

GH3234

GEOHYDROLOGICAL INVESTIGATION

AT POFADDER AND
SURROUNDING AREA

BY

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GH3236 is a summary entitled "Pofaddergrondwateronderzoek", by T.S. Kok

ABSTRACT

A geohydrological investigation was conducted with the aim of augmenting the existing municipal ground-water supply of Pofadder.

A comprehensive geophysical and drilling programme was undertaken on the townlands, concentrating on structural features. Selected boreholes were successfully developed with explosives to increase their yield. A number of groundwater samples were collected for quality determinations and some limited objective pump tests conducted.

The strongest yielding borehole drilled was 3.2ℓ/sec. The investigation did not succeed in locating on municipal property the quantities of water required.

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1. INTRODUCTION

1.1 Aim of the investigation

The purpose of this geohydrological investigation is to assess the groundwater potential of the Pofadder municipal area, with the overall objective of augmenting the existing groundwater supply of the town.

Exploratory drilling was to be confined to municipal property only.

1.2 Background to the investigation

The Division of Geohydrology was initially approached by a firm of consulting engineers Rayon, Theron, Bower & Viljoen of Kimberley, acting on behalf of the municipality of Pofadder.

A short preliminary site investigation was undertaken in July 1981 by Dr. T. Kok (later joined by the author) to delineate promising structures and areas for detailed investigation. The main field programme was conducted between August 1981 and July 1982 in conjunction with other ad hoc investigations in the area.

1.3 Pofadder : Location, Economy, Communication

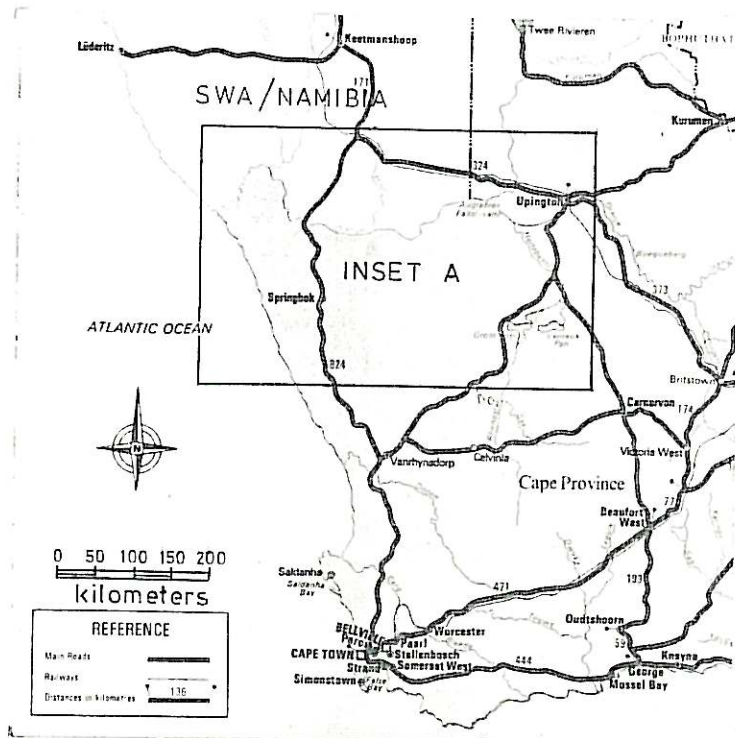
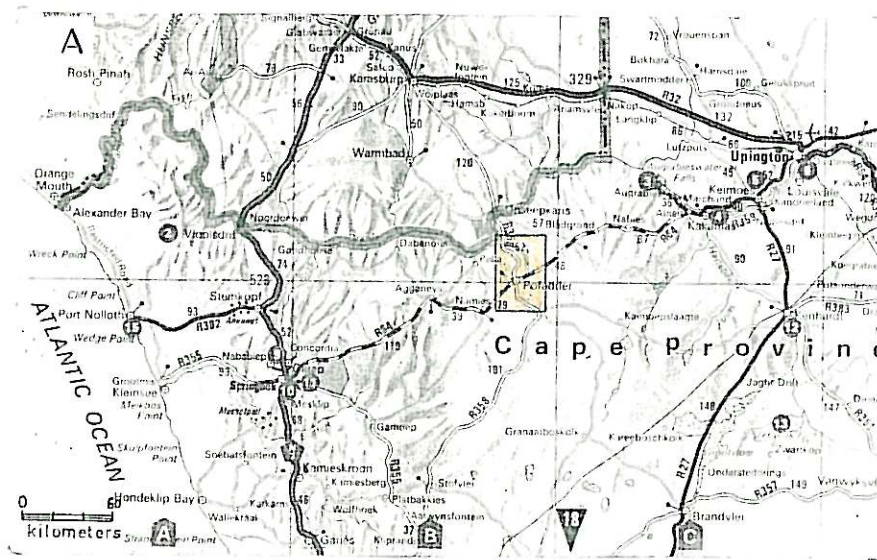
Pofadder, with a population of some 3 200 people * (600 "whites", 2 600 "Colourds") is situated in Boshmanland in the North-western Cape Province, approximately 30 km south-east of the S.W.A./ Namibian border (Orange-River). The nearest towns are Aggeneys, a recently developed base metal mining community, 80 km to the west and Kakamas, a small rural community 155 km. to the east (see fig.1)

