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British Columbia Hydro and Power Authority

GEOTHERMAL PROJECT MEAGER CREEK

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Summary Report for 1981-82

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CONCLUSIONS

1. Deep drilling during the 1981-82 year at the Meager Creek South Reservoir has encountered temperatures in excess of 250°C. This resource temperature, if associated with suitable formation permeability, is potentially adequate for commercial power generation in steam turbines using steam flashed from the geothermal fluids.

2. However, drilling and well testing to March 1982 has not encountered zones of permeability sufficient for economic extraction of the geothermal heat. One of the principal objectives of further drilling in the South Reservoir, therefore, is to find permeable zones, if they exist, within the reservoir.

3. Although the wells drilled to March 1982 appear to be low producers and probably non commercial, nevertheless medium term output testing will provide much necessary and useful information on the characteristics of the resource. Early implementation of the appropriate testing programme will assist in a proper understanding of the resource and could avoid inappropriate decisions in the future exploration and drilling programme.

4. Available data on the North Reservoir is sufficiently encouraging to justify a more detailed scientific exploration programme during 1982 with the objective of determining a deep well target(s) for drilling in 1983.

1. INTRODUCTION

1.1 Previous Work

Prior to 1981, BC Hydro had carried out a programme of geothermal reconnaissance and exploration over a period of some eight years in the Meager Mountain area in the Upper Lillooet River region of British Columbia.

During this time the principal exploration effort had been in the Meager Creek Valley, south of the Meager Mountain complex, where underlying hot conditions had been established in an area referred to as the South Reservoir. Approximately five out of fourteen slim diamond drillholes showed measured temperature in excess of 100°C with encouraging signs of convective heat flow. A maximum temperature of 202°C at 367 m was recorded in hole M7.

Recent exploration on the north of Meager Mountain complex had outlined an apparent thermal anomaly, referred to as the North Reservoir, where one diamond drillhole had recorded a maximum temperature of 103°C.

1.2 Work done in 1981-82

From an initial analysis of the South Reservoir data available early in 1981, BC Hydro concluded that a deep well exploration programme be commenced in this area. Proposals were invited for management of a single vertical well programme. During negotiations KRTA, on the basis of their analysis of the available data, concluded that the best prospects for an exploitable reservoir might lie beneath the Meager Mountain complex. Accordingly KRTA recommended an initial programme of three deep deviated wells targeted beneath the Meager Mountain complex. This recommendation was accepted by BC Hydro and KRTA were engaged in June 1981 to provide drilling management, geoscientific, environmental science and geothermal engineering services for the deep well programme in the South Reservoir. Subsequently, this engagement was extended to include additional geoscientific services for both the South and North Reservoirs and at other potential geothermal areas elsewhere in southwestern British Columbia.

Implementation of the environmental programme during 1981 was carried out by BC Hydro with KRTA providing advisory services.

Drilling operations, specialised drilling services and materials supply for the deep wells were performed by several firms under direct contract to BC Hydro, with KRTA providing drilling engineering and rig supervision.

Rig geology on the deep wells was carried out by others under the direction of KRTA.

In addition to the above work, other aspects of the exploration programme were continued by BC Hydro during 1981 at both the Meager South and North Reservoirs. This work is to be reported separately by others and includes continued geological mapping, dipole resistivity, soil chemistry and diamond drillhole programmes.

This Summary Report summarises the work done, and conclusions reached, by KRTA up to 31 March 1982.

2. WORK DONE BY KRTA

The work carried out by KRTA during the 1981-82 year fell into the following groupings

- general exploration strategy
- deep well programme at Meager South and the associated geoscientific work and environmental programme
- limited geoscientific work at Meager North
- geochemical reconnaissance and review of other potential geothermal areas in southwest British Columbia

A descriptive list of the more significant KRTA project activities is included in Appendix A.

The following sections summarise the principal KRTA project activities during the 1981-82 year.

2.1 Geothermal Exploration Strategy

The development of a geothermal exploration strategy was necessarily preceded by a review of all available previous data and information. Following this review, internal papers and reports were prepared dealing with various aspects of geothermal strategy initially for Meager Creek South and siting of the deep wells, and subsequently for the wider region of southwest British Columbia. One purpose of these reports was to clarify to BC Hydro, the KRTA approach to an appropriate geothermal exploration strategy for the area, and in particular to discuss the relevance or otherwise of exploration methods being used or proposed.

2.2 Meager Creek - South Side

The work at Meager South has comprised both the resistivity, geochemistry and environmental work of general application to the area, and the specific deep well programme.

The resistivity programme involved Schlumberger configuration field survey work at high altitude on the Meager Mountain complex, and evaluation of these results in conjunction with previous dipole resistivity data at the base of the mountain. This work identified a promising low resistivity anomaly in the area selected for the deep well targets.

The geochemistry programme involved sampling and analysis of water samples, from a number of springs, seeps and wells, leading to the formulation of a preliminary geochemical model of the South Reservoir.

The BC Hydro environmental study and protection programme was reviewed. Recommendations included greater emphasis on the effects of a water dominated type of geothermal resource as anticipated at Meager Creek, and early attention to the satisfactory disposal of geothermal well fluid during well testing. Internal papers on specific geothermal aspects of the programme have been prepared for the BC Hydro environmental team.

In the deep well programme at 31 March 1982, two wells (MC-1, MC-2) had been completed and a third well (MC-3) spudded in. Well MC-1 was initially discharged prior to Christmas 1981 and has been on continuous bleed through to the end of March 1982. Further information on well data is presented in section 3.2.1. of this report.

The design of casing and wellhead equipment, and the drilling and cementing practices adopted have been chosen to meet specific geothermal criteria for thermal conditions, corrosion resistance, well production and safety. All deep wells have been designed, drilled and completed as potential producing wells.

The objective of the deep exploration wells is to obtain data on reservoir temperature, pressure, permeability, output and water/gas chemistry, together with subsurface geology and petrology data.

Cuttings at 5m intervals and cores at 500m intervals have been subject to geological classification, and petrological analyses have been performed on selected cores and cuttings. The objective of the latter is to provide data on the present hydrothermal system from the alteration and precipitate minerals present.

At the completion of drilling operations on each well, pumping tests have been carried out to determine well injectivity and transmissivity. Measurement of downhole temperature profiles is commenced during the pumping tests and continued during both well heatup stage and after discharge. Water and gas samples are collected from the well discharge and subject to chemical analysis.

Consideration will be given to commencing downhole sampling of the geothermal fluids for chemical analysis after the wells are judged to have discharged all drilling fluids and reached a stable geochemical condition. Output discharge testing of each well over a period of weeks is necessary to obtain definitive data on well performance and reservoir characteristics. This stage of well testing was not implemented during the 1981-82 year.

2.3 Meager Creek - North Side

Investigation in this area by KRTA during the year was only of a minor nature. Preliminary resistivity field surveys by Schlumberger methods were carried out at high altitude on the north side of the mountain complex, but further work is necessary to enable any meaningful assessment of possible anomalies.

The Pebble Creek springs were sampled and analysed to determine water chemistry. These were the only warm springs on the north side positively identified at the time of this work. A comprehensive geochemical exploration programme is planned for 1982-83.

2.4 Other Areas

KRTA work has been confined to a geochemical reconnaissance of selected potential geothermal areas in southwest British Columbia, carried out at the end of the field season. Springs and seeps were sampled and analysed to determine water chemistry.

Available data and information prepared by others on the potential geothermal areas, were reviewed in conjunction with the above results, and an assessment made of the most promising areas for further investigation.

3. SUMMARY OF RESULTS AND EVALUATION

3.1 Geothermal Exploration Strategy

Formulation of an exploration strategy for southwest British Columbia has included an appraisal of the principal regional conditions likely to impinge on the successful exploration and development in the area, and an assessment of the suitability of the various reconnaisance and exploration methods under these conditions. Apart from the regional and local geology of the area, the principal significant conditions are a plentiful supply of cold near surface groundwater, the rugged terrain and basement rocks of low permeability.

The plentiful supply of cold groundwater dilutes the near surface geothermal waters to a greater extent than is usual in other countries. This probably contributes to the lack of high temperature surface manifestations of geothermal activity in British Columbia. Because of dilution of geothermal water, the chemical techniques commonly used to indicate likely subsurface temperatures become less reliable, and careful interpretation of results is required.

Resistivity surveys, which are frequently used to show distribution of subsurface hot water, are less reliable in rugged terrain and where the hot water is diluted. KRTA have recommended the use of Schlumberger array, combined with some electrical soundings, in preference to dipole resistivity techniques for geothermal conditions. Geological and petrological information from shallow diamond drillholes will assist in determining what the resistivity is responding to.

The low permeability of the basement rocks, and the apparent absence of porous hot reservoir rocks, particularly at Meager Creek, will be significant in the ability to extract heat from any geothermal resource. Successful production wells will need to intersect permable areas such as major fracture zones, or brecciated or unconsolidated contact zones associated with intrusive dykes or eruptive centres.

The relative merits of other reconnaissance and exploration techniques for use in geothermal development in the British Columbia setting have been reviewed. These techniques have included temperature gradient holes, soil chemistry, regional and local geological mapping, petrology and various electromagnetic methods.

At Meager Creek the possibility that the two postulated South and North Reservoirs represent one large reservoir extending under the width of the Meager Mountain complex cannot be discounted. Comparitive geochemistry from deep well fluids in both reservoirs is essential to further progress in this matter.

The existence of a single large reservoir should not necessarily discourage separate and independent development of both sides of the Meager Mountain complex. Nevertheless, it is recommended that suitable drilling targets be identified and deep wells drilled and tested in the north side as soon as possible to enable evaluation of optimum development of the single reservoir should it exist.

A review of the environmental programme up to mid 1981 conluded that it was strongly influenced by work done at the vapour dominated Geysers field. The differing requirements for an environmental programme at a water dominated field, as anticipated at Meager Creek were included in a revised programme recommended to BC Hydro.

3.2 Meager Creek - South Side

3.2.1 Deep Drilling Programme

As previously mentioned, analysis of available data lead KRTA to conclude that the best prospects for commercial production lay beneath the Meager Mountain complex. A 3000m well (MC-1) with planned 1200m offset and vertical depth (V.D) of 2450m was recommended (fig.1).

The well was drilled to the programmed depth but unfortunately, more than 500m of drill pipe then became stuck in the well. In view of the apparent lack of well permeability determined as drilling proceeded, it was decided not to by-pass the fish at that time but instead to pull out and move the rig to the next well. The options of moving back over MC-1 at some later date and by-passing the fish will be kept under review.

Petrological studies on cores and cuttings suggested temperatures of 260°C. However maximum measured temperature at the top of the fish was only 219°C (fig. 2) with a conductive gradient to 1900m (V.D). This discrepancy is discussed later in this report.

The well discharges spontaneously, apparently from a zone of limited permeability of about 1300 - 1400m (V.D) with present temperatures of about 190°C. The inability of the well to sustain continuous discharge through a line larger than 75mm diameter at present is indicative of its low overall permeability. Chemical analysis indicates that drilling fluids were still present at March 1982 in the discharge and that stable geochemistry is still to be achieved. The immediate objective is to establish a stable continuous discharge to enable initial output measurement to be made.

The second well, MC-2 was drilled from the same pad with a more easterly heading (fig. 1) in order to increase the prospect of finding permeability. This well target, like MC-1, lies within the area of the resistivity anomaly. The well was completed to 3500m and although nowhere near recovery from drilling operations (at 31 March 1982) has already shown temperatures of 253°C (fig. 3). Water loss tests suggest that the permeability in the bottom section of the well might be sufficient to provide worthwhile potential. Extended testing however will be needed to substantiate this.

The third deep well, MC-3 has been programmed to head in a westerly direction (fig. 1) to intersect the No-Good Zone at about 2800 m depth and to extend to 3500 m depth. This zone is a belt of volcanic vents crossing the Meager Mountain complex and therefore offers the possibility of more permeable formation. The targets for MC-3 lies close to and inside the west boundary of the anomalous resistivity area.

3.2.2 Resistivity

The resistivity survey work has shown a low resistivity anomaly (fig.1) which is consistent with the outline of the top of a rising column of hot water. The temperature data from diamond drillholes suggested high temperatures at depths below the resistivity anomaly. Collectively, this data is regarded as strong evidence of a geothermal resource and justifies the decision to proceed with deep drilling in this area.

The boundary zone, depicted on figure 1, represents the inferred boundary at a few hundred metres below ground surface. The north boundary zone at high altitude must be regarded as tentative, and it will be difficult to establish its location with confidence.

3.2.3 Geochemistry

The results of geochemical analysis of well and spring fluids in Meager Creek Valley are summarised on a Piper diagram (fig. 4). Three fluid groups were present, cool undiluted sodium chloride fluids associated with low flow rates, warm diluted sodium chloride fluids associated with higher flow rates, and cold calcium bicarbonate groundwater. The last group is considered to have no geothermal significance but is important in considering the shallow mixing process.

Based on analysis of available geochemical and petrographic data, a first attempt at a geochemical model of the South Reservoir fluids has been postulated (fig. 5). The principal features of the model are

a) A hot mineralised fluid, containing 3000-4000 mg/kg of chloride, underlies the Meager Creek resource. Petrographic evidence and MC-2 measurements indicate the temperature is of the order of 260^{o}C plus.

b) There are indications of deep fluid movement towards higher reservoir levels, either by quite permeable pathways in which mixing with shallow circulating groundwater takes place, or up channels with limited permeability where no mixing is possible. The former alternative is believed to be associated with the warm diluted chloride waters and the latter to the cold undiluted chloride waters.

On the basis of the above model, the South Reservoir is confirmed as a suitable target for deep drilling.

3.2.4 Petrology

Reference has already been made to the discrepancy in MC-1 between measured downhole temperature (219°C maximum) and assessed geologically recent temperatures of 260°C based on fluid inclusion petrographic studies.

The alteration and precipitate mineralogy is in equilibrium with the measured temperatures down to approximately 1400 - 1500m (V.D). Below this level it is out of equilibrium with the present system temperatures. It is proposed that either the system is cooling with the formation below 1500m (V.D) having been sealed by mineral precipitation from the most recent reservoir fluid, or that rapid upflow of fluid from about 2500m vertical depth has occurred through fractures which have subsequently been sealed with the development of the measured conductive gradient from about 1500 to 2000m (V.D)

In MC-2 Petrographic analysis of cores and cuttings revealed very little evidence of hydrothermal minerals formed in response to the present geothermal system. Anhydrite, indicative of temperatures above 175°C, was encountered below 1900m (V.D). This compares with measured temperature of about 170°C at that depth in MC-2.

3.2.5 Environmental Programme

The Preliminary Planning Report for project licence application requires that all environmental matters be considered. Many of the matters will be typical of any large engineering project. Potential changes to air and surface water quality are of special significance in a geothermal project.

It is characteristic of geothermal power plants that adverse environmental effects tend to peak at some point during the exploration/ development stage. Long term adverse effects tend to be minor in comparison with other generation methods and are restricted to the plant vicinity.

Disposal of geothermal waste waters by deep reinjection is currently envisaged for long term utilisation at Meager Creek. Until sufficient deep well data on the geothermal gas and fluid characteristics has been accumulated, it will be possible only to reach tentative conclusions on air quality.

The principal objectives of the environmental programme at the present stage of exploration are the continued collection of baseline data and satisfactory disposal of well drilling and discharge fluids.

The BC Hydro monitoring and data collection programme was recommended for revision to take into account the chemical and thermal characteristics of the large quantities of hydrothermal water produced from a water dominated resource both during exploration and production stages. Urgency has been given to obtaining baseline data on watercourse and sediment chemistry and on the salmon fishery. The fishery will probably prove to be the primary environmental concern, but any adverse effects of project development are likely to be insignificant particularly in comparison with the effects of logging in the area.

Drilling fluids and initial clearing discharge fluids are typical af any deep well drilling operation and have an insignificant deep geothermal fluid component. Holding and disposal of these fluids is being carried out by BC Hydro in accordance with accepted British Columbia requirements.

Medium term output testing of the deep wells has not yet commenced but disposal of these geothermal fluids by reinjection either into the existing adjacent deep wells or into specially drilled reinjection wells, typically 200-250m deep, is proposed. As part of the reinjection feasibility studies for this site, a programme of ground water investigation is proposed for the 1982 field season.

3.3 Meager Creek - North Side

Despite much earlier work and several diamond drillholes there is at present (March 1982) an insufficient basis on which to locate a deep well. Resistivity anomalies are extensive but have been shown by diamond drilling to be associated in part with non geothermal factors. Of four diamond drillholes, only one (L1) is known to KRTA to have encountered temperatures over 100°C.

However, the existence of this temperature and the evidence of hydrogen sulphide emission at the head of Job Creek are sufficient encouragement to proceed further. Other sectors of interest are the area of most recent volcanic eruption on the slopes of Plinth Peak and determination of the source of waters emerging in Pebble Creek Hot Springs. Geochemical analysis of these latter springs have indicated warm sodium bicarbonate waters (fig.4). Possible explanations for this chemistry is either that they may represent the steam condensate fraction from a large geothermal reservoir (fig.5) or that they may merely be derived by leaching of young volcanic rocks.

KRTA has recommended that the above areas, including an extension west of Job Creek to beyond Boundary Creek, be examined by Schlumberger resistivity survey methods including areas at high altitude on the north face of the Meager Mountain complex (fig.2). In order that the response to the resistivity technique, particularly in the high country, can be better evaluated, several diamond drillholes of approximately 500m in these areas have been recommended. Because of the high altitude of these holes and relative level of hot fluids encountered in well L1, it is not anticipated that these holes will reach geothermal fluids.

The objective of this resistivity work and other subsequent scientific work during 1982 field season is to select a target for deep drilling in 1983.

APPENDIX A

DESCRIPTIVE LIST OF KRTA PROJECT ACTIVITIES 1981-82

A.1 General Exploration Strategy and Analysis

A.1.1 Mention has already been made of the KRTA recommendation during negotiations with BC Hydro, for an initial deep well exploration programme of three deviated wells in the South Reservoir.

A.1.2 Review of available data leading to the report on Geothermal Exploration Strategy at Meager Creek in an internal report to BC Hydro. Specific recommendations in this document included the target for the first deep well in both the South and North Reservoirs.

A.1.3 Recommendations for additional work and expenditures in response to BC Hydro senior management request to investigate means of accelerating progress and of developing the project to its full potential.

A.1.4 A geoscientific analysis of available information on hot springs of southwest British Columbia.

A.1.5 The exploration strategy for Meager Creek in item 2.1.2 was taken a step further in internal reports to BC Hydro on -

a) extension to encompass geothermal exploration strategy elsewhere in British Columbia

b) further recommendations for geoscientific work at Meager Creek.

A.2 Resistivity - Meager Creek

A.2.1 Schlumberger configuration resistivity survey work was implemented at higher altitudes on the Meager Mountain complex. Evaluation of this work, in conjunction with previous dipole resistivity data in an internal report to BC Hydro, showed a promising low resistivity anomaly in the South Reservoir in the area selected for the deep well programme. Insufficient data was obtained to interpret a possible anomaly in the North Reservoir.

A.2.2 Specific recommendations were also made for further resistivity survey work, particularly on the north side of the Meager Mountain complex.

A.3 Geochemistry - Meager Creek

A.3.1 Available geochemical data for the Meager Creek area was reviewed and a programme of creek, spring, seepage and well sampling and analysis implemented. Results and evaluation of this work, and of earlier published work by others, have been reported in an internal report to BC Hydro and a geochemical model of the geothermal fluids postulated.

A.3.2 Discharge fluids from well MC-1 have been sampled and analysed but indications are that the well chemistry had not stabilised as at March 1982.

A.3.3 Associated with the work in item A.3, KRTA have established with the BC Hydro Research Centre, appropriate procedures for laboratory analysis of geothermal fluids and gases. Recommendations were also made for BC Hydro to establish a field laboratory at Meager Creek, with appropriate equipment and facilities.

A.4 Petrology - Meager Creek

A.4.1 An evaluation of available previous petrology and a detailed petrographic analysis of selected cores from diamond drillhole M-10 was made in an internal report to BC Hydro. The objective was to determine which alteration and precipitate minerals may be indicative of the present hydrothermal system, thus setting a petrological baseline for analysis of cores and cuttings from subsequent deep exploration wells.

A.4.2 Selected samples from deep wells MC-1 and MC-2 have been examined petrographically and the results and evaluation are contained in separate internal reports to BC Hydro.

A.5 Environmental Programme

A.5.1 Discussions were held with the BC Hydro environmental team on the requirements for the environmental study and protection programme, with emphasis on the exploration and development of the water dominated type of geothermal resource at Meager Creek.

A.5.2 BC Hydro were advised on the environmental aspects of using drilling additives containing chromium in geothermal wells.

A.5.3 BC Hydro were advised of several environmental issues recommended for consideration by BC Hydro prior to discharge of the first deep well.

A.5.4 BC Hydro environmental status reports and a proposal by others to BC Hydro for 1982-83, were reviewed for BC Hydro.

A.6 Drilling Management

A.6.1 Following progressive selection of drilling sites and targets for each well, drilling and wellhead programmes were prepared for deep wells MC-1 (previously MCGA-1), MC-2 and MC-3.

A.6.2 Design and preparation of drawings and specifications for a special rig cooling tower for geothermal drilling fluids were completed.

A.6.3 Advice and assistance including several tender evaluation reports were provided to BC Hydro for the procurement of drilling rigs, specialist drilling services, casing materials and wellhead components.

A.6.4 Rig supervision and drilling engineering advice during drilling, casing and cementing operations for wells MC-1 and MC-2 was provided.

A.6.5 Preparation of completion reports for wells MC-1 and MC-2 (ref. Well Completion Report MC-1 June 1982, Well Completion Report MC-2 September 1982).

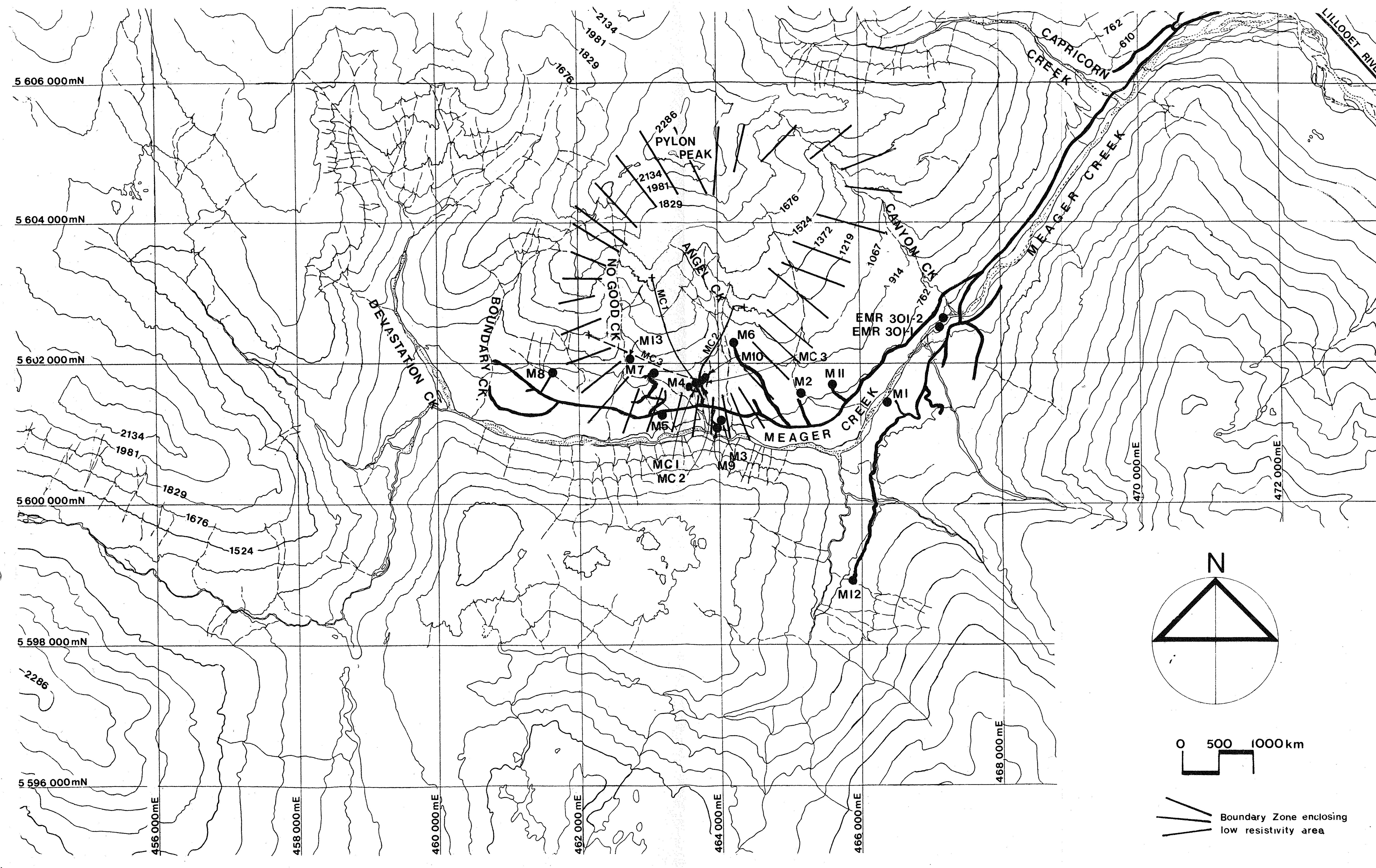
A.6.6 Review of draft British Columbia Geothermal Drilling and Production Regulations as part of BC Hydro submission to the Provincial Government authorities.

A.7 Geothermal Engineering

A.7.1 Preparation and implementation of well completion tests for wells MC-1 and MC-2 and analysis of results (see refs under item A.6.5).

A.7.2 Monitoring of well heat-up and initial discharge of well MC-1 (see refs under item A.6.5).

A.7.3 Design and preparation of drawings and specifications for portable silencers, two phase separator, and supply and reinjection pipework for well output testing.



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CAPRICORN CREEK
LILLOOET RIVER
MEAGER CREEK
CANYON CK
ANGEL CK
NO GOOD CK
BOUNDARY CK
DEVASTATION CK
EMR 301-2
EMR 301-1
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
MC1
MC2
MC3
N
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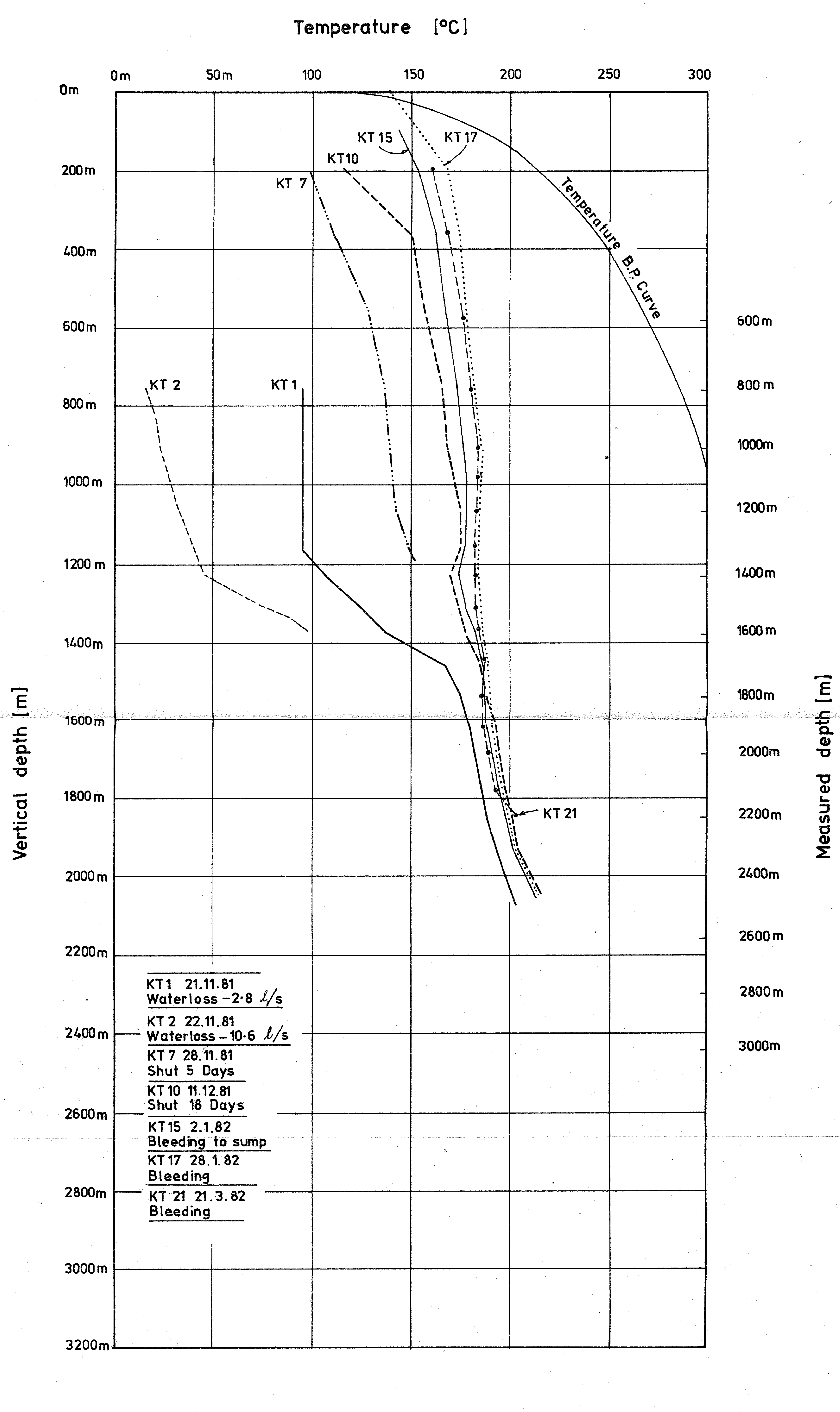
Boundary Zone enclosing low resistivity area

Project No 7010/2 July 82, PGMI, BC Hydro Meager Ck. Summary Report 1981 - 1982.



Meager Creek - Well MC-1 - Temperature vs depth profiles

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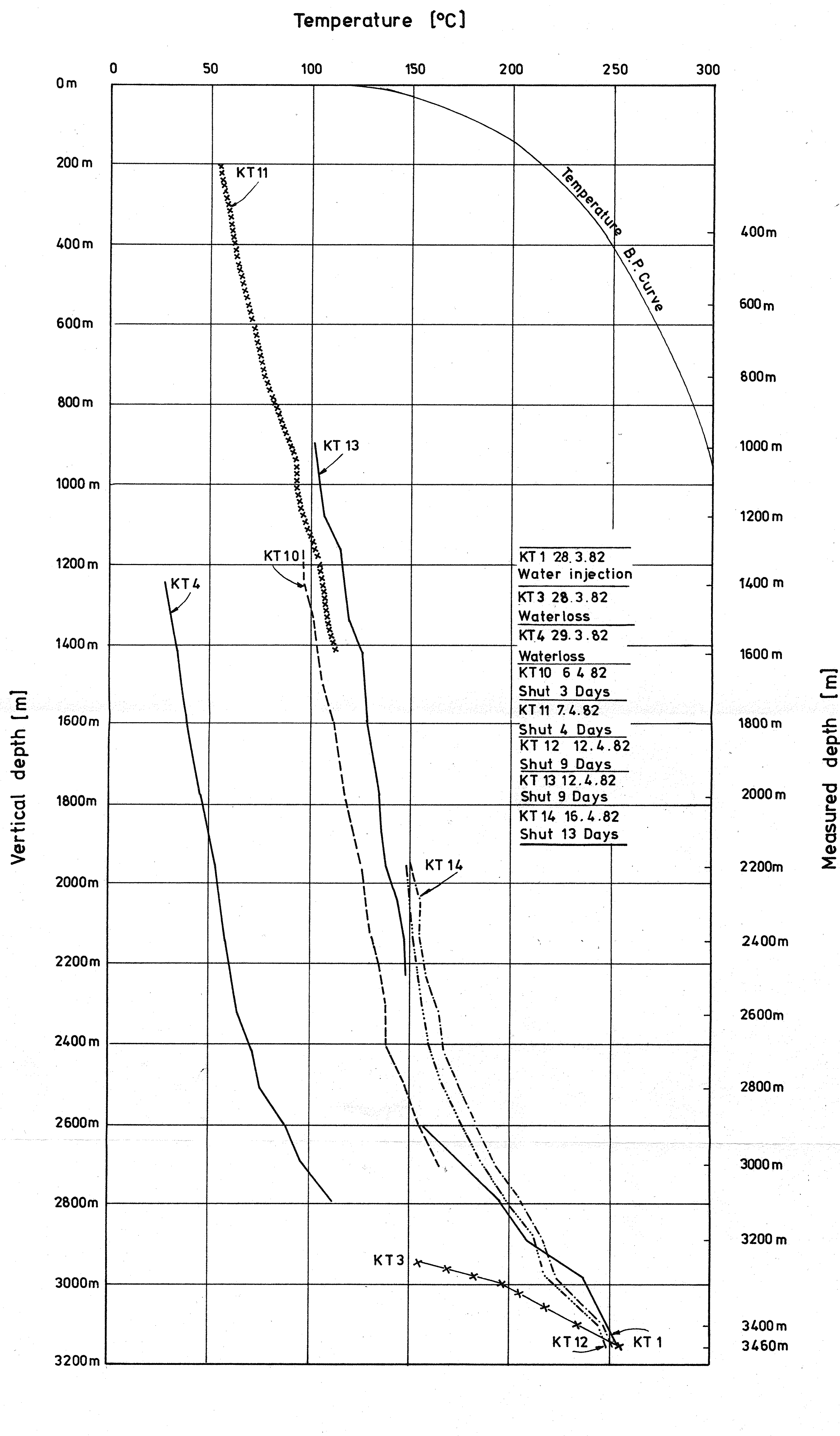

eager Creek - Well MC-2 - Temperature vs depth profiles

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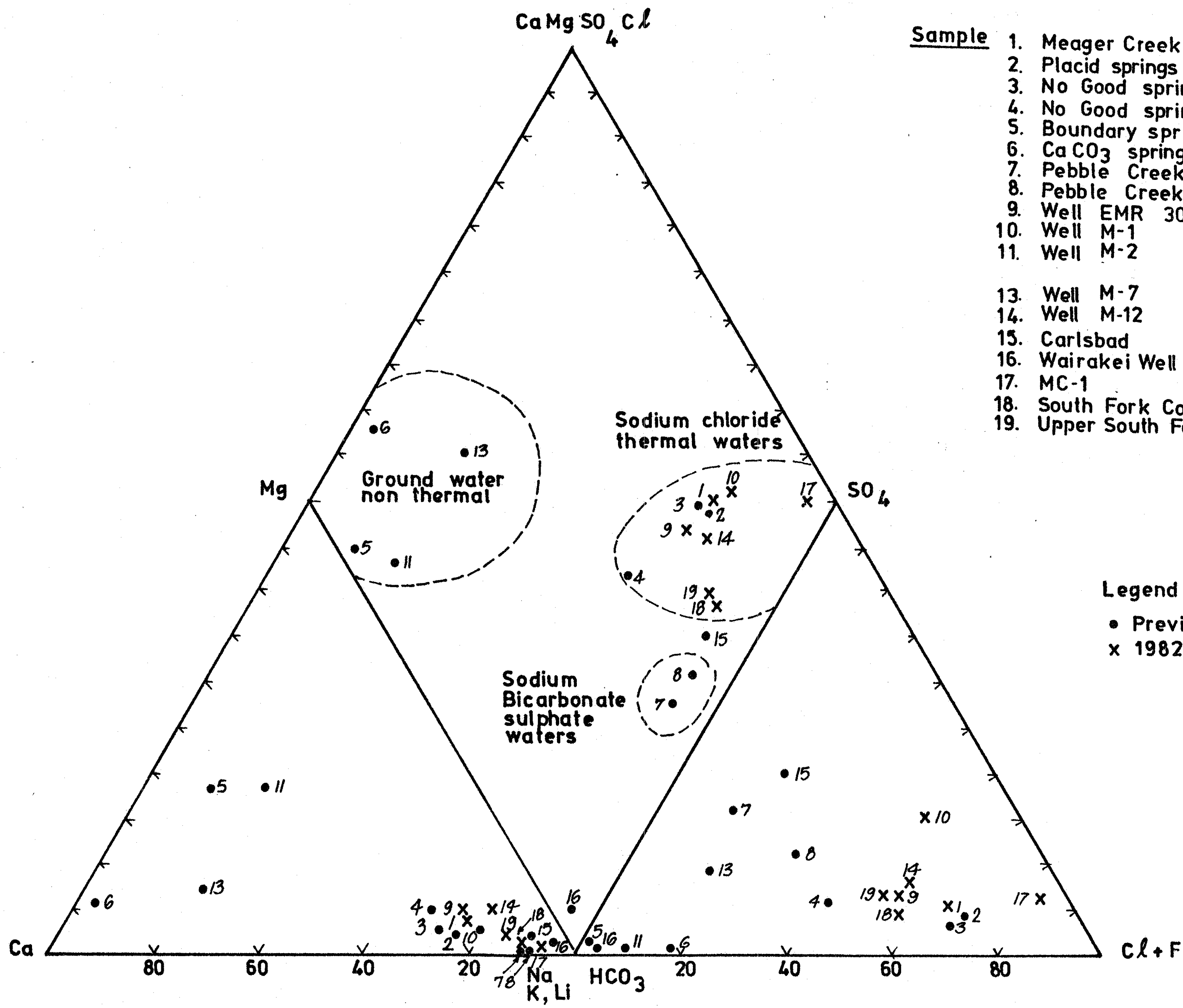

Sample

1. Meager Creek hot springs
2. Placid springs
3. No Good spring no 1.
4. No Good spring no 2.
5. Boundary spring
6. $CaCO_3$ spring
7. Pebble Creek spring no 2
8. Pebble Creek spring no 1.
9. Well EMR 301-1
10. Well M-1
11. Well M-2

13. Well M-7
14. Well M-12
15. Carlsbad
16. Wairakei Well 5
17. MC-1
18. South Fork Cond Swamp
19. Upper South Fork Swamp

Legend

• Previous data
x 1982 data

Fig 4 **Meager Creek - Piper diagram of fluid types**

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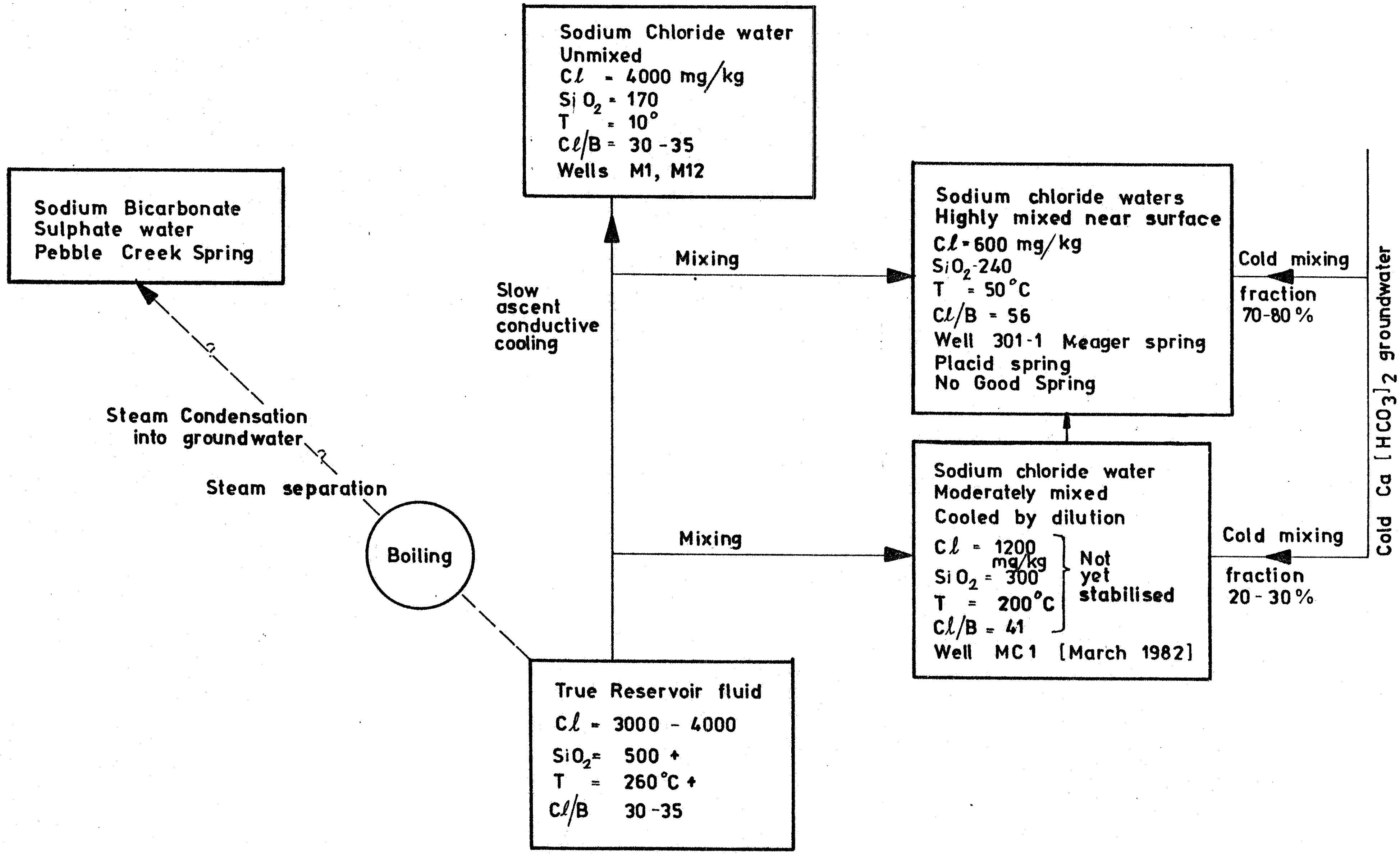

Fig 5 **Meager Creek - Geochemical Model of Resource**

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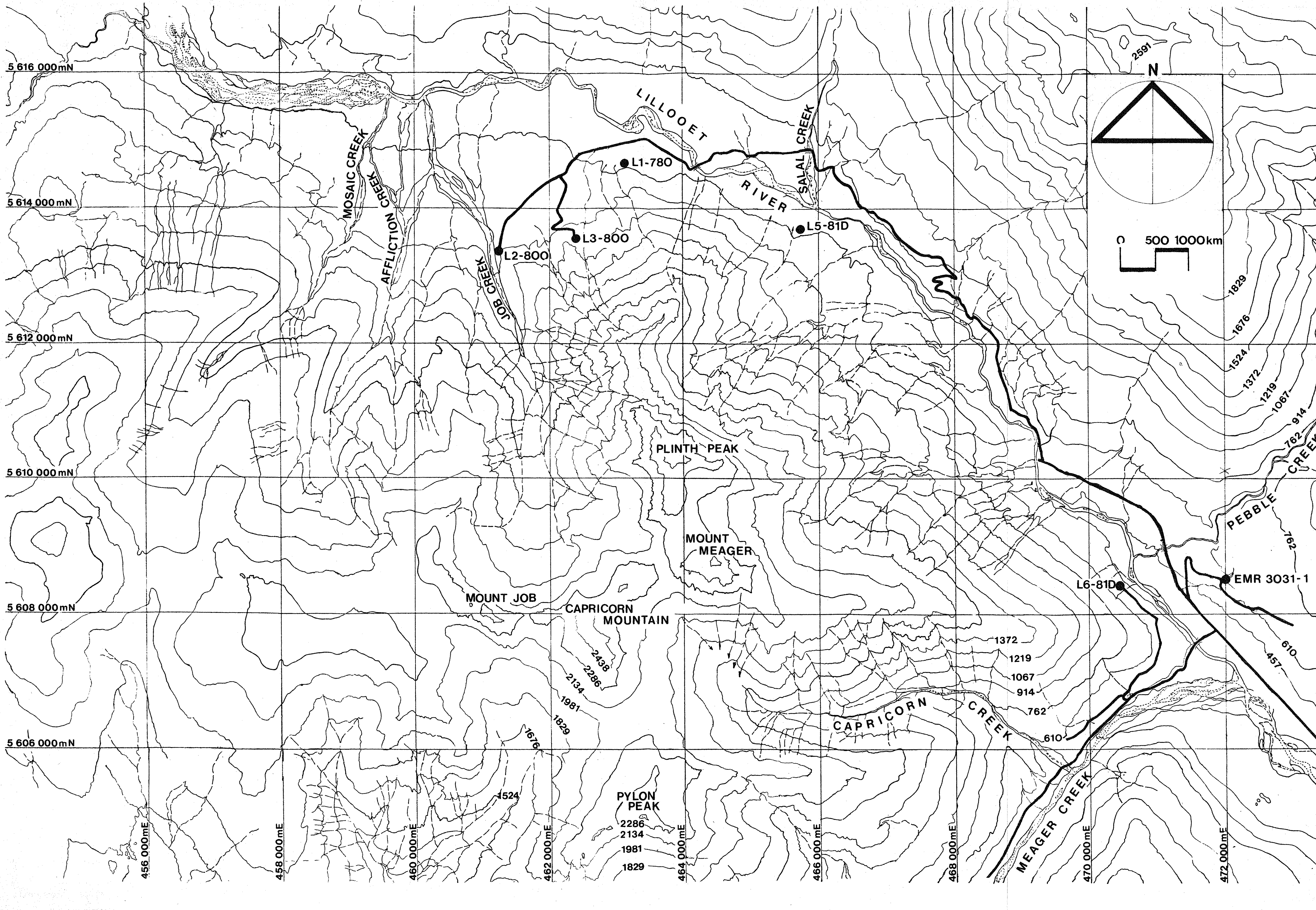
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LILLOOET
RIVER
SALAL CREEK
MOSAIC CREEK
AFFLICTION CREEK
JOB CREEK
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L2-800
L3-800
L5-81D
L6-81D
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MOUNT MEAGER
MOUNT JOB
CAPRICORN MOUNTAIN
CAPRICORN CREEK
MEAGER CREEK
PEBBLE CREEK
PYLON PEAK
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