly through channels along preexisting closed fractures, i.e. fractures transmitting shear stresses. Inversion of focal mechanisms for determining the stress field yields principal stress directions which are not in agreement with those determined by hydraulic tests (HTPF method). This is attributed to the fluid percolation process. This perturbation does not seem to be caused by the opening of fractures, but by the variation of fluid pressure in preferential directions. This is in agreement with the tilt observation and therefore supports the hypothesis that the percolation process through this fractured rock mass is controlled by channelling and not by significant fracture opening. (author).

86

Fracture filling mineralogy and geochemistry at the Swedish HDR research site. Eliasson, T.M.; Tullborg, E.-L.; Landstroem, O. pp. 425-435 of Hot dry rock: geothermal energy. Baria, Roy. London (GB);

Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A study of the fracture filling mineralogy has been conducted in the 511 m long drill core of the second 500 m deep well at the Hot Dry Rock research site in the Bohus granite, south west Sweden. Ocular standard core logging together with XRD, trace and major element analyses (INAA) were carried out on different fracture filling minerals. Stable isotope analyses of O and C were made on calcite samples from open as well as sealed fractures at different depths. Geochemical analyses were also performed on fresh and altered granite samples. The dominating fracture filling minerals are calcite, smectite (mainly Ca-smectite), hematite, chlorite, quartz, biotite, muscovite, epidote and rust (FeOOH). The study shows that the fracture filling material provides information about e.g. water conducting fractures and redox potential in the indigenous groundwater in the bedrock. Textural evidence, isotopic and geochemical data show that the hematite/chlorite and calcite mineralisations occurred principally during the same hydrothermal event. The smectites were formed by in situ weathering of the host rock granite during a later event. Four major episodes of fracture generation and/or activation can be distinguished. (author).

87

Geochemical assessment of potential circulation fluids for a 200 deg C reservoir in granite. Savage, D.; Bateman, K.; Milodowski, A.E.; Cave, M.R.; Hughes, C.R. pp. 446 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

An important consideration in the development and operation of a Hot Dry Rock geothermal system is the selection of a heat transfer fluid and the chemical composition of this fluid during circulation. The chemical reaction of the circulation fluid with the reservoir rock may lead to the undesirable corrosion or scaling of the reservoir itself, or associated engineering structures. This communication describes laboratory experiments aimed at the characterisation of the chemical reaction of a

number of potential circulation fluids (surface streamwater, NaCl fluids, sea-water) for use in a deep (200°C) HDR system in granite. "Batch" autoclave experiments have been carried out at 200°C, reacting candidate fluids with granite, in order to assess the chemical evolution of the fluid phase with time, as well as to characterise the amount and type of solid reaction products. The results of the study will be discussed in terms of the suitability of each of the fluids as a heat exchange medium for a HDR system in granite. (author).

88

Cooling of the Rosemanowes HDR reservoir. Nicol, D.A.C. pp. 477-486 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The Hot Dry Rock geothermal reservoir created between wells RH12 and RH15 at Rosemanowes Quarry, Cornwall, UK has been significantly cooled over its lifetime. Simple lumped parameter models, which treat the reservoir as being in steady state, successfully describe the overall reservoir performance. Detailed description of the thermal performance is difficult because of lack of resolution in the available data. However, using the available thermal and flow logs, in conjunction with tracer data, it has been possible to identify the joint which produces the fluid with the lowest residence time. This joint also produces a lot of fluid with longer residence times, and thus the options in sealing cooling joints may be limited. (author).

89

Lifetime calculations for multiple stimulated HDR reservoirs. Elsworth, D. pp. 487-497 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

A conceptual model is presented to describe thermal recovery from a candidate HDR geothermal energy scheme through a multiple arrangement of near spherical production zones. The arrangement facilitates advective draw-down within a series of well mixed and thermally equilibrated production zones

and by conductive recharge from the geologic host. Dimensionless thermal drawdown $T\text{-bar}_D$ with dimensionless time t_D is controlled by the distribution of dimensionless flow rates (Q_{Di}), thermal porosity (Φ_{Di}) of the k stimulated zones, and by the relative system geometry as expounded through the separation parameter a_i/s_{ij} . Sensible agreement with previous models allowing for thermal disequilibrium is obtained and results from previous HDR experiments show encouraging agreement. Production histories are presented for colinear arrays of producing zones. The steady condition is a unique function of circulation rate Q_{Di} and relative geometry a_i/s_{ij} . For small circulation rate magnitudes ($Q_D < 10^2$), the steady production temperature is finite and may define considerable thermal potential not apparent from 'closed-system' analogues. The timing of conductive recharge may be sufficiently early to enhance the economics of HDR geothermal projects. (author).