The economy of the immediate area is based on base metal mining and agriculture, mainly sheep-rearing and Pofadder provides service functions for the surrounding farming community.

Though lacking a rail linkage, the town boasts a small airstrip as well as a recently completed tar road connecting the town with Springbok and Upington.

* Figure given is for 1981; Source - Mr. L. Groenwald (Town Clerk, Pofadder).

FIGURE 1: LOCATION OF THE STUDY AREA



1.4 Pofadder municipal water supply - A SUMMARY

Pofadder initially obtained its water supply from local springs. Later a number of private boreholes were drilled from which residents obtained individual supplies of low yield (0,5 - 1,0 l/s).

In 1964 a successful borehole was drilled on municipal property west of the town (labelled PT-1 in this report). A pump test was conducted by Nieuwoudt as well as by a local resident. The maximum yield was reported to be approximately 10 l/s. Around 1966 another successful borehole was established on the same geological feature, but some 420 meters to the west, (labelled PT-3 in this report).

Initially an electrical submersible pump was installed in PT-1 and subsequently in 1971, in PT-3 also, as part of an overall Pofadder Water Scheme undertaken by consulting engineers and incorporating **storage reservoirs**, pump house, chlorination plant and distribution network. The scheme meant a change from individual household supply with its attendant potential health hazards of consuming untreated water derived from shallow wells in the vicinity of domestic sewage pits, to a more reliable and sanitary municipal supply.

At present (1981) the water supply for Pofadder is derived entirely from groundwater sources via three production boreholes (marked 1, 2 and 3 on Enclosure 1) which all penetrate the same geological feature (see plates 1, 2 & 3). The main production boreholes, PT-1 and PT-3 are pumped singly (i.e. non-concurrently) for periods varying with demand and provide the bulk of the towns water requirements. A smaller pumped supply from borehole PT-2 is used mainly for the coloured township as well as stock watering purposes.

The three boreholes together supply a reported 6 000 m³/month to the town at present. On the basis of the current population assessed at 300 liters/day per capita for "whites", and 150 liters/day per capita for "coloureds", a supply of approximately 18 000m³/month is calculated as the requirement to cover the towns present needs. An additional 12 000m³/month is therefore required.

1.5 Approach to the investigation

A preliminary borehole survey of the Pofadder area was undertaken in order to collect and collate sufficient hydrogeological data on which to base future project planning. The information obtained of a borehole distribution and yields, piezometry and groundwater quality was compiled and analyzed with the aim of achieving a better understanding as to the lithological types and structures likely to yield the strongest supplies.

