Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

# Reducing Geothermal Resource Risk and Project Schedule Prior to Exploration Drilling

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**Keywords:** geothermal risk, drilling, preliminary survey, civil works, schedule, project development

## ABSTRACT

The biggest project risks for a green-field geothermal development are almost always related to the limited knowledge of the geothermal resource in early stages of the development. Confirmation of the presence of a resource, assessing resource capacity, optimal development size and operational parameters for plant are significant issues for project developers and potential project investors.

This initial project uncertainty is typically reduced progressively through an initial phase of preliminary scientific reconnaissance work, surface scientific exploration surveys and then exploration well drilling. Staged decision points serve as gates for successive stages of increasingly costly work that progressively de-risks the resource and is used to inform the most appropriate development strategy. Surface exploration surveys have typically been undertaken in stages starting with geology and chemistry, followed by geophysics. Then planning drilling locations requires planning access roads that requires terrain mapping and geotechnical assessments. The result can be that this staged approach extends schedule substantially. This in turn adds to project risk as it can reduce overall return on investment and potentially mean that geothermal license timing requirements that are imposed in most regulatory regimes may not be met. A more balanced approach drives a need to 'front end load' surface exploration work as much as possible, and include any studies that are required for well access planning.

The information obtained at the early stage is multi-disciplinary and must factor in topographical, environmental, geotechnical and other project constraints. Spatial data is combined with a synthesis of scientific data in the form of a conceptual model of the system.

Geoscientific investigations to assess resource character, energy potential and likely drilling targets can be conducted in parallel with developing an understanding of the costs for land access, permitting and civil works to access the area and for the proposed drilling program. This information enables an informed and fully integrated decision to proceed to exploration drilling in an expedient manner.

This paper outlines an approach to conducting surface exploration to the point of deciding drilling locations. This has been tested by experience with a green-field geothermal surface exploration program applied as a single phase that concludes with a gated decision to proceed with exploration drilling.

## 1. INTRODUCTION

Confirmation of the presence, quality and long term capacity of the geothermal resource is naturally a critical component in the development of a geothermal project. This provides the confidence in the long term "fuel supply" for the project upon which a decision to construct a power generation project can be based. This resource proving, or exploration phase, of a project usually involves a series of activities that progressively provide stronger indications of the geothermal resource quality.

A "project" will normally only be defined based on some preliminary indicators for the presence of a geothermal system secured from reconnaissance that may have identified general conditions suitable for the presence of a system, including probably some indicators of thermal discharges such as springs or fumaroles. There are however, many instances where geothermal development areas are licensed for investigation by government agencies based on relatively little evidence or because particular types of geothermal aquifers may be expected based on offset regional data.

From these initial indicators, the developer needs to embark on an exploration program to prove the resource sufficiently to eventually base a financial decision to invest in the capital-intensive power generation development. However, the individual activities required for that resource proving are also capital-intensive, particularly deep drilling, and so require good evidence to justify the expenditure in this exploration process that is made at risk. This has normally driven a staged exploration process that has progressively improved confidence in the geothermal resource and at each step supported the decision for investment in the subsequent stage of exploration.

An indicative type of development program showing the typical conventional exploration and power developments stages and how risk is reduced at each stage is presented in Figure 1.

Typically each stage has had greater cost than the previous one, and so this staged process with successive decision "gates" has made good sense in terms of managing risk. Gehringer and Loksha (2012) provide additional context around the identification and management of geothermal project development risk. The staged process means, however, that the development program can extend over a substantial period. The schedule indicated in Figure 1 has activities conducted in parallel where possible, and is very optimistic when measured against the progress of real projects. In reality, many other factors such as environmental permitting and land access have a major influence on schedule which means project exploration stages can be extended well beyond that required for the scientific exploration work alone. This schedule delay has impacted many projects in terms of meeting licensing requirements needed to retain tenure on the project and so is a risk factor that needs managing in many regions.

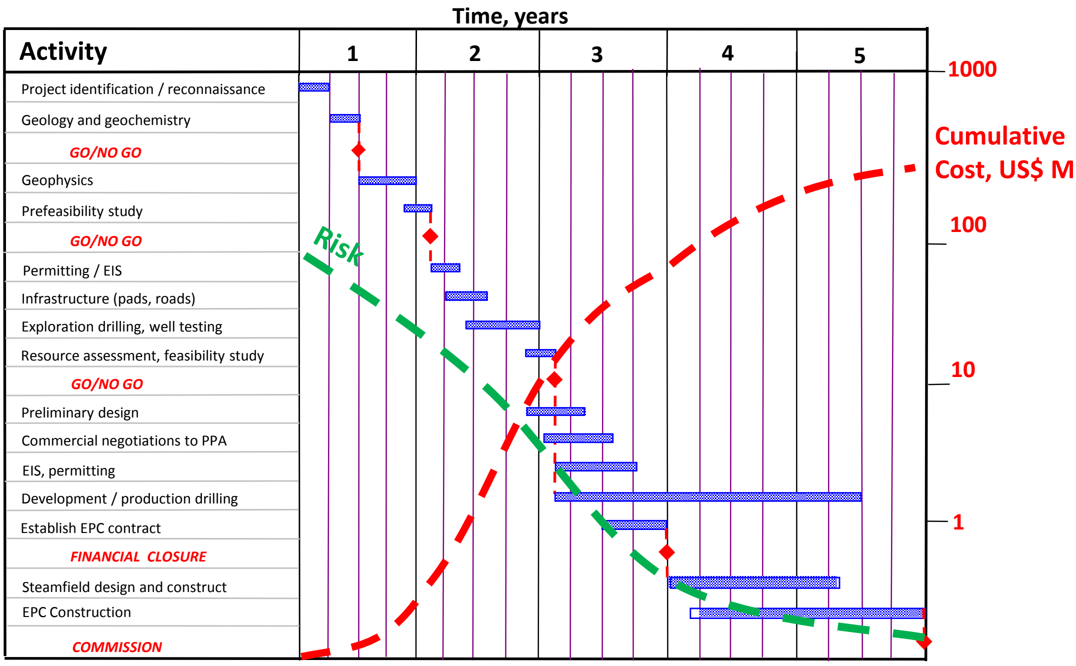


**Figure 1: The progressive reduction of project risk achieved through successive stages of resource exploration. This is normally achieved through expenditure of progressively more costly investigations.**

We often see that very specific project description information is required for environmental permits for drilling (regarding well locations and associated infrastructure) and then there is a long lead time in most approval processes. So the early exploration results are key inputs to obtaining the necessary permits for drilling in many jurisdictions. This specific well location information is also needed for land access permissions (lease or purchase) which can also require lengthy processes. This means there is high value in obtaining all information needed for planning exploration and delineation drilling as early as possible to minimize schedules that inevitably extend longer than required just for the technical delivery of the exploration surveys and drilling.

Decisions on drilling and specific well locations are based on a range of input in addition to the assessment of the geothermal resource obtained from surface exploration. These factors include civil and geotechnical considerations for road access and drilling pads, pre-assessment of well types and rig requirements, and definition of the technical requirements for meeting funding decisions. So advancing these elements can also assist with keeping a project on a reasonable schedule and help realize some overall project execution efficiency savings.

## 2. SHORTENING THE SURFACE EXPLORATION PROGRAM

The exploration of high temperature geothermal systems has in general followed a staged sequence as follows:

| Stage | Activities | Objective |
|---|---|---|
| 1 Reconnaissance | Initial desktop appraisal of existing data (including geospatial data such as satellite imagery) that can be obtained for the area of interest. | Early indication of the probability that a system suitable for exploitation exists. |
| | Short field survey considering geological environment and sampling selected thermal discharge features. | Assist with planning subsequent stages of fieldwork. |
| 2 Geology and Geochemistry surveys | Detailed geological mapping<br><br>Mapping of thermal ground and hydrothermal alteration.<br><br>Sampling and chemical analysis of all thermal fluid discharges. | Understand possible age of heat source, structures controlling permeability, natural heat flow from the system, understanding the system hydrology and deep reservoir temperature and chemistry. |
| 3 Geophysics surveys | Typically comprising Magnetotelluric (MT) resistivity mapping, but possibly supplemented by gravity and magnetic surveys. | Map probable depth and size of geothermal system. Determine characteristics of any major structures. |

| Stage | Activities | Objective |
|---|---|---|
| 4 Supplementary surveys (some modern survey techniques such as LiDAR and TIR are relatively recent innovations in geothermal exploration) | Additional surveys such as temperature gradient drilling, soil temperature and gas flux, micro-earthquake monitoring. | Target the resolution of specific “problems” that are identified by the previous surveys such as confirming current presence of temperature in the “clay cap” identified by MT in “blind” systems with no thermal discharges. |
| | Initial appraisal of potential water supply sources for drilling. | To support planning and assessment of exploration drilling. |
| | Geohazard assessment/survey. | Mapping likely geohazards (e.g. volcanic ashfall, pyroclastic hazard areas, lahar flow paths) can inform future decisions around geothermal power plant and steamfield concept. |
| | LiDAR (Light Detection And Ranging) terrain mapping and aerial ortho-imagery. | Assist structural mapping, provide good quality and reliable terrain models and base-maps for the project, assists in environmental mapping and permitting. |
| | Thermal infra-red (TIR) imagery. | To identify areas with anomalous surface heat, and other features that may not have been previously reported. |
| 5 Exploration drilling | Deep drilling into reservoir using slim or production diameter wells. | Prove the existence of the geothermal reservoir having conditions (temperature, permeability and chemistry) that are generally suitable for commercial development. |
| 6 Delineation or appraisal drilling | As for exploration, but usually using well diameters that are suitable for later production. | Prove reservoir capacity (volume) to support the planned development and also to demonstrate well productivity as a measure of the commercial viability of the project. Complete drilling sufficient to meet financial investment decision for project. |

If each of these stages were undertaken in sequence with each comprising a process of planning, budgeting / approval, contracting services, permits, execution, interpretation, evaluation and recommendations for next stage, then the overall program will have considerable duration. Given the other factors of environmental and other permitting that can extend schedule and which typically get inserted in between surface exploration activities and drilling, we have identified that there is significant value to be gained from combining as many of the surface exploration stages into one pre-approved program as possible.

While it has commonly been assumed that geological and geochemical surveys are necessary to enable planning of geophysics surveys, there is a counter argument that well-planned geophysics surveys that have the flexibility to provide initial wide area coverage and then, based on preliminary interpretation, focus more detail in areas of interest may be better at providing guidance for focusing geological and structural mapping and also highlight areas for additional geochemical or thermal mapping investigations. In particular, the ability to map subsurface hydrothermal alteration (and by implication, system extent) with MT surveys has revolutionized how we investigate geothermal systems and highlights how interrelated all the geosciences are in providing information necessary for understanding the nature and shape of a geothermal system.

For this reason, we have increasingly encouraged the application of an integrated geoscience program that comprises geology, geochemistry, thermal area mapping and geophysics (MT, plus gravity where likely to be useful). These surveys may be planned to be conducted in one field program, but some flexibility is needed to enable all surveys to adapt to what is found during the program.

Interpretation led by experienced geoscientists during the program enables refinement or extension of the program. This input needs to be considered and accounted for in how the surveys are planned and contracted. The geophysics program should have in-built flexibility to adapt the survey coverage based on interpretation of initial data. Allowance should be made for additional geology or geochemistry checking at the conclusion of the main program to close out any “loose ends” based on initial integrated interpretations.

This integrated program approach can provide at least as good exploration and interpretation as a staged approach, and arguably has the advantage of a more holistic and integrated approach between the key exploration disciplines. The advantages of planning just one field program with the necessary community consultation (incorporating consideration for Corporate Social Responsibility (CSR) aspects), health / safety / evacuation plans, budgeting / approval, and integrated interpretation effort has advantages in terms of the owner’s “soft costs” as well as schedule.

## 3. ADDITIONAL REQUIREMENTS BEFORE DRILLING

While the outputs from the surface exploration program are fundamental to planning an exploration drilling program, there are other inputs necessary in order to finalise drilling plans.

The geoscience team may be able propose exploration well targets based on the surface exploration program, but any exploration drilling program also needs to consider:

1. Overall objectives for the program to reach a financial investment decision – including development size, steam proving requirements, and well capacity. This may require a pre-feasibility study to establish project commercial parameters and coordination with prospective project lenders.
2. Well designs and drilling options – consideration of well types and available equipment and associated procurement options and costs.
3. Assessment of physical access to sites – determination of routes and costs for roads and well pads to assess well numbers and overall viability of the program. This may require detailed topographic mapping plus geotechnical and geohazard assessment of specific areas. The identification of an adequate and reliable water supply source should also be considered at an early stage of the program.

While the first two are activities that a prudent developer is likely to be considering in parallel with their overall exploration process, the civil engineering aspects commonly follow the initial assessment of well targets based on surface exploration.

We have found that the modern technologies for topographic mapping that are justified at the stage where civil works are being planned also can have high value if undertaken along with the surface exploration works. LiDAR (Light Detection and Ranging) terrain mapping and the aerial ortho-imagery normally collected in association with the LiDAR provide valuable spatial resources that assist the geology, geochemistry and geophysics surveys. Having high resolution elevation models that are often "seeing" through heavy vegetation cover can greatly assist the structural mapping conducted across a prospect area. An example of this application is shown in Figure 2. Thermal infra-red (TIR) imagery can also be used to help identify areas with anomalous surface heat, and other features that may not have been previously reported. The aerial imagery similarly assists with mapping thermal areas and for planning all surveys in some detail from the office, before going to the field.

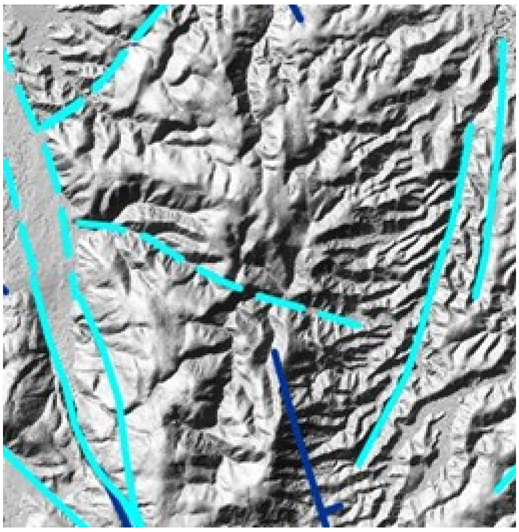

**Figure 2: Example of LiDAR terrain model being used to assist with structural mapping. Dashed lines represent probable faults deduced from LiDAR terrain model.**

Conducting a comprehensive LiDAR terrain mapping and ortho-imagery program has modest cost for the coverage necessary for most geothermal exploration areas and provides the advantage that the geoscience, drilling and civil engineering teams are all working from good quality and reliable terrain models and basemaps. The imagery also assists with mapping natural and cultural features as required for environmental assessments and also for assisting in planning land procurement requirements. In our experience it is prudent to 'oversize' the LiDAR survey areas as the increased incremental cost is outweighed by the value of information at this early stage.

LiDAR terrain models are proving almost essential in planning access roads in more rugged terrain, and in most cases are sufficient also for planning general power plant layouts and the conceptual design of steamfield piping systems. In complex terrain with geotechnical challenges such as being seen recently in many projects in Sumatra, Indonesia, the cost for civil works has approached that of the actual drilling costs for exploration wells and so the information available from good spatial mapping has high value through enabling the planning of cost effective civil construction solutions.

Having these fundamental data available early in the exploration program facilitates all the activities that lead to ability to start exploration drilling and has potential to accelerate schedule, and avoid later rework.

## 4. FRONT END LOADING ALL EXPLORATION RELATED ACTIVITY

Our experience is that bringing forward the activities necessary for planning civil works and environmental permitting has strong advantages in terms of achieving better quality of exploration by having all "geo" and spatial data sets available concurrently to improve the overall resource interpretation and to better plan exploration drilling programs.

This then enables reliable development plans to be integrated with environmental and land permitting processes that can have long lead times for approvals. In parallel, the information from good spatial data (terrain models and ortho-imagery) assists with determining plans and costs for civil works that can be substantial components of any exploration drilling program. Effective data management systems established early within the project lifecycle are critical for capturing the key information acquired during the various stages of an exploration and development project. In recent years we have found the use of webhosted Geographic Information System (GIS) platforms to be an effective and economic means of information sharing, particularly where project stakeholders are typically not geographically co-located.

The relationship between these early activities and their consequent assessments, plans and permitting processes is presented in Figure 3. There are interrelationships between the activities at all stages, though some key ones are where well location plans flow into the environmental and land access processes. There are additional benefits in standardizing this process, to align to a developer's internal decision making and corporate governance processes. We consider that it is best practice to workshop the results of the front end exploration work with project shareholders. This is so all parties can understand the level of uncertainty and risk ahead of the investment required for exploration drilling. Part of the decision making process to proceed with exploration drilling involves an evaluation of all inputs against the shareholder's defined feasibility criteria (i.e. sufficient Net Present Value, no known 'fatal flaws').

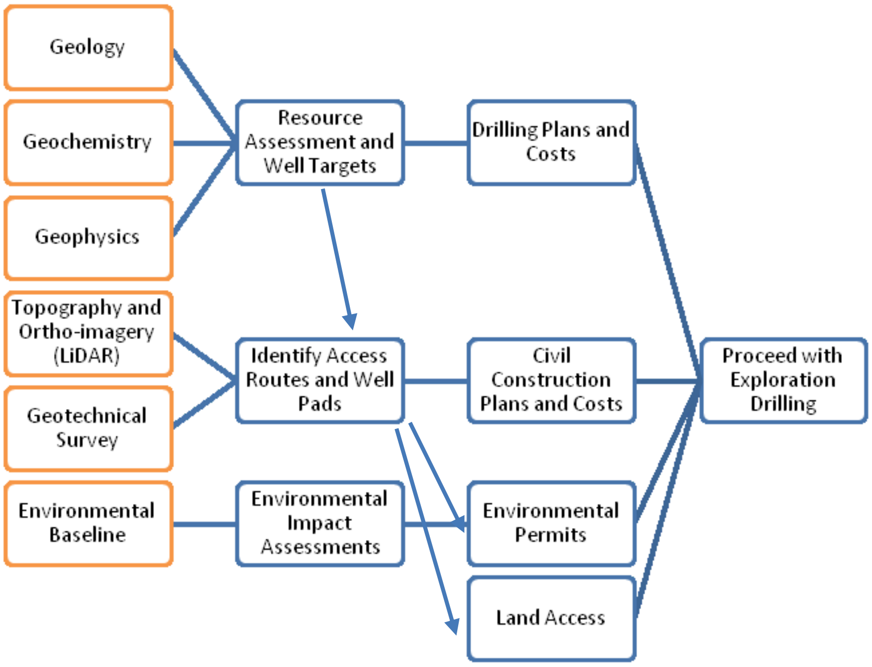


**Figure 3: The processes leading to a decision gate to proceed with exploration drilling. Highlighted activities on the left are those which can be "front end loaded" in one program to shorten the overall schedule.**

## CONCLUSIONS

While a staged approach to an exploration program has advantages in managing risk, there are strong benefits to be achieved from conducting all the traditional geoscience surveys within one field program. We have also found that conducting the spatial mapping of terrain and aerial ortho-imagery before or concurrent with the "geo" program has additional benefits in terms of achieving better quality exploration. It can also serve as the basis for better development of the exploration well drilling strategy that is a pre-requisite to securing environmental and land access permits. This integrated spatial and resource data being available as soon as practicable also enables sensible planning of costly civil access roads and drilling pads, to enable exploration drilling costs to be determined to facilitate final decisions on proceeding with an exploration drilling phase.

Such an accelerated exploration phase program can be justified if the early reconnaissance data provides a strong indication that the full exploration program will show that there is a high probability that a commercial resource exists. This preliminary assessment is often possible form an experienced review of the known thermal features and general geologic setting. If, however, there is less certainty in the quality of the resource, then a more traditional and staged approach may be warranted to more progressively test the resource before deciding to proceed with permitting and planning any drilling program.

## ACKNOWLEDGEMENTS

We would like to acknowledge the input of Ken Mackenzie in his review and contributions to this paper.

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