90

Reservoir water loss modeling and measurements at Fenton Hill, New Mexico. Brown, D.W. pp. 498-508 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

An extensive series of pressurized water loss experiments are presently being conducted in the deeper Phase II hot-dry-rock reservoir, at Fenton Hill in New Mexico. The objectives are: 1. To measure the boundary permeation loss rate at a number of equilibrium reservoir pressure levels, and as a function of time; and 2. with this pressure-and time-dependent water loss rate data, to determine the joint dilation (i.e., mean joint porosity) of the reservoir as a function of pressure up to about 23 MPa (as measured at the surface). Gangi's permeability model has been used to help explain the water loss rates as previously measured during two reservoir flow tests of 7 and 30 days duration. During the 30-day flow test, the model strongly suggests that the reservoir was actively growing, even at injection pressures as low as 27 MPa. Peripheral reservoir growth by fracture extension during the 30-day test is confirmed by seismic observations. During the current series of pressurization experiments, the water loss rate

due to permeation has thus far been measured at two reservoir pressure levels. For comparable times after the start of pumping, the permeation loss rates are 0.17 l/s and 0.51 l/s respectively, for reservoir pressure levels of 7.5 MPa and 15 MPa. These measured loss rates compare favorably with those predicted by the model. (author).

91

Technical-economic aspects of the utilization of geothermal waters. Barbier, E. pp. 489-511 of Workshop on materials science and the physics of non-conventional energy sources. Furlan, G.; Nobili, D.; Sayigh, A.M.; Seraphin, B.O. Teaneck, NJ (USA); World Scientific Pub. Co. (1989). 550p. (CONF-8708295-).

From Workshop on materials science and physics of non-conventional energy sources; Trieste (Italy) (26 Aug - 18 Sep 1987).

A description is given of the physico-chemical parameters characterizing a hot water geothermal reservoir and of its exploitation by means of single or coupled (doublet) wells. The technical aspects of geothermal heat to the users is discussed, beginning with corrosion of materials caused by seven main agents: oxygen, hydrogen sulphide, carbon dioxide, ammonia, hydrogen, sulphates and chlorides. A brief mention is made of scaling due to calcium carbonate, silica and calcium sulphates. The basic components of a geothermal plant for non-electric uses are discussed: production pumps, surface pipelines, heat exchangers, heat pumps and reinjection pumps. The advantages and disadvantages of the different equipment and materials used in the geothermal sector are also presented. A list is given of the criteria used in the energy and economic balance of a geothermal operation.

92

Water production profile derived from temperature survey [hot-dry-rock systems]. Bruel, D. pp. 549-556 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

This paper presents a study which is part of a research programme on heat extraction from impervious deep rock formations. Its purpose is to interpret thermal logs as flowmeter logs. It is

shown how the flow rate of each producing zone of a well under production can be determined. (author).

93

Flowpath characterisation of the Rosemanowes HDR reservoir using inert tracers. Richards, H.G.; Oskui, G.P.; Kwakwa, K.A. pp. 557-574 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The experimental Hot-Dry-Rock (HDR) geothermal reservoir at Rosemanowes links Wells RH12 (injector) and RH15 (producer). During circulation, the production temperature declined in a way that indicated the existence of a thermal short circuit. Inert tracer tests were performed to characterise the flow distribution in the interwell region, and hence to identify the flowpath or paths most likely to be associated with the short circuit. The reservoir was considered as consisting of six possible flowpaths, linking two inlet zones of flow in the injection well with three outlet zones in the production well. Pulses of tracer were injected downhole above each inlet, whilst sampling downhole above each outlet. Four of the six possible flowpaths were found to be carrying 10% or more of the production flow. One flowpath was carrying about 60% and had the shortest fluid residence times. About a quarter of the flow in this hydraulic short circuit path was responsible for the thermal short circuit. This path correlated with a geological structure identified from microseismic events created during earlier hydraulic injections, before the creation of the RH12/RH15 reservoir. This adds weight to the idea that short circuits in HDR reservoirs are likely to be controlled by natural geological structures. (author).