The initial aim was to investigate a well-jointed quartzite formation as well as some ^ebrocciated north-south linear structures. A drilling programme was initiated at these localities - the exact sites being selected on the basis of geological evidence only. A lack of significant water strikes at these sites prompted an expansion of the exploration programme to investigate the numerous fracture traces west of the town, clearly visible as discrete persistent lineaments on aerial photographs.

An extensive electromagnetic (E-M) survey was conducted across most of the major fractures of interest in order to ascertain which lineament showed the most potential. On the basis of the geophysical results obtained as well as other geological field evidence, a new drilling programme was ^{started,} ~~investigated~~ concentrating on the most promising ⁱⁿ ~~view~~-filled fracture lineaments. Downhole electrical resistivity logs were obtained from most of the exploration boreholes, as well as some existing boreholes in order to assist in the interpretation of the geological logs. In addition, more comprehensive downhole log "suites" were obtained from selected boreholes to help evaluate specific problems.

Controlled detonations of small explosive charges were conducted later in the investigation in an attempt to improve the yields of certain boreholes. Some boreholes were developed with sodium - hexametaphosphate with the same aim.

Short duration, limited objective pumping tests were conducted at four borehole sites.

A total of 83 groundwater samples were collected during the investigation for comprehensive chemical analysis.

1.6 Previous work

Available previously published hydrogeological work for the Pofadder area is limited to a single brief report by Nieuwoudt in 1964, which incorporated a pump test on PT -1 (Nieuwoudt's borehole No. 3) and described in general terms the hydrochemistry of ten water samples, stressing their high T.D.S. and fluoride contents.

Von Backstrom and De Villiers (1972) mapped the geology of the northern part of the present study area as detailed on their Onseepkans 2819 sheet.

J
Noubert (1974), in the course of a regional mapping programme covered the more important parts of the study area, including Pofadder townlands and its immediate vicinity.

1.7 Climate

The climate of the Pofadder area is semiarid with an average yearly rainfall of 122mm (1956-1981) as recorded at the meteorological station in the town (see table A2). Most of the rainfall occurs between February and April.

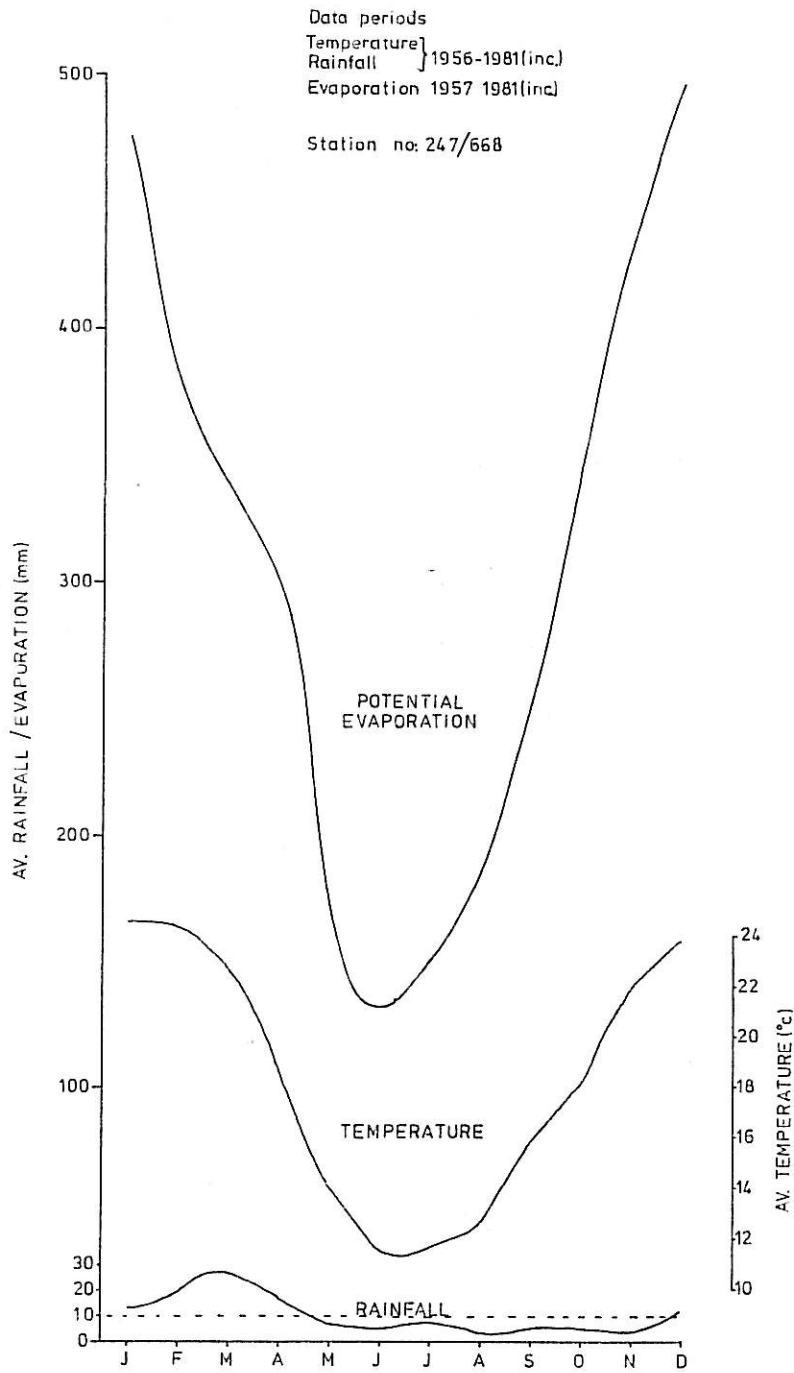
The marked contrast between precipitation and potential evaporation can be seen in figure 2, which also shows the monthly mean temperatures. (see also tables A3 And A4). Average maximum monthly temperatures often exceed 33°C in the summer months.

1.8 Relief

The topography of the study area is ^{also} determined by two prominent hill-lines to the north and south.

The southern hill-line with elevations in excess of 1100 meters (a.m.s.l.) represents the highest topographic feature of the area, and trends in a north-easterly direction. From the base of those hills the ground slopes gently to the west and north, the landscape having a flat featureless appearance, until terminated by the north-westerly trending hills north of the town which rise some 60 meters above the adjacent plain to heights of 1 000 meters (a.m.s.l.)

FIG: 2 - POFADDER AVERAGE MONTHLY RAINFALL
POTENTIAL EVAPORATION & TEMPERATURE



Both hill-lines are reflections of the geology and are due to the presence of more resistant quartzite formations.

1.9 Vegetation

According to Acock¹⁶, the two veld types present in the Pofadder District are the Namaqualand Broken Veld, which occurs over most of the area and the False Succulent Karoo, which has a more restricted distribution in the southern portion of the townlands.

An indication of the overall sparse nature of the vegetation can be seen in plates 4 and 8.

Vegetation differences are often associated with many of the east-west fracture features, such as a greater density of certain shrubs and plants or the occurrence of lines of ganna bushes which appear to be directly related to underlying better weathered or more conductive zones as defined by the geophysical and drilling programmes.

Drainage

1.10 Two main river systems are present, both of which are non-perennial and drain towards the Orange River to the north-west. The rivers are usually dry but do flow on occasions for short periods in response to sustained precipitation.

The density of the drainage network is high as is typical of semi-arid areas.

2. GEOLOGY

2.1 Stratigraphy

Joubert (1974), on the basis of his regional mapping work in the Pofadder area, compiled the following succession :-

- (top) 7. Grey gneisses with some schists and minor amphibolites.
6. Quartz moscovite schists and nodular gneiss with amphibolites.
5. Magnetic quartzites (thin and inconsistent).
4. White metaquartzites, usually ferruginous at the base.
3. Biotite and sillimanite schists with thin dark quartzites and thin amphibolite at the base.
2. Pink gneisses, often with leptites at the top.
- (base) 1. Porphyroblastic granite gneiss.

In addition, both large and small mafic intrusive bodies are common in the east and south of the study area, most notably on Nouzees as hypersthene gabbros and olivine norites and also on Samoep as anthophyllite - cordierite rocks. All ^{were} ~~live~~ apparently intruded prior to the emplacement of the basal granite gneiss.

The main units investigated in the hydrogeological investigation were those designated 1, 2, 4 and 7 in the preceding stratigraphic table.

Other lithological types present in the area are :-

- (i) Pegmatite veins - which are fairly common throughout but ^t ~~at~~tain their largest concentrations in the grey gneisses.
- (ii) Quartz veins - (discussed in more detail later) are also quite common but most prominent in the granite gneiss west of the town.
- (iii) Alluvial deposits - of limited thickness and restricted to the dry river courses.

Joubert presents a case for the emplacement of the basal granite in batholithic proportions, probably during the main F2 deformations (see following page) and cites field observations in support of this. He suggests a pre-metamorphic origin by volcanic and igneous processes for the pink gneiss, with the aluminous rocks being derived from leached volcanic rocks, the sillimanite deposits representing metamorphosed concentrations of alumina. (see Enclosure 1 for the geology of the study area).

2.2 Structure

The entire area was affected by the Namaqua Event, consisting of four separate episodes of deformation as follows :-

F1 = Folds of this episode can be most easily distinguished in well-banded rocks and are characteristically of high amplitude and short wavelength with a sharp hinge zone.

F2= This is the most important episode during or just after which the highest degree of regional metamorphism was attained. The form of the folding is variable from F1 - like but with rounded hinge zones to open folds very similar to F3 types, though usually with penetrative axial plane foliation.

F3 - These folds are of the flexural slip type with much movement and shearing along the existing foliation planes during folding. This episode is responsible for the large open east-west structures such as the synform at Samcep.

F4 - These folds are poorly developed in the Pofadder area, but where present, trend north-west and are monoclinical with steep limbs to the east. The pegmatites are most frequently associated with F4 structures, forming pinch and swell features in the folds or are emplaced along F4 fractures.

The entire Namaqua Event is thought to have terminated some 900 million years ago. The area was affected at a later date by shear deformation, most notably to the north of Pofadder which resulted in a right-lateral displacement of the strata (see enclosure 1). Branching out of this 'zone' and in places cutting across it are north-westerly striking faults along which the rocks have been mylonitized. These fractures have the same strike as most of the F4 folds and east and south-east of Pofadder prominent quartz veins follow the faults.

2.3 General

Field studies on the townlands revealed the following geological observations relevant to the overall geohydrological investigation -

- (i) A well jointed quartzite formation is present in the north of the townlands. Two joint sets are present, the better developed set having an average joint spacing of 27cm and a high angle of dip ($\alpha = 86^\circ \text{w}$). Joint separation is minimal at the surface with signs of recrystallization. Weakly defined bedding planes show a dip averaging 42°n . The high degree of joint development contrasts markedly with the minimal jointing in the underlying gneiss.
- (ii) A number of vein-filled fractures are present on the townlands, mainly to the west and north-west of the town. Two general orientations of these structures can be discerned :-
 - (a) An east-west set of fractures usually less than 30 cm in width partially or wholly infilled or lined with medium to coarsely crystalline quartz, often exhibiting a drusy texture. Calcite is often in association with the quartz, either in massive or disseminated form or occasionally as a readily



PLATE 4: Lineament B (see enclosure 2) looking west towards Site 3. Note abundant float material from vein and the presence of ganna bushes

recognisable late mineralization phase displaying rhombic crystal forms (clearly shown near PT-1, refer to Plates 1 to 3).

Often the moderately to highly porous nature of such vein fill material was evident from the pock-marked appearance of samples or nearby surