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地热能的战略开发

——2009国际地热协会西太平洋分会地热研讨会论文集

主　编　郑克棪　J.劳莱士　田廷山　董　颖

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内 容 简 介

本书收集了国际地热协会西太平洋分会地热研讨会的论文32篇，包括四个方面：地热能的发展战略，地热能的勘查研究，地热能的开发利用，地热新技术新领域。系统反映了目前国际地热的发展状况以及我国地热勘探、开发的实际状况，探索了未来地热能的发展方向。

本书可供从事地热能勘探、开发以及管理的人员参考使用。

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网 址：http://www.gph.com.cn
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前　言

国际地热协会西太平洋分会于2006年在新西兰成立并与新西兰地热协会联合举办研讨会，2007年在菲律宾与菲律宾能源开发公司第28届地热研讨会联合举办活动，2008年在印度尼西亚与印度尼西亚地热协会联合举办活动，2009年来中国与中国能源研究会地热专业委员会联合举办国际地热培训和地热研讨会。

全球性的高温地热带有环太平洋地热带、大西洋中脊地热带和地中海-喜马拉雅地热带。西太平洋地区拥有高温地热资源的优势，是世界地热发电潜力最大的地区之一。中国东南沿海和台湾省在西太平洋地热带内，而西藏在喜马拉雅地热带内。毫无疑义，丰富的地热资源背景为我国地热工作者施展才华奠定了基础条件。

中国能源研究会地热专业委员会约有800名会员，由我国地热行业的院士、研究员、教授、专家、工程师、企业家和政府管理人员等组成。中国能源研究会地热专业委员会是国际地热协会的会员，一方面，我们得到国际上的支持和援助，另一方面，我国的地热发展又为世界地热事业添彩。

天时、地利、人和，我们庆幸今年的难得机遇：国际地热协会专门派遣专家为我们培训地热发电，接着是国际地热协会西太平洋分会与中国能源研究会地热专业委员会联合举办地热研讨会，大会的主题是“发挥地热资源优势在能源发展战略中的作用”。我们将西太平洋地区与会者提交地热研讨会的论文编辑成了《地热能的战略开发》论文集。本书共选论文32篇，其中，地热能的发展战略10篇，地热能的勘查研究8篇，地热能的开发利用6篇，地热新技术新领域8篇。正如国际地热协会西太平洋分会主席吉姆·劳莱士在题词中所说：“相信这将引导地热能的新发展”。

祝愿西太平洋地区和中国的地热事业迎来更美好的明天！

编　者

2009年8月

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地热能的发展战略

A Code for Geothermal Resources and Reserves Reporting

A. F. Williams[1] J. V. Lawless[2] M. A. Ward[3] F. L. Holgate[4] and A. Larking[5]

(1. Geodynamics Limited, PO Box 2046, Milton, Queensland, Australia 4064, adrian. williams @ geodynamics. com. au; 2. JLawless@ skm. co. nz; 3. mward@ geothermaladvisory. com; 4. fiona. holgate@ kuthenergy. com; 5. alarking@ greenrock. com. au)

Abstract: Geothermal companies are increasingly using both equity markets and the finance sector to raise funds to develop their projects. At the same time, the industry is pursuing new concepts such as hot rocks and engineered geothermal systems, and the large scale use of geothermal energy is a relatively new concept in many parts of the world. The industry is thus faced with the challenge of building understanding and reputation in the market place, with investors, regulators and the public. This is certainly the case in Australia, where the industry has grown rapidly from zero to almost 50 companies pursuing geothermal energy in the eight years from 2001 to 2009.

The development of a Geothermal Reporting Code and its adoption by operating companies to guide the way they report their geothermal exploration results, resources and reserves, is an important step in the growth of the geothermal energy industry.

This paper reports the development of a Geothermal Reporting Code by the geothermal industry in Australia, in a way that aligns with similar codes in the world for mineral and petroleum industries. The Code covers all forms and uses of geothermal energy (except ground source heat pumps) and sets out the minimum and mandatory requirements for Public Reports, but it is not prescriptive as to how estimates of resources and reserves are made. Accompanying estimation guidelines have also been prepared but are not mandatory.

The Code was launched in Australia in August 2008, with the support of the Australian geothermal associations and, importantly, the Australian Securities Exchange (ASX). It has been developed by the Geothermal Reporting Code Committee under the auspices of the Australian Geothermal Energy Association (AGEA) and the Australian Geothermal Energy Group (AGEG).

Key words: geothermal, code, resources, reserves, reporting, Australia, finance, regulation

1 INTRODUCTION

The Australian geothermal sector has evolved in a way that is almost unique in the world. Historically the industry has been confined to a single small, low temperature geothermal power station in a remote community and a few community heating projects. With the appreciation of the potential of geothermal energy to replace static fossil fuel energy on a large scale from about 2000,

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the Australian industry has grown from zero to some 48 companies holding about 385 geothermal tenements with associated work commitments exceeding US $ 1bn in 2009. Ten of these companies (and all of the most active ones) are listed on the ASX and more will follow when the equity markets improve.

Utilities have played little part in the primary expansion of the Australian industry. Funding has come from stock market IPOs and subsequent issues, joint venture project buy-ins and some government grants. The reliance on stock market funding in particular has driven the Australian industry to develop a regime to make Public Reports on their value-driving assets (their geothermal resources and reserves) that is acceptable to market and investment regulators, as well being comprehensible by investors. At the same time, the reports produced under this regime need to be able to be used comparatively and numerically by non-market financiers (fund managers and banks).

The *Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves* was developed in 2008 after widespread consultation between the industry participants, government technical authorities and investment regulators. After considering a number of possible models, it was based on the well developed Australian code for Public Reporting on minerals resources and reserves, called the "JORC" Code and maintains JORC's principals of materiality, transparency and competence in public resources reports.

The Code is a formal regime for stock-exchange listed companies to make reports to the market and also acts as a template for other entities to document their resources and reserves in a standard way that private debt and equity providers can understand and use. The code does not dictate the technical methodology used to estimate the resources and reserves. The technical person has freedom to use whatever methodology or data they think appropriate.

A crucial facet of the Code is that any Public Report by a company must be signed off by a Competent Person before the report is released. The Competent Person is usually the senior technical person responsible for writing or compiling the original resources or reserve estimate and must have at least five years of relevant experience in the type of Geothermal Play under report. The Competent Person is personally named in the Public Report and therefore must be prepared to defend his or her work if challenged by their peers.

2 STRUCTURE OF THE CODE AND RELATED DOCUMENTS

Methodologies for classifying reserves are well established in the petroleum and mineral industries. Because many of the companies active in the Australian geothermal industry have a strong mining background, and because of the simplicity and wide acceptance of the JORC code which is most commonly used for reporting of mineral reserves and resources, it was decided to model the geothermal code on that, rather than the other obvious alternative of modeling it on a petroleum reporting code such as that of SPE.

The JORC code conforms to the CRIRSCO standard (see: http: //www. crirsco. com/welcome. asp) and is recognized by both the Australian and Toronto stock exchanges. The relation-

ship between the JORC and Australian geothermal codes is formally summarized as follows in the Code:

This Geothermal Code is based closely on that of the Joint Ore Reserves Committee's "Australasian Code for the Reporting of Exploration Results, Mineral Resources and Ore Reserves" (the JORC Code 2004 Edition), and this has been done with the support of the JOR Committee. Nevertheless this Geothermal Code should be interpreted and applied as an independent Code.

In accordance with JORC principles, the Australian Geothermal Resources and Reserves Reporting Code ("the Code") covers a minimum, mandatory set of requirements for the Public reporting of Geothermal Resource and Reserve estimates. While it tabulates a large number of issues to be considered in reporting, it is not particularly prescriptive as to methodology in making the estimates that are reported.