94

Development of a new hydraulic fracturing method (casing reamer and sand plug method). Kaieda, H.; Hibino, S. pp. 593-601 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

We have developed a new hydraulic fracturing method by which a multi-stage fracture can be created in a well without using open-hole packers. Applying the method to a well of 400 m depth drilled into Tertiary lapilli tuff, fractures were created at 3 different depths. These fractures were observed by a bore hole TV scanner (BTVS) survey, permeability measurements and acoustic emission (AE) observation. (author).

95

Basic experiment for hot dry rock development in Akinomiya area, Akita prefecture, Japan. Umieda, H.; Hibino, S.; Hori, Y. *Denryoku Doboku (Electric Power Civil Engineering) (Japan)*; No. 227, 58-67 (30 Jul 1990). (In Japanese).

This is a report on the result of basic experiment for hot rock power generation carried on since 1986 at Akinomiya area, Akita Prefecture, Japan. Studies on the practicability of fracture method in rocks which is indispensable to hot rock power generation, and on the evaluating method of the created fracture surface were carried out. As the result, 3 fracture surfaces in different depths were successfully produced from a 400m class well, which were evaluated by AE and BTVS observations. By the AE observation, the development direction of the second stage fracture surface was estimated, and a continuity well was drilled basing on the knowledge. The continuity through the fracture surface was confirmed because the water injected in the fracture well was recovered from the continuity well. However, the produced flow from the continuity well was 1 to 2% of the injected flow into the fracture well according to the water circulation test using the two wells. The cause was assumed that the development of fracture surface during the circulating test was different from that at the time of water pressure fracture test. 24 refs., 9 figs., 1 tab.

96

Influences of parameters on geothermal reservoir interferences. Fukuda, M.; Itoi, R.; Koga, A.; Akibayashi, S. *Nippon Chinetsu Gakkaishi (Japan)*; 12: No. 3, 213-228 (25 Jul 1990). (In Japanese).

This paper describes the study with an reservoir's model which was carried out in order to discuss the interferences between an existing geothermal reservoir and a reservoir to

be newly developed. For a simple model of a reservoir, changing some of the parameters of the reservoir and the aquifer, and the conditions of production and reinjection, the influence of lately developed reservoir against the existing reservoir was examined. When the existing reservoir lie near the heat reservoir the influence is very little, but it is located far from the heat reservoir the influence appears. The interference increases as the flow rate of production increases and the reservoir porosity decreases. Larger permeability coefficients of the aquifers and shorter lengths of aquifers, increases the interference during the early production stages. However, under the same conditions, the interference is reduced in the later stages of production. The interference increases as the distance of two reservoirs decreases and the distances between the reservoirs and the heat source increase. 3 refs., 8 figs.

97

Developments in geothermal energy in Mexico: Pt. 31: Prediction of geothermal cement durability from field tests. Morales, J.M.; Garcia, A.; Santoyo, S. *Heat Recovery Systems and CHP (UK)*; 10: No. 5-6, 491-498 (1990).

Cement data reported in 1985 by the Geothermal Cements Task Group of The American Petroleum Institute (API) Committee 10 on cements standardization are presented. In order to obtain adequate cement compositions for geothermal environments, the API and National Bureau of Standards (NBS), USA and the Comision Federal de Electricidad (CFE), together with the Instituto de Investigaciones Electricas (IIE), Mexico, have completed a programme to evaluate 16 cement compositions in the Cerro Prieto geothermal field in both down-hole baskets and in surface chambers. (author).

