SUGGESTED GUIDELINES FOR REPORTING ON THE GEOTHERMAL POTENTIAL OF A PROSPECT

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ABSTRACT

The concept, estimation and terminology for defining ore reserves in the mining industry have become better based in recent years. They are now usually disclosed under the following categories: Proven/Probable/Possible/Presumptive Prospect. In the past, few have used equivalent terms when describing geothermal potential and even those that have done so give only limited descriptions to their definitions. In many cases overly optimistic figures have been presented with little or no justification. While this may have been in the hope of encouraging development, the reverse has often been the case, due to the uncertainties inherent in such inflated estimates.

It is suggested that defining estimates of geothermal potential in a satisfactory manner is no different to that for any mineral resource. It follows that if similar guidelines to those demanded for the mining industry are accepted, greater confidence in geothermal developments will result.

INTRODUCTION

While recognising specific reservations, it is often convenient to classify geothermal energy as though it were a mineral resource, with the reservoir equivalent to an ore body. Both are prescribed by nature as to location, grade of ore, or reservoir characteristic, and ultimate potential. None of these factors can be measured precisely until the resource is finally exhausted. In practice therefore, feasibility studies for the development of either geothermal or mineral prospects must rely entirely on estimates. Such estimates demand value judgements and assumptions, as much as simple calculation.

For many years this has been of vital concern for the mineral industry and recently the result of a three year in-house study by CRA Ltd has been made available. While the final opinions remain those of King et al (1982) the report has benefitted from collaboration by those actively involved in the CRA group's mining activities and it represents a major contribution to the critical evaluation of ore reserve estimation.

As a safeguard to investors, many stock exchanges now require, as one of the listing requirements for a mining company, that they use recognised and acceptable terms when reporting on the reserves of an ore body. Such terms are usually mutually agreed between the stock exchange, appropriate professional bodies, mining interests and government departments. As with any definitions, they need periodic review. Such has been carried out recently by the Joint Committee of the Australasian Institute of Mining and Metallurgy and the Australian Mining Industry Council on Ore Reserves.

In addition to revising terminology they found - "that reserves should be expressed so as to convey an explicit indication that they are estimates and not precise calculations". Other aspects relate to the need to distinguish between "in situ" and "recoverable" reserves, and the need to move away from the presently available options in reserve definitions in favour of "proved reserves, probable reserves and possible ore".

With concern for future energy supplies and the escalating prices for liquid fuels, many countries are now actively investigating their geothermal resources. In so doing they have encountered a situation analogous to that in mining. Both for planning national energy policies and for appraising possible development of a specific prospect, non-specialists need to have the geothermal potential expressed so that the reliability of the estimate can be clearly understood. For such purposes it is insufficient to quantify the potential without defining its limitations.

Unfortunately, such estimates are not merely matters of calculation. They involve judgement and assumptions about the geological, operational and investigational factors. Likewise, predictions as to the actual amount of ore or energy that can be extracted involve further assumptions.

Schumacher (1973), in cautioning about the difficulties of establishing useful estimates, points out that - "It is fashionable today to assume that any figures about the future are better than none. To produce figures about the unknown, the current method is to make a guess about something or other - called an "assumption" - and to derive an estimate from it by subtle calculation. The estimate is then presented as the result of scientific reasoning, something far superior to mere guesswork. This is a pernicious practice which can only lead to the most colossal planning errors, because it offers a bogus answer where, in fact, an entrepreneurial judgement is required".

Acceptance of this philosophy does not, however, entitle those who must make these "entrepreneurial judgements" to evade defining, as best they can, their reliability. Indeed failure to accept this responsibility must be regarded with suspicion and estimates valued accordingly.

Modifications to methods developed within the mining industry are suggested as one way to identify the reliability of estimates made for the geothermal potential of a prospect.

Historically, it is unfortunate that, as with the mining industry, enthusiasm has often been allowed to override prudence when estimating the geothermal potential of a prospect. If these predictions are not realised, a loss of confidence in geothermal as an energy source may result in premature abandonment or contraction of its development. Of equal consequence is the effect on national and international finance organisations where doubts or failures, through over-optimistic estimates, may curtail further geothermal investment.

It is for these reasons that exaggerated or over-optimistic estimates of a nation's geothermal potential, besides being misleading and of questionable probity, often become counter-productive.

This note puts forward suggestions as to how these estimates might be derived and the use of a recognised terminology to describe their reliability.

BACKGROUND FROM THE MINING INDUSTRY

Invitations were extended in 1971, by the Melbourne Stock Exchange and the Australian Senate Select Committee on Securities and Exchange to the Australasian Institute of Mining and Metallurgy and the Australian Mining Industry Council, for comment and suggestions on the lack of suitable standards and terminology for expressing ore reserves. Accepting the invitation, the Committee published its first report in 1972 and endorsed this, without change, in April 1975. In order to consider developments since that time and to recommend changes considered necessary, the Committee was re-convened in 1978 and its revised report issued in March 1981.

The principal events taken into account by the Joint Committee and their importance in considering comparable proposals for reporting the geothermal potential of a prospect are as follows:

1. 1943 - US Bureau of Mines adopts a three-fold classification - MEASURED, INDICATED, INFERRED (in order of increasing degree of risk) - for estimation of national resources. It was explicitly stated (Sub-Committee on Public Lands, May 1947) that the classification was not adapted to "a mining operation".

2. 1950/54 - Institution of Mining and Metallurgy (London) has a Committee looking into the question of standard terminology. No decision reached and no action by Council.

3. 1953/55 - The Australasian Institute of Mining and Metallurgy has a Committee studying the same question. Diversity of opinion among members of The Institute found to be too great for standardisation. No further action.

4. 1953/56 - Society of Economic Geologists has a Committee studying the same question. The Committee has representatives from South America, Europe, United States, Great Britain, Africa, Australia, North America and Asia. For use in mines, it recommends the traditional terms PROVED, PROBABLE, POSSIBLE. It recommends that MEASURED, INDICATED, INFERRED and equivalent terms are appropriate only for assessing "the reserve or resource position of a whole industry or of a region or a nation".

5. Current practice of the US Securities Exchange Commission recognises two categories of ore reserves - PROVEN and PROBABLE.

6. 1975 - Department of Energy, Mines and Resources, Canada, publishes report on Departmental Terminology and Definitions of Reserves and Resources, classifying ore reserves as MEASURED (or PROVED), INDICATED (or PROBABLE), INFERRED (or POSSIBLE). It was noted that the inclusion of INFERRED reserves in total reserve figures was not acceptable.

The Committee's findings relevant to equivalent estimates of geothermal potential are given below, slightly abbreviated, but without modification.

Conclusions

A. Whilst the enquiries were originally concerned primarily with instances of significant divergence between estimates or opinions given at an early stage of investigation, more recently the need for standardisation of nomenclature for ore reserve statements generally has emerged.

B. The Committee considered that standardisation of classification and nomenclature of ore reserves was desirable but, because estimation of ore reserves involved a factor of judgement, standardisation of procedures would not by itself yield improved estimates.

C. It followed therefore that estimates of ore reserves, and reports on related matters at earlier stages, should be prepared by "responsible professionally qualified" persons of appropriate experience.

D. The Committee should propose standards and terminology that could be recommended by The Australasian Institute of Mining and Metallurgy, in its capacity as a professional organisation.

The Committee presented a series of recommendations, the more relevant of which included:

Pre-Ore Terminology

Pre-Reserve Terminology

Precision

Qualification

While, in their present form the cover of these factors is not of direct application to reporting on the geothermal potential of a prospect, they provide a useful framework for parallel considerations. What follows is, therefore, only of direct relevance to the development of geothermal energy and not to the rest of the mining industry in general.

INVENTORY TERMINOLOGY

As a precursor to proceeding to the reconnaissance phase of a systematic geothermal investigation, an inventory of all thermal manifestations on the surface is generally compiled. These features include hot seepages, springs, geysers, fumaroles, steaming ground, mud pools, sinter deposits and areas of hydrothermally altered rock. This inventory provides the initial step for any subsequent exploration programme.

In most cases, aside from the essential visit to the prospect site, the compilation of such an inventory relies heavily on previously prepared documents. These often lack specific reference to geothermal problems and cannot be used to rank the prospect in any suitable order of priority.

For this reason, it is recommended that at the inventory stage, all geothermal areas be considered only as prospects. If this convention is adopted, it follows that no estimates of potential should ever be given at this stage of an investigation. Instead, the term Presumptive Prospect is suggested as a suitable term to cover such prospective areas.

If, on the basis of earlier published work, it is believed that estimates can be provided, this categorisation and its terminology no longer remains appropriate. Such a prospect would instead need to be transferred to one of the categories as defined in the next section and restrained by their restrictions.

RECOMMENDED TERMINOLOGY FOR CATEGORISING ESTIMATES OF GEOTHERMAL POTENTIAL

While no company or consultant can be compelled to report an estimate of the geothermal potential of a prospect, it is recommended that any estimate made should be in accordance with strictly defined terms. These should indicate to all using the estimates what degree of reliability can be placed on the values assigned to each prospect.

Here the recommendation is that each estimate should be classified according to one of the following categories:

A. PROVEN

B. PROBABLE

C POSSIBLE

These are to be defined as follows:

'PROVEN' GEOTHERMAL POTENTIAL

Such estimates are possible for fields that have been adequately defined in three dimensions by surface exploration and the drilling and testing of wells. With data derived from these sources, the potential of the prospect is calculated in a demonstrable fashion and becomes a PROVEN resource. The calculations should be based on:

a. the areal extent of the reservoir, with an indication of the method and accuracy by which it has been delineated;

b. the thickness, porosity and the degree of saturation of the rocks in the reservoir;

c. the amount and characteristics of the fluids discharged from the wells;

d. the temperature and pressure of the fluids in the reservoir;

e. the amount of extractable heat, dependent on the proposed utilisation of the fluids; and

f. any other assumptions, such as rate of conversion for well fluids to electricity and allowance for non-condensible gases. These must be specified in the calculations.

The estimate of the geothermal potential of a field, calculated from the above data, would be considered accurate, either to within stated limits or, if these limits are not given, within 25 percent of the computed figure.

Despite these stringent conditions it is reiterated that all statements on reserves remain estimates and not precise calculations. The development of a geothermal field by incremental stages is therefore strongly endorsed. Such exploitatiori provides the opportunity to refine the data used in the calculations, and enables fresh estimates of the reserve to be evaluated.

'PROBABLE' GEOTHERMAL POTENTIAL

This is the best estimate that can be made at the finish *of* surface exploration but before the completion of sufficient wells needed to confirm the reservoir extent and allow the field's potential to be computed.

For a field to be placed in this category, the boundaries of the reservoir, its area, structure and geologic setting must be defined, and conservative estimates of underground temperatures produced. Nevertheless, despite the scientific evidence that is produced, the type of field, characteristics of the fluids, underground conditions in the reservoir and the extractable reserves of energy remain as assumptions and require confirmation before the field can be considered a PROVEN reserve.

Estimates in this category are less reliable than for PROVEN reserves and rely heavily on the calibre of the exploration programne. They are also dependent on the experience of the estimator, and his ability to compare the resource with others that exhibit similar characteristics and which have already been exploited.

Estimates in this category will also include situations where exploration wells are:

a. too shallow to penetrate the reservoir,
b. too sparse in number, or,
c. located where they are unable to confirm the areal extent of the field.

These limitations do not preclude the use of these estimates for national or regional planning, provided the degree of uncertainty is recognised. However, further drilling will be needed before a final feasibility study can be completed and detailed plans formulated for the field's development.

'POSSIBLE' GEOTHERMAL POTENTIAL

This class of estimates is based on a broad knowledge of the geothermal character of a prospect for which only limited data is available. Such estimates would be made at the completion of the reconnaissance phase when only limited geological and geochemical investigations have been undertaken and the size and location of the reservoir remains speculative.

The reliability of these estimates is poor, relying on an assumed similarity with better known fields. They remain as crude values until further exploration of the prospect is undertaken.

As exploration proceeds, a steady improvement of these estimates can be expected. Thus, provided the prospect remains viable, figures originally ranked in the POSSIBLE category should progress to a PROBABLE ranking as exploration continues.

It is inadvisable to include estimates in the POSSIBLE category in other than the broadest national or regional planning, and even then their limitations must be recognised. When this category is used, it is undesirable that it should stand alone, and should only accompany PROVEN and PROBABLE estimates for other prospects. By this means, the reliability of estimates in this POSSIBLE category can be gauged.

Despite the obvious difficulties in providing meaningful estimates in this category, it is essential that all prospects be ranked to allow the planning of future work programs. Recognising these difficulties an alternative approval has been suggested elsewhere based on an allocation of probabilities (Seal 1982). The method, while crude, has the added advantage of being able to combine economic and local limitations as well as technical considerations. Such an approach has often proved a useful alternative where large numbers of prospects have been identified but little factual information has been gathered.

PRECISION

It must again be stressed that all estimates of geothermal potential remain only estimates and are not precise calculations. They are dependent on interpretation of available evidence, its relevance, reliability and extent. It is therefore important that all estimates be accompanied by a statement as to their basis and assumptions.

For PROVEN estimates it is essential that all calculations be disclosed and their degree of precision be included in the figures. All assumptions must be clearly stated, as must any reservations as to data, method or accuracy.

POSSIBLE estimates, although of lesser reliability, still need documentary evidence as support. Detailed reports summarising the surface scientific exploration undertaken should be mandatory, Without such supporting evidence it is recommended that entry into this category should be denied, These studies, should delineate the apparent boundaries of the reservoir and provide evidence as to the type and temperature of the fluids expected to be encountered in the reservoir.

The precision of estimates in this category should always err conservatively so as not to mislead. Where practical, they should give some indication as to the reliance that can be placed on them, preferably as a percentage variation around the estimate.

PROBABLE estimates, even though the least reliable, still require the production of documentary evidence. A minimal requirement would be expected to include reliable geothermal descriptions together with sufficient geochemical evidence to support the existence of satisfactory underground temperatures in the reservoir.

In view of the obvious difficulty of providing reliable estimates for "presumptive prospects" within this category, the alternative suggestion of using crude probability values is recommended as more valid for determining priority rankings.

For all categories it is of prime importance that, on every occasion where the geothermal potential of a prospect is stated, the relevant degree of precision should automatically accompany the estimate. Failure to observe such a convention should caution users of the figures in placing too much reliance on them as reliable estimates.

QUALIFICATIONS ON QUOTED FIGURES

The basis of estimated potential will depend on the use to which the resource is expected to be put but forms an essential part of any calculation. The limitations imposed by the end use will determine how much of the ultimate energy potential can be utilised, but whatever the imposed restrictions, there will always be a major difference between the theoretical capacity of the field and its practical extraction.

Accordingly this note clearly draws the distinction between values given for individual prospects or cumulative totals in which reference is made to either "in situ" or "extractable" potential.

An "in situ" potential is defined as the total energy contained in a system, or systems, relative to its expected use. Because only a limited amount of this energy can be utilised, such potential remains a theoretical and possibly misleading figure. If it is used in producing estimates, attention should be drawn to its limitations and possible confusion.

The smaller but more realistic "extractable" energy potential is more desirable and its use preferred. It is dependent not only on the total energy contained in the system but -

1. The state and conditions within the reservoir.
2. The ease with which fluids can be withdrawn.
3. The intended use to which the fluids will be put.
4. The properties of the fluids that are withdrawn.
5. The time over which the estimated potential can be extracted and the rate at which this can be achieved.

The extractable potential of a given prospect provides the best and only reliable estimate. By the insistence on disclosing and quantifying those factors that govern extraction of the working fluids, the reliability and validity of the estimates can be appraised. For these reasons, it is strongly recommended that only the extractable potential be considered as acceptable in describing a geothermal prospect.

WORKED EXAMPLE OF 'PROVEN' POTENTIAL

An early attempt using the proposed scheme provided a preliminary estimate of the geothermal potential of Indonesia which it was hoped could be of assistance for National and Regional Planning. An updated version of this was published recently (Seal 1982). As the paper summarised detailed results from a number of independent fields no supporting evidence was presented.

Accordingly a worked example of how the geothermal potential can be estimated at the completion of exploration drilling is now given. It is taken from the feasibility report covering scientific, engineering, environmental and economic aspects of a proposed development for electricity production at Kamojang, West Java, Indonesia (GENZL, 1976).

The example is chosen deliberately to illustrate the difficulties of evaluating a field's potential even when results from early exploration wells are completed. It recognises assumptions that have to be made, and remaining unknowns that will affect the final result. Because of these, the suggested +25 percent range for the estimate was judged inappropriate and increased accordingly.

On completion of the five exploration wells, the exploration phase of development was finished and the first reliable estimate of the field's potential practiced. The boundaries of the field as determined by geophysical methods, and the location of the wells within this boundary, are taken from the feasibility study.

Earlier detailed reports were published by Hochstein (1975) and Kartokusomo et al (1975). These described some of the scientific exploration studies already carried out and proposed a model of the system. The exploration wells substantially confirmed these predictions but many unknowns remained and details of the reservoir lacked precision. In particular, the degree of saturation of the rocks in the reservoir was not known.

The following estimates of the field's potential made at this time are taken directly from the Feasibility Report.

Making a conservative assessment of the electrical potential the following conditions have been used in the calculations:-

a. out of the $14 km^2$ reservoir area indicated by the resistivity boundary, only $10 km^2$ is exploitable;
b. the bottom of the condensate layer lies at 500m depth and has a mean temperature of 160°C;
c. fluid can be extracted down to a depth of 1.5km, in which zone the fluid has an average initial temperature of 234°C;
d. at the end of 25 years, reservoir fluid conditions will be 180°C and 10 bars absolute;
e. the rock has a porosity of 0.15, a unit thermal capacity of 2.1 MJ/m/C, and will release up to one-third of its excess heat to cooler water;
f. the concentration of the non-condensible gases in the steam is taken as 1.5%;
g. the rate of energy conversion from well fluids to electricity is 100 kWh per tonne of dry saturated steam at 5 bars absolute.

Because the enthalpy of the fluid initially in the reservoir is not known with certainty, the estimates cover the full range of saturation conditions. Also, to give effect to the low 33% recovery of rock heat, it is assumed that the perimeter of the reservoir remains at its original temperature of 234°C.

There is a high probability that there will be a recharge of fluid into the reservoir as the pressure in it declines, but the magnitude of this inflow cannot be gauged until a substantial volume has been discharged from storage. The results also take no account of the natural heat flow which is equivalent to 20MW(e).

Because the degree of saturation of the reservoir remained in doubt, the power potentials for a 25 year period were calculated on the basis of four possible steam water ratios. The results from such calculations are summarised as follows:

Initial Fluid in Reservoir:	Steam Only	1:1 Mix by weight	1:1 Mix by volume	Water Only
Electrical power potential :		megawatts		
From Fluid expansion	7	18	144	195
From condensate	91	82	nil	nil
	98	100	144	195

This study of the Kamojang field concluded that a proven potential of between 100-200 MW(e) existed, suitable for the generation of electricity over a 25 year period.

Following the publication of this Feasibility Report the Indonesian and New Zealand Governments, under a Bilateral Aid Programme, approved the first 30 MW(e) stage of the field's development. Production wells now deliver a cumulative total of steam production equivalent to 60 MW(e). Of equal importance for this paper is the upgraded data that the results from these wells have provided.

This new data has allowed fresh estimates to be made which largely confirm the earlier values. Mountfort (1980) has recently calculated that the Kamojang Field's potential is now at least 120-150 MW(e) with a life expectancy of 35-45 years.

SUMMARY

Any estimate of the potential of a geothermal field should be accompanied by some indication of the reliability of the figure. Failure to provide such indications must raise questions as to the importance of any such estimates and suggest .caution in their use for planning or other purposes.

A possible method for categorising the reliability of estimates, based on similar difficulties encountered in the mining industry, is presented. On the basis of recent improvements in estimation and terminology for defining ore reserves, similar degrees of confidence are proposed for geothermal resources. While the precise geothermal definitions may require modification, it is hoped that the concept will prove acceptable and that estimates based on crystal ball gazing or pious hopes may then become relics of the past.

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Anon, 1981: Reporting of Ore Reserves. The Aust. I.M.M. Bulletin No. 452, May 8.

GENZL, 1976: Geothermal Energy Development, Kamojang Power Station Feasibility Report.

Hochstein, M.P., 1975: "Geophysical Exploration of the Kawah Kamojang Geothermal Field, West Java". Second UN Symposium on the Development and Use of Geothermal Resources, San Francisco 1975, Vol. 2, 1049-58.

Kartokusomo, W., Mahon, W.A.J. and Seal, K.E., 1975: "Geochemistry of the Kawah Kamojang Geothermal System, Indonesia". Second UN Symposium on the Development and Use of Geothermal Resources, San Francisco 1975, Vol. 1, 757-60.

King, H.F., McMahon, D.W. and Bujtor, G.J., 1982.: "A guide to the Understanding of Ore Reserve Estimation". Proceedings of the Australian Institute of Mining and Metallurgy. Supplement to Proceedings No. 281, March 1982.

Mountfort, M.V., 1980: GENZL Internal Report on Kamojang Reservoir Assessment.

Schumacher, E.F., 1973: Quotation from "Prospect for Coal". National Coal Board London, 1961 in "Small is Beautiful" Blond and Briggs Ltd.

Seal, K.E., 1982: "The Geothermal Potential of Indonesia". Offshore South East Asia 82 Converence, Singapore.