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NATIONAL GEOTHERMAL INFORMATION RESOURCE

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National Geothermal Information Resource

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That development of the United States energy resources is essential to our nation's progress and economic well-being cannot be questioned. Based on the availability of domestic energy sources, industrial and electrical utility plants are modified, private and public transportation is affected, and rules and regulations concerning energy are changed. A very thin line separates an uneconomical energy resource from a viable reserve upon which so much of our current and future lifestyle depends. The need for sound data is obvious.

In order that geothermal energy may more readily contribute its share to the energy needs of the United States, there must be an effectve transfer of information covering all aspects of geothermal exploration, evaluation, and utilization. The gap between the time when data are obtained and when it becomes public knowledge must be minimized. Of equal importance to compilation and dissemination are both the evaluation and the critical review of the status of numerical data.

In this work, numerical data are defined as the magnitudes of specific physical or chemical properties of well-characterized geothermal gases, solutions, and rocks and minerals (Ref. 1). These data are extracted from the literature, evaluated, and recommended values together with estimated limits of reliability are determined by the National Geothermal Information Resource (GRID).

Besides evaluation, timely reviews on the current status of information

are important in a rapidly growing field such as geothermal science and technology. The reviews provide the national geothermal energy program with annotated and indexed references to unevaluated data for use in preliminary estimates, calculations, and modeling.

In this report, the principal GRID categories for compilation of geothermal information are described, and examples given of current activities. Included also is a brief description of our computer-aided document file.

Introduction

The Lawrence Berkeley Laboratory is sponsored by the U. S. Energy Research and Development Administration to establish a National Geothermal Information Resource. The objective of the GRID program is mainly to collect, organize and disseminate evaluated data on the following 6 major categories of geothermal science and technology: (1) physical chemistry, (2) exploration and evaluation, (3) utilization, (4) environmental aspects, (5) institutional considerations, and (6) reservoir characteristics. For example, current GRID activities include the following: (1) development of a thesaurus of geothermal data descriptors. This is part of an effort centered around dissemination of data in computer-processable form on a multilateral and global basis. (2) A review and evaluation of numerical data covering the basic physicochemical properties of geothermal vapors, solutions, and rocks at elevated temperatures and pressures. For example, the density of sodium chloride solutions. (3) Current bibliographic information on exploration, with a review of the status of data on geochemical methods. (4) Electrical and non-electrical uses of geothermal energy. An example is the compilation and evaluation of fundamental data on hot water (brine) transport and space heating applications. (5) Computer-aided updating of environmentally-

oriented geodetic maps.

We have found that the geothermal literature generally falls into one of the following classes: (1) Unevaluated numerical data covering basic physical chemistry. The change in density of sodium chloride solutions at elevated temperatures and pressures is an example of laboratory-generated data. (2) Evaluated and analyzed information which is scattered through the literature; this is compiled and indexed by GRID so that it will be available for quick retrieval by the user. Geochemical exploration is an example of this class of information. (3) Data on important aspects of geothermal development that are neither widely disseminated nor evaluated. An example of this class is geothermal subsidence.

The discussion which follows centers around a description of the information contained in these six major categories and examples of results of the work.

Physical Chemistry

Geothermal physical chemistry covers laboratory measurements and theoretical calculations of basic scientifc data on gases, solutions, and rocks covering initially temperatures to 500°C and pressures to 500 bars. (See Table 1). Such data are important to understanding and predicting the behavior of a reservoir which is used for either electrical or other applications. For example, data on the solubility of silica and calcium carbonate are needed to predict scaling in pipes caused by precipitation due to a change in operating temperature or pressure as compared with that at depth. Density data are important in calculating partial molal volumes and in calculating and evaluating hydrostatic pressure relationships. For example, density data are needed to convert pressures into the

Table 1. GEOTHERMAL PHYSICAL CHEMISTRY
(See Ref. 2, 3)

Basic scientific numerical data on gases, solutions, rocks at temperatures to 500°C, pressures to 500 bars; covering the evaluation and status of:

A. SOLUTIONS

1. Sodium, potassium and calcium chlorides

   a. Density
   b. Vapor pressure
   c. Heat of solution
   d. Partial molal heat content
   e. Enthalpy change
   f. Heat capacity
   g. Electrical conductivity