98

Developments in geothermal energy in Mexico: Pt. 30: Conclusion of the corrosion in Mexican geothermal wells project. Sampeiro, J.A.; Rosas, N.; Diaz, R.; Dominguez, B. *Heat Recovery Systems and CHP (UK)*; 10: No. 5-6, 481-490 (1990).

This paper is complementary to part 19 of this series, in which partial results from the joint IEE/CFE studies were presented. The objective was to define the specifications for steel used in geothermal well construction in Mexico

and to characterize and control identifiable corrosion inducing factors. The complete results of corrosion testing in wellhead pressure chambers, down hole chambers and in an autoclave simulation system are included. Also shown are chemical, mechanical and metallographic studies on steels commonly used in Mexican geothermal wells, as well as the main conclusions. (author).

99

Developments in geothermal energy in Mexico: Pt. 29: Scaling studies at the Cerro Prieto geothermal field. Hurtado, R. *Heat Recovery Systems and CHP (UK)*; 10: No. 5-6, 469-479 (1990).

The high silica content (over 900 p.p.m.) of Cerro Prieto geothermal brine causes problems of scaling at the electric power facility. The scaling tendency is a direct function of the silica saturation ratio. Scaling rates of 1-10 mm per year were experienced at low saturation ratios (SR) <2 and scaling rates of 100-400 mm per year at (SR) >3. Pilot plant tests satisfactorily predict scaling rates in commercial equipment. Amorphous silica deposited in process equipment can be dissolved by NaOH, KOH and NH_4HF_2 . The use of chemical products to remove scale from well liners is a good method of control. The removal of colloidal silica by using 20-30 p.p.m of lime has been developed. (author).

DIRECT ENERGY UTILIZATION

100

Direct uses of earth heat. Gudmundsson, J.S.; Lund, J.W. pp. 189-220 of *Applied geothermics*. Economides, M. New York, NY (USA); John Wiley and Sons Inc. (1987). 237p.

Direct uses of geothermal energy are traditional and well established worldwide. The people of Japan have used earth heat for centuries, mainly in the form of bathing. Other nations have similarly taken advantage of hot springs for bathing and other utilizations. Nowadays there are many large-scale uses of geothermal energy. Well-known examples are district heating in Iceland, Greenhouse heating in Hungary and process heating with steam in New Zealand. Direct applications of geothermal energy are also

called non-electrical uses. The purpose of this chapter is to identify the principal elements of direct uses of geothermal energy. The chapter concerns the technologies needed to bring geofluids from resource to user.

101

Direct uses of geothermal energy in Japan. Sekioka, M. *Geothermics (International Journal of Geothermal Research and its Applications) (UK)*; 19: No. 2, 223-232 (1990).

The purpose of this review is to outline the present state of direct uses of geothermal energy in Japan as of April 1989. Firstly, the representative examples are illustrated. Secondly, an analysis is carried out to characterize each application, with a diagram combining the inlet temperature with the flow rate of individual direct use facilities. Finally, the total installed thermal power and the total thermal energy used are estimated at 171 MWt and 107 MWt yr, respectively, resulting in a total average load factor of 63%. The oil saved by geothermal direct uses is also evaluated at .06% of national consumption.

GEOTHERMAL DATA AND THEORY

102

(LBL-24725)

Coupled transport processes in semipermeable media. Jacobsen, J.S.; Carnahan, C.L. (Lawrence Berkeley Lab., CA (USA)). Mar 1990. Contract AC03-76SF00098. 21p. NTIS, PC A03/MF A01 - OSTI; GPO Dep. Order Number DE91004138.

The thermodynamics of irreversible processes leads to nonlinear governing equations for direct and coupled mass transport processes. Analytical solutions of linearized versions of these equations can be used to verify numerical solutions of the nonlinear equations under conditions such that nonlinear terms are relatively small. This report presents derivations of the analytical solutions for one-dimensional and axisymmetric geometries. 7 refs.

103

(LBL-25618)

Coupled transport processes in semipermeable media. Carnahan, C.L.; Jacobsen, J.S. (Lawrence Berkeley Lab., CA (USA)). Apr 1990.

Contract AC03-76SF00098. 36p. NTIS, PC A03/MF A01 - OSTI; GPO Dep. Order Number DE91004139.