The Code is accompanied by a 'Geothermal Lexicon' which provides guidance on how Geothermal Resources and Reserves can be estimated for reporting purposes. The techniques described in the Lexicon are not a mandatory part of the Geothermal Code. However, any significant deviations from the Lexicon should be disclosed and explained when reporting under the Geothermal Code.

3 CURRENT STATUS

At the time of writing (August 2009) the status of the Code was as follows.

- The First Edition of the Code and Lexicon were formally launched in mid August 2008 and have been submitted to the International Geothermal Association (IGA), who have recognized the Code as appropriate and endorsed the Lexicon;
- The Code and Lexicon have also been submitted to the International Energy agency (IEA);
- Discussions have been held with the JOR Committee and agreement reached to maintain independent mineral and geothermal Codes, but with close coordination;
- The Code and Lexicon had been submitted to the Toronto Stock Exchange and Ontario Securities Commission and preliminary discussions held with the Canadian Geothermal Energy Association with the objective of aligning the forthcoming Canadian Code with the Australian one;
- From the use and discussion in Australia and internationally, a number of improvements in the Geothermal Code have been identified and a Second Edition of the Code is scheduled for November 2009;
- Discussions have been held with the Australian Securities Exchange (ASX). AGEA has begun the process of having the Second Edition formally incorporated into the ASX Listing Rules which in turn will bring about mandatory compliance under Australian federal law. This process will take at least a year.

The Primary Industries and Resources Department of the government of South Australia is acting as the secretariat for the Code. Copies can be obtained from:

http://www.pir.sa.gov.au/geothermal/ageg/geothermal_reporting_code

4 HOW GEOTHERMAL ENERGY REPORTING DIFFERS FROM PETROLEUM OR MINERALS

The mineral and petroleum reporting approaches include a two-dimensional classification based on:

- Reliably of the information defining the physical resource, and
- Commercial extractability of the resource.

Those distinctions are applied here to geothermal.

As mobile resources petroleum reservoirs have many similar characteristics to their geothermal equivalents but geothermal resources are subject to a variety of thermodynamic processes under extraction. Mineral resources generally have greater variability and less continuity and so require greater sampling density to assure the magnitude of contained resource.

Geothermal resources in convective hydrothermal systems further differ from both minerals and petroleum resources by being renewable through recharge, albeit usually at a slower rate than energy is extracted. The rate of this recharge can vary significantly from system to system, and can be stimulated to a varying degree by production.

Unlike most minerals and oil which have an internationally defined dollar value, electrical energy prices can vary by an order of magnitude from place to place both because of physical alternative sources of supply and regulatory policies. Therefore the "cut off grade" for geothermal resources cannot be defined as a single internationally applicable number for certain "mining criteria". It is highly country and region specific.

Furthermore, in the case of electricity generation, the "cut off grade" has to take into account the practical limitations and cost of the conversion process. It is perfectly technically feasible to generate power from fluid at 100°C or less, but it is only economic to do so in a few locations.

Geothermal projects where economics are the prime driver are typically sized to fully utilize a resource over a period of about 20 to 25 years that relates to the life of the wells and energy conversion plant, with a suitable margin for contingencies. It is therefore important to state the reserves in terms of the rate of extraction.

5 MAJOR PRINCIPLES OF THE GEOTHERMAL CODE

One of the most fundamental principles of the Code is the role of the Competent Person. The Competent Person is personally named in the Public Report and ultimately takes responsibility as to its content, having consented in writing to the form and content of the report (possibly after first requiring changes to the wording or format of the draft report to ensure its technical integrity)

A further principle in the Code is the demarcation of a reserve as opposed to resource with the taking into account of commercial viability. A '**Geothermal Resource**' is a Geothermal Play (see below) which exists in such a form, quality and quantity that there are reasonable prospects for eventual economic extraction. A '**Geothermal Reserve**' is that portion of an Indicated or

Measured Geothermal Resource which is deemed to be economically recoverable after the consideration of both the Geothermal Resource parameters and Modifying Factors.

5.1 The role of the Competent Person

The Geothermal Reporting Code states:

A Public Report concerning a company's Exploration Results, Geothermal Resources and/or Reserves is the responsibility of the company acting through its Board of Directors. Any such report must be based on, and fairly reflect, the information and supporting documentation prepared by, or under the direction of, a Competent Person or Persons. A company issuing a Public Report shall disclose the name (s) of the Competent Person or Persons, state whether they are full-time employees of the company and, if not, name their employer. The Public Report shall be issued with the written consent of the Competent Person or Persons as to the form and context in which it appears.

The last sentence effectively means that the Competent Person must be satisfied with and consent in writing to the content of each Public Report which quotes from the original technical work. Whilst occasionally administratively burdensome, this protocol is specifically designed to prevent the over-exuberant or over-simplified portrayal of resource or reserve estimates, the quantum and quality of which may have a material impact on the value of the company doing the reporting. At the extreme, it is designed to put a brake on selective quotation of Resource and Reserve figures by companies and to give the person who will be held responsible for the work, a say in how the work is presented.

A Competent Person must have a minimum of five years experience relevant to the type of Geothermal Play under consideration and to the activity that the person is undertaking. For instance, if the Competent Person is preparing or signing off on a report on resource estimates on a particular EGS play, the five years of experience must be relevant to the estimation, assessment and evaluation of geothermal resources as well as to EGS type plays. As a general guide, persons being called upon to act as Competent Persons should be clearly satisfied in their own minds that they could face their peers and be asked to demonstrate competence in the type of Geothermal Play and situation under consideration.

In the Public Reporting of Reserves, it is likely that a number of Competent Persons will be involved, each covering different or overlapping disciplines such as geoscience, reservoir engineering, electricity generation and so on. Each will take responsibility for defined sections of the Public Report.

The Competent Person must also be a member of a recognized professional organization and be able to be held accountable to the Code of Ethics of that organization.

At the end of the day, a Public Report made by a company in relation to geothermal resources, reserves or exploration results is a document agreed by the company and the Competent Person (s) and each party can be held accountable for the content for which it is responsible.

5.2 Categories of Geothermal Reserves and Resources

Categories of Geothermal Resources and Reserves are important to provide explicit under-

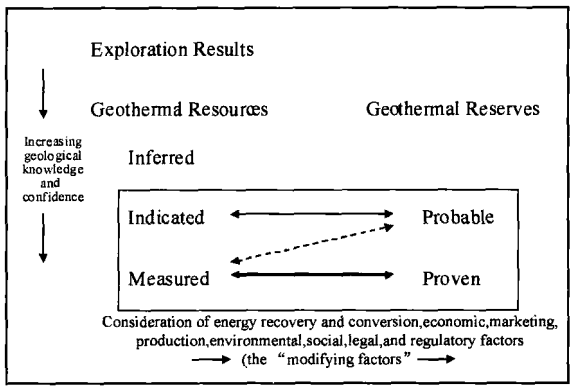

Figure 1 Relationship between Exploration Results, Geothermal Resources and Geothermal Reserves

standing of the certainty (quality and reliability) of the information that is used to define their magnitude.

The classification regime for geothermal energy resources under the Geothermal Reporting Code is illustrated in Figure 1.

The Geothermal Reporting Code recognizes three levels of Geothermal Resource (Inferred, Indicated and Measured) based upon increasing levels of geological knowledge and confidence.

Geothermal Reserves are estimated from Geothermal Resources by consideration and application of "Modifying Factors". These factors include capital and operating costs and energy pricing, plus the regulatory, environmental and social constraints on delivering a profitable outcome. Two categories of Geothermal Reserve are recognized (Probable and Proven) based upon the Modifying Factors being applied to either Indicated or Measured Resources respectively.

The relatively low level of confidence in Inferred Resources is such that they can never directly be converted into Reserves.

The actual category of Resource or Reserve which is ultimately defined is a matter for the Competent Person's judgment.

5.3 Categories other than Reserves and Resources

The term **Geothermal Play** is used as an informal qualitative descriptor for an accumulation of heat energy within the Earth's crust. It can apply to heat contained in rock and/or fluid. It has no connotations as to permeability or the recoverability of the energy. A Geothermal Play does not necessarily imply the existence of a Geothermal Resource or Reserve.

Exploration Results include data and information generated by exploration programs that may be of use to investors. The reporting of such information is common in the early stages of exploration when the quantity of data available is generally not sufficient to allow any reasonable estimates of Geothermal Resources.

Examples of Exploration Results include results of hot springs/fumarole sampling, surface heat flow, geochemical results and geophysical survey results, conductivity measurements, temperature measurements and temperature extrapolations (to a reasonable degree and on a rational basis).

5.4 Certainty of Data: Resources

A three stage classification (Inferred, Indicated Measured) is used to define how reliably the resource is technically defined (quality and quantity of information), and two categories (Probable, Proven) for Reserves.

The location, quantity, temperature, geological characteristics and extent of a Geothermal Resource are known, estimated or interpreted from specific geological evidence and knowledge.

The term 'Geothermal Resource' covers those Geothermal Plays which have been identified and estimated through exploration and sampling and within which Geothermal Reserves may be defined by reduction of the risk after the consideration and application of the Modifying Factors.

Documentation of Geothermal Resource estimates should clearly identify any known potential risks, including geological factors such as faults which could prejudice production or sources of cool fluid intrusion which could degrade the resource.

An '**Inferred Geothermal Resource**' is that part of a Geothermal Resource for which thermal energy in place can be estimated only with a low level of confidence. It may optionally also be reported as recoverable energy and assumed electricity generation with assumptions and rate stated provided there is a reasonable basis for doing so for example, through use of close analogies. This category of Geothermal Resource is inferred from geological, geochemical and geophysical evidence and is assumed but not verified as to its extent or capacity to deliver geothermal energy. There must be a sound basis for assuming that a Geothermal Play exists, estimating the temperature and having some indication of its extent.

The Inferred category is intended to cover situations where a Geothermal Play has been identified and limited measurements and sampling completed, but where the data are insufficient to allow the extent of the Geothermal Resource to be confidently interpreted. It is based mainly on indirect measurements, for example extrapolation of temperature profiles (to a reasonable degree and on a rational basis) and other associated measurements such as conductivity and heat flow, and requires a reasonably sound understanding of the subsurface geology in three dimensions derived, for example, from geophysical surveys, to indicate temperature and dimensions.

A large fraction of the stored heat contained in the reservoir of a resource will be left in the geothermal reservoir at the time that development ceases. The amount that will be left behind may depend on technical, physical or commercial limitations.

Commonly, it would be reasonable to expect that a significant proportion of estimated Inferred Geothermal Resources would be upgraded to Indicated Geothermal Resource estimates with continued and reasonably proximate exploration such as drilling. However, due to the uncertainty of Inferred Geothermal Resource estimates, it should not be assumed that such upgrading will always occur.

Confidence in the estimate of Inferred Geothermal Resources is usually not sufficient to allow the results of the application of technical and economic parameters to be used for detailed planning. For this reason, there is no direct link from an Inferred Resource to any category of Geothermal Reserves. Caution should be exercised if this category is considered in studies of technical and economic viability.

An '**Indicated Geothermal Resource**' is that part of a Geothermal Resource which has been demonstrated to exist through direct measurements that indicate temperature and dimensions so that the thermal energy in place can be estimated with a reasonable level of confidence. It may optionally also be reported as recoverable thermal energy and assumed electricity generation with assumptions and rate stated, especially with regard to the cut-off temperature and technology path-

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