2. Ferric chloride, ferrous chloride, sodium sulfate

   a. Heat of solution
   b. Partial molal heat content
   c. Heat capacity
   d. Enthalpy change

B. ROCKS AND MINERALS

1. Heulandite - clinoptiloite; chlorites; illite and montmorillonite clays; pargasite - ferropargasite amphibole:

   a. Enthalpy
   b. Entropy
   c. Free energy
   d. Heat capacity
   e. Porosity

2. Others (e.g., zeolites, micas, glasses)

C. ROCK-SOLUTION INTERACTIONS

1. SiO_2 solubility vs. pH
2. SiO_2 - silicates - H_2O equilibria

D. ENERGY CONVERSION

1. Isobutane properties

E. CORROSION AND SCALING

equivalent of hydrostatic depth for $NaCl$-KCl-$CaCl_2$ solutions; this permits estimating the maximum temperature likely at a given depth in a convecting hydrothermal system. While there are data available for the density of chloride solutions, it is contained in a large number of publications. The data are both difficult to access and largely unevaluated. See Table 2 for typical uses of density data.

Table 2. Typical applications of density data to geothermal systems.

Direct Use	Calculated
Depth-boiling point curves	Partial molal volume
Fluid inclusion thermometry	PVTX
Mineral solubility	
Hydrodynamics	Free energy
Reservoir modeling	

Additional information on the needs for basic scientific data are found in A Recommended Research Program in Geothermal Chemistry (Ref. 2), and the Conference on Thermodynamics and National Energy Problems (Ref. 3).

Exploration and Evaluation

Geothermal resource exploration and evaluation activities center around reviews of the status of data, and indexed abstracts on the methodology used to locate and evaluate geothermal resources covering the following principal categories:

Geology	Hydrology
Geochemistry	Land-Use Factors
Geophysics	Resource Assessment
Drilling	

These techniques are used to: (1) locate subsurface regions which contain a high temperature anomaly, and (2) estimate the extent of the

reservoir, its temperature and its potential for use in power production or non-electrical applications. See Table 3. As shown in the table, geochemical data are an important aspect of exploration methodology.

Geochemical data are used mainly (1) to infer the temperature of the reservoir at depth from chemical analysis of surface waters. The SiO_2 and Na-K-Ca content of brines are two examples of commonly used chemical geothermometers. See Table 4. Geochemical sampling and gas and water analyses are based on standardized methods, for example, see Reference 4. (2) To provide information on the sources of reservoir original and recharge water by measuring isotope concentrations, for example, the ratio $^{16}O/^{18}O$. (3) To predict the likelihood of problems which may be encountered in utilization of the fluid. Silica precipitation which can cause scaling, low fluid pH which enhances corrosion, and H_2S content which may pose an environmental problem are three examples.

Additional information on geochemical exploration methodology is obtained from a number of publications. For example, D. E. White's section on "Geochemistry Applied to the Discovery, Evaluation, and Exploitation of Geothermal Energy Resources" (Ref. 8).

Environmental

The GRID compilation of environmental aspects of geothermal energy currently covers a review of the status of data on man-related effects to Air, Water, and Land compartments of the environment due to the exploration and utilization of geothermal energy. See Table 5. Generally, a review of the status of geothermal environmental data will center on the following information: (1) statement of the problem, (2) effects of the environmental quality parameter to Air, Water, or Land, (3) methods

TABLE 3.

Typical Methods for Geothermal Exploration

(See References 5-8.)

Typical Data Sought	Commonly Used Method
SURFACE	
Site Location	Literature search; observation of hot springs, fumaroles; infrared aerial photography.
Site Evaluation	Rock hydrothermal alterations.
Measurements:	
Geochemical	Dissolved constituent concentrations; isotope ratios.
Geophysical	Electrical resistivity; temperature gradient; gravity; seismic; magnetic; drilling (< 1 km depth).
Inferred (Predicted):	
Reservoir Temperature	Dissolved constituents.
Recharge Water Sources	Isotope ratio.
Reservoir Depth	Electrical resistivity.
Category of Reservoir:	
Vapor	Electrical resistivity; Cl concentration.
Hot Water	Electrical resistivity; Cl concentration.
Power Potential of Field (Megawatt-years)	Electrical resistivity; reservoir temperature; surface temperature gradient.
Model of Reservoir	Data from measurements.
SUBSURFACE	
Category of Reservoir	Drilling (≥ 1 km depth).
Vapor	Fluid composition.
Hot Water	Fluid composition.
Temperature of Reservoir	Drilling.
Rock Properties:	Drilling; core samples.
Porosity	Laboratory testing.
Permeability	Laboratory testing.
Density	Laboratory testing.
Hydrothermal Alterations	Petrological examinations.
Enthalpy	Ratio of heat flow over fluid mass flow.
Model of Reservoir	Data from drilling samples.

Table 4. Commonly Used Aqueous Chemical Geothermometers (Ref. 5, 6, 8)

Quantitative Temperature Estimates

SiO_2

Na - K - Ca

Qualitative Temperature Estimates

$CaHCO_3$

Cl - dilution

Temperature Indicators

Mg

Mg/Ca

Na/Ca

Na/K

Na/Rb

Na/Li

$Cl/(HCO_3 + CO_3)$

Cl/F

Cl/SO_4

Dissolved volatiles (B, NH_3, Hg)

Trace Elements (Hg, W, Sb)

used for control and abatement, (4) mechanism and pathway of the parameter, (5) instrumentation for monitoring and measuring the environmental effect, and (6) recommendations in areas where data are needed because it is either currently insufficient or unavailable.

Table 5. Typical environmental parameters associated with geothermal energy resources. (Ref. 9, 11, 12)

AIR:	H_2S, NH_3, Toxic Metals (e.g., Hg, As, Se)
WATER:	H_2S, Boron, Silica, Toxic Metals
LAND:	Soil Degradation, Noise, Land Use
SUBSURFACE:	Subsidence, Seismicity

Additional information on environmental aspects of geothermal energy may be obtained from An Environmental Study of the Wairakei Power Plant by Axtmann (Ref. 9) and the Bibliography of Geothermal Resources (Ref. 10).

Utilization

This category contains information on the current and expected electrical and non-electrical uses of geothermal energy including the following:

Hot Water (Brine) Transport
Space, Process, and Agricultural Heating
Power Generation
Binary Cycle Power Generation
Corrosion, Erosion, and Scaling
Resource Evaluation

Institutional

This category covers Federal, state, and local organizational, legal, and regulatory considerations in the development of geothermal energy:

Land Use
Exploration and Production
Operating Regulations

Industry Financial Incentives
Sale of Geothermal Power
Fluid Transport

Reservoir Characterization

Reviews and evaluation of data relevant to the development and production of wells covering:

Porosity
Artificial Stimulation
Natural Recharge
Artificial Recharge
Modeling
Well Tests and Measurements

Additional information on utilization, institutional, and reservoir characterization is contained in "Geothermal Energy: National Proposal for Geothermal Resources Research" (Ref. 13), and "National Plan for the Development of Geothermal Energy" (Ref. 14).

Documentation File (GEODOC)

GEODOC is a computer based file which contains the descriptive cataloging and indexing information for all documents processed by the National Geothermal Information Resource Group. This file (along with other GRID files) is managed by DBMS, the Berkeley Data Base Management System. Input for the system is prepared using either the IRATE Text Editing System with its extended (12 bit) character set, or punched cards. (Ref. 15).

Each record in the GEODOC file contains the descriptive cataloging, abstracting, and indexing information corresponding to a single document. The information within a given record is subdivided into "data elements". Table 6 lists the definitions of all the data elements which may appear in a GEODOC record. Some data elements (e.g., authors name) can occur repeatedly within one record. An "m" in the third column of Table 6 indicates that such multiple occurrences are allowed. The "LBL tag" for each data

Table 6. GEODOC Data Elements
(Ref. 15)

LBL Tag	INIS Tag	m*	n*	Data Element Definition
SC	008			document short code: unique identifier for document
TY				type of document/bibliographic levels/literary indicator
DES-CAT		m	n	delineates information for one bibliographic level
BL	009			bibliographic level indicator
PT	200			primary title (translated into English if necessary)
PS	201			primary subtitle (translated into English if necessary)
TA	620			title augmentation
L	600			language (for non-English document)
OT	230			original title (non-English) or journal/series title
OS	231			original subtitle (non-English) or journal/series subtitle
ED	250			edition
CODEN				journal CODEN
AUTHORS		m	n	delineates author-affiliation group
AU	100	m	n	author's name
AN	100			author note (ed., comp., eds., comps.)
AA	100	m		author's affiliation
AC 700				affiliation code
CE	110	m		corporate entry
CC	710			corporate code
DG	111			academic degree
SPO		m		sponsor
SPC				sponsor code
SCN		m		sponsor contract number
RN	300			report or patent number
SN	310			secondary numbers
INT	320			International Standard Book Number or Patent Code
PUB	402			publisher
PUP	401			place of publication
PUD	403			publication date
COL	500			collation (volume, issue, page)
N	610			note
COT	210			conference title
COP	211			conference place
COD	213			conference date
AV				availability and price

Table 6. GEODOC Data Elements (Con'd.)

LBL Tag	INIS Tag	m*	n	Data Element Definition
REL-REF		m	n	delineates information for one related reference.
RL				relator
RLR				relationship and reference
RSC				related short code
ABSTRACT		m	n	delineates one abstract
ABS				abstract
ABSO		m		abstract source
INDEX		m	n	INDEX.1 general indexing. INDEX.2, 3,...N splits
CQ		m		category/qualifier
TICC		m		TIC category
DE	800	m		descriptor from thesaurus
DD	800	m		data descriptor from thesaurus
ID				identifier
PD	810	m		proposed descriptor
CONTROL			n	internal LBL data elements
LA		m		local availability
BR				borrow/return
DCSO		m		descriptive catalogers initials, date and comment
AISO		m		abstractor-indexers initials, date and comment
DATA-FILE		m		data file name
POT		m		data descriptor for potential data
IN		m		data descriptor for included data

*m-This data element may have multiple entries
*n-This data element contains no value and need not be entered on input. It serves to delineate a group of data elements.

element is shown in the left hand column of Table 6. These tags are used to label the data elements within a record.

The data elements bear certain hierarchical relationships to each other; that is, some data elements are subordinate to, or, conversely, parents of, others. Figure 1 is a diagram of this hierarchical structure. The structure is also indicated in Table 6 by indenting the tag names of subordinate data elements and placing them after their parents. The data elements may be input to the system in any order except that subordinate data elements must follow the occurrence of the parent to which they are associated.

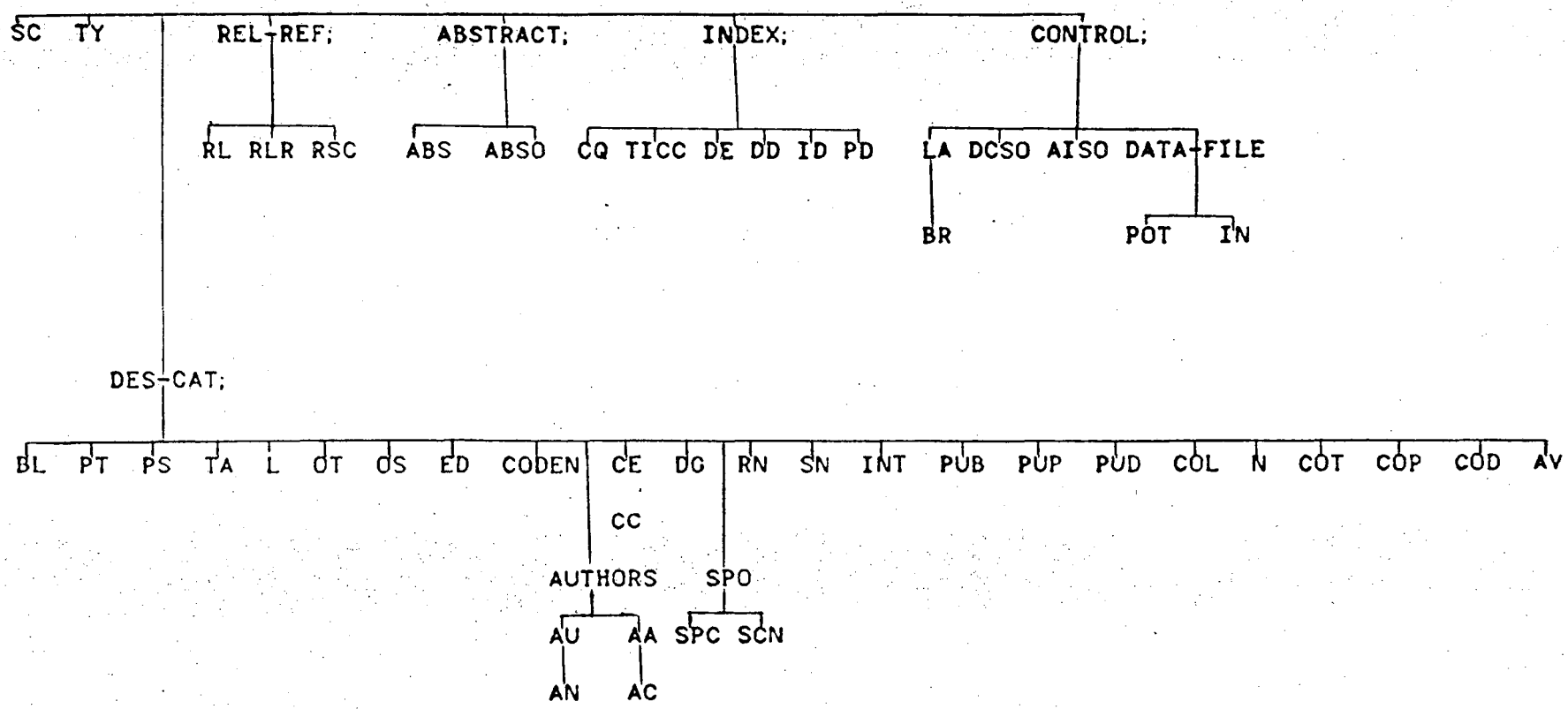
The GEODOC descriptive cataloging techniques are modeled after those of the International Nuclear Information System (INIS) of the International Atomic Energy Agency (Ref. 15). The data elements have been chosen to correspond as closely as possible with those used by INIS to facilitate information exchange on a multilateral and global basis. An INIS tag is shown in Table 6 for those data elements whose internal format is identical or almost identical to the GEODOC format. This is primarily for convenience in referencing INIS documentation.

Other GRID files similar to GEODOC but with appropriately defined data elements will be used to store and retrieve numerical data (e.g., physical chemistry data).

Conclusions

After reviewing the current geothermal resources information in light of the data requirements, some general observations are appropriate. While data currently available are satisfactory in some respects, there are still some inadequacies. The optimum future data activities should include:

Fig. 1 GEODOC Record Structure (Ref. 15)



(1) Laboratory measurements of the thermodynamic and transport properities of materials likely to be encountered in vapor-dominated and hot-water (brine) systems. The data are needed in areas including prediction of the operating parameters of electrical and non-electrical plants, and in modeling reservoirs. ERDA and USGS laboratories are currently actively engaged in these studies on basic scientific information.

(2) Compilations of information on known geothermal resource areas within the United States. Urgently needed are numerical data on surface water chemical analyses, reservoir fluid physical and chemical properties, and geophysical measurements. These data are valuable for many uses including: correlating theoretical models with actual reservoirs; indicating corrosion, erosion, and scaling problems which might arise; providing a basis for research and development of materials (e.g., piping) which come in contact with geothermal fluids. Currently, such U.S. data are not readily available for general dissemination.

(3) Evaluation of the economically viable geothermal energy resource of the U. S. The information is important in assessing the potential for geothermal energy to produce electricity, and for other uses (e.g., space heating). The U. S. Geological Survey recently issued a report on Assessment of Geothermal Resources of the United States - 1975. (Ref. 6).

(4) Measurements on environmental aspects of geothermal energy exploration and utilization, particularly centered around background data. This will permit an accurate differentiation of environmental effects due to utilization of geothermal energy from the naturally occurring effects. This is currently an active area, for example, the subsidence network in Imperial Valley, California, (Ref. 16).

(5) Methods and models for evaluating data from KGRA's, facilitating future predictions of pollutant distributions and alteration of land subsurfaces. For example, currently at LBL, there is a project sponsored by ERDA utilizing computer generated plots to update geodetic maps.

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