The thermodynamics of irreversible processes (TTIP) is used to derive governing equations and phenomenological equations for transport processes and chemical reactions in water-saturated semipermeable media. TTIP is based on three fundamental postulates. The first postulate, the assumption of local equilibrium, allows the formulation of balance equations for entropy. These equations are the bases for the derivation of governing equations for the thermodynamic variables, temperature, pressure, and composition. The governing equations involve vector fluxes of heat and mass and scalar rates of chemical reactions; in accordance with the second postulate of TTIP, these fluxes and rates are related, respectively, to all scalar driving forces (gradients of thermodynamic variables) acting within the system. The third postulate of TTIP states equality (the Onsager reciprocal relations) between certain of the phenomenological coefficients relating forces and fluxes. The description by TTIP of a system undergoing irreversible processes allows consideration of coupled transport processes such as thermal osmosis, chemical osmosis, and ultrafiltration. The coupled processes can make significant contributions to flows of mass and energy in slightly permeable, permselective geological materials such as clays and shales.

104

(LBL-25619)

Coupled transport processes in semipermeable media. Jacobsen, J.S.; Carnahan, C.L. (Lawrence Berkeley Lab., CA (USA)). Apr 1990. Contract AC03-76SF00098. 36p. NTIS, PC A03/MF A01 - OSTI; GPO Dep. Order Number DE91004140.

A numerical simulator has been developed to investigate the effects of coupled processes on heat and mass transport in semipermeable media. The governing equations on which the simulator is based were derived using the thermodynamics of irreversible processes. The equations are nonlinear and have been solved numerically using the n-dimensional Newton's method. As an example of an application, the numerical simulator has been used to investigate heat and solute transport in the vicinity of a heat source buried in a saturated clay-like medium,

in part to study solute transport in bentonite packing material surrounding a nuclear waste canister. The coupled processes considered were thermal filtration, thermal osmosis, chemical osmosis and ultrafiltration. In the simulations, heat transport by coupled processes was negligible compared to heat conduction, but pressure and solute migration were affected. Solute migration was retarded relative to the uncoupled case when only chemical osmosis was considered. When both chemical osmosis and thermal osmosis were included, solute migration was enhanced. 18 refs., 20 figs.

105

Steam tables in SI-units/ Wasserdampf tafeln. Griquill, V.; Straub, J.; Schiebener, P. New York, NY (USA); Springer-Verlag New York Inc. (1989). 140p. Springer-Verlag New York Inc., 175 Fifth Ave., New York, NY 10010 (USA).

This book presents steam tables for solving problems in the field of power and chemical engineering, where water and steam are serving as working or process medium. All tabulated values given were recalculated; the thermodynamical properties have been calculated according to the 1984 IAPS formulation, the remaining properties result from IAPS's current releases. The increments for temperature and pressure for the saturation tables were decreased. In addition ten properties were added. Three new h,s-diagrams for compressed water will be useful in geographical and in jet cutting applications.

106

Origin of late Cenozoic volcanic rocks of the Carpathian arc, Hungary. Salters, V.J.M.; Hart, S.R.; Panto, G. pp. 279-292 of *The Pannonian Basin*. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

Medium to high K calcalkaline (CA) volcanics in the Carpathians are remnants of an Eocene and Micoene volcanic arc. This volcanism was followed by alkali basalts (AB) in the Quaternary. The CA rocks vary in composition from basaltic andesite to rhyolite, while the ABs are restricted in composition to 44-48% SiO₂. CA rocks have ⁸⁷Sr/⁸⁶Sr = 0.70426-0.71125, ¹⁴³Nd/¹⁴⁴Nd = 0.51274-0.51221. The ABs have ⁸⁷Sr/⁸⁶Sr of 0.70320-0.70421 and ¹⁴³Nd/¹⁴⁴Nd of 0.51292-0.51270.

The complete suite forms a narrow array on the Nd-Sr isotope correlation diagram, despite its large geographic and compositional variation. Pb isotopes exhibit a restricted range for $^{207}\text{Pb}/^{204}\text{Pb} = 15.61\text{--}15.72$ and $^{208}\text{Pb}/^{204}\text{Pb} = 38.99\text{--}39.2$. $^{206}\text{Pb}/^{204}\text{Pb}$ variation is larger, ranging from 18.69–19.42. On the Pb-Pb and Nd-Sr isotope diagrams the Carpathian volcanics overlap the array defined by oceanic island volcanics, and lie in the field of other arcs often associated with crustal contamination. This paper discusses how the isotopic and trace element characteristics of the volcanics can be explained by two different three-component mixing models.

107

Helium isotopes in geothermal waters from northwest Hungary. Deak, J.; Horvath, F.; Martel, D.J.; O'Nions, R.K.; Oxburgh, E.R.; Stegena, L. pp. 293–296 of *The Pannonian Basin*. Royden, L.H. Tulsa, OK (USA); American Association of Petroleum Geologists (1988). 390p.

$^3\text{He}/^4\text{He}$ ratios and helium concentrations have been measured for 15 thermal waters from northwest Hungary. All show a large enrichment in helium, relative to equilibrium solubility at recharge. The $^3\text{He}/^4\text{He}$ ratios ($0.22 > R/R_a < 1.07$) show an appreciable component of mantle-derived helium in all samples.

108

Long term performance of geothermal circulation system -significance of water/rock interaction. Shoji, T.; Watanabe, K.; Takahashi, H. pp. 436–445 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371–).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27–30 Jun 1989).

This paper describes a simulation of the long term performance of a geothermal circulation system, based on a consideration of the water/rock interaction. During the long term circulation of geothermal fluid through a crack-like reservoir, the crack aperture can be changed by dissolution and/or precipitation of rock minerals. These changes have a significant effect upon the flow impedance of the system, and under some conditions, precipitation from the fluid can lead to plugging of the crack-like reservoir. (author).

109

Mechanisms of dissolution-precipitation processes induced by hot water circulation in a fractured granite: Pt. 1: Mass balance of wall-rock alterations and vein deposits. Turpault, M.-P.; Berger, G.; Meunier, A. pp. 457–466 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371–).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27–30 Jun 1989).

Fluid circulation in fractured rocks is known to produce zoned alteration. Zonation is classically considered to be related to chemical or temperature gradients; the mechanisms of the zone growth are not known. Most of the studies describe secondary products in order to determine the physicochemical conditions prevailing during the alteration. Little is known concerning the dynamic of the processes from the opening to the sealing of a fracture. The aims of this study is to determine these dynamic processes by quantifying, as far as it is possible, the dissolution-recrystallisation features. The calculation of bulk mass balance and the analysis of the secondary phase distribution enable the relationships between dissolution of primary phases and precipitation of secondary ones at different times to be defined. (author).

110

Mechanisms of dissolution-precipitation processes induced by hot water circulation in a fractured granite: Pt. 2: Modeling of water-rock interaction. Berger, G.; Turpault, M.-P.; Meunier, A. pp. 467–474 of *Hot dry rock: geothermal energy*. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371–).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27–30 Jun 1989).

Little is known about the working process of hydrothermal fractures, in particular about the filling mechanism and its kinetics. We have investigated this problem by applying two different approaches. Quantitative petrographical observations, carried out on hydrothermal alterations of the La Peyratte's granite (France) provided precise data on temperatures, water-rock ratios (W/R), sequences of secondary phases and chemical

budgets of the alteration (part I). Water-rock interaction simulations were performed with computer codes in order to ascertain the chemical composition of the fluid compatible with this kind of alteration, and to evaluate step-working and the time evolution of these veins. In this part, we present the calculations carried out with the EQ3/6 software package. The input constraints (temperature, starting solids, rate laws) were determined from petrographical and bibliographical data. The effect of the fluid composition on the secondary assemblage have been tested by changing the initial fluid composition. (author).

111

Prediction of changes in elastic moduli due to water-rock interaction during operation of granitic HDR geothermal system. Wada, C.; Takahashi, H. *Geothermics (International Journal of Geothermal Research and its Applications)* (UK); 19: No. 1, 61–76 (1990).

Young's modulus of granitic rock samples under the simulated conditions of a geothermal reservoir, such as a pressurized high temperature water environment up to 350°C, was measured by means of the compliance calibration technique. The results obtained indicate a significant change in modulus with increasing test temperature and exposure time in a hydrothermal environment, which can be considered as a consequence of an increase in microcrack aperture due to chemical dissolution. The applicability of the laboratory results to hot dry rock geothermal field data is also demonstrated.

112

Temperature field simulation with stratification model of magma chamber under Los Humeros Caldera, Puebla, Mexico. Verma, M.P.; Verma, S.P.; Sanvicente, H. *Geothermics (International Journal of Geothermal Research and its Applications)* (UK); 19: No. 2, 187–198 (1990).

A simulation of the temperature field underlying Los Humeros caldera is obtained through numerical solution of the energy-conservation equation for a conductive heat flow process. The update information on geological, geochemical, geophysical and geochronological studies is used to estimate the parameters of the internal structure of the caldera. The simulation is carried out under a model of the

stratification of a magma chamber. The existence of such a stratification is supported by geological and geochemical evidence. The boundary conditions, the equality of temperature and heat flux are programmed in the numeric solution of the energy-conservation equation by considering the boundary of a very small, finite thickness and smoothing the temperature curve at every step of calculation.

113

Gamma-ray spectra survey in geothermal area. Mogi, T.; Okada, S. *Nippon Chinetsu Gakkaishi (Japan)*; 12: No. 3, 295-308 (25 Jul 1990). (In Japanese).

The authors have examined the data processing of gamma-ray spectra survey, and propose an idea on judging method for detection limits of each element and estimating method of statistical errors of calculated values. And then, they describe the results of the gamma-ray spectra survey carried out at Komatsu geothermal area, Oita Prefecture. In this study, a data analysis method based on Covell (1959) method, including the error estimation of observed data was used, and the adaptation of detection limits of gamma-ray from each element based on Currie (1966) method is also proposed. The results of the survey show that high gamma-ray intensity areas for Bi well correspond to high 1 m depth temperature areas, and high intensity areas for Ti correspond to the locations of fumaroles distributed around high 1 m depth temperature areas. They conclude that the high gamma-ray intensities of Bi and Ti are potential indicators for the existence of ascent of thermal water. 12 refs., 7 figs., 1 tab.

MISCELLANEOUS

114

Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Hot-dry-rock (HDR) research covers a large number of disciplines and the papers submitted to the conference show a remarkable diversity. They have been broadly classified as follows: the HDR environment; current status of HDR technology; HDR energy resource and economics; reservoir creation and development. (author).

115

Opening address. Rae, John. pp. 1-11 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

The development of hot-dry-rock (HDR) research and technology in the United Kingdom is reviewed within the context of the international effort in this area. It is part of the Department of Energy's programme of research and development on renewable energy. The main objective of the HDR programme is to determine the technical and economic viability of the HDR systems for electricity generation, combined heat and power or the direct use of heat. It has been established that the most cost effective route for HDR in

the UK is likely to be electricity generation and a sizeable resource appears to be available, mainly in South West England. Some problems will remain, however, in establishing a practical means for extracting heat energy. (UK).

116

The U.S. hot dry rock program. Mock, J.E. pp. 149-158 of Hot dry rock: geothermal energy. Baria, Roy. London (GB); Robertson Scientific Publications (1990). 624p. (CONF-8906371-).

From Camborne School of Mines international hot dry rock conference; Redruth (UK) (27-30 Jun 1989).

Hot Dry Rock (HDR) research, initiated in the US in 1970, has been strongly supported by the government because: it is an indigenous resource secure from fuel interruptions; it can provide price stability during periods of rapid escalation of fuel prices; it is a large resource; and it is environmentally benign. The US Department of Energy's (DOE) outlook on geothermal energy production and its plans for future geothermal research are discussed. Current use of geothermal energy to generate electricity and to serve as a source of heat is also described. DOE has initiated a study to compare several independent evaluations of the economics of prospective HDR systems. Some possible directions for advanced research and industrial development are presented. (author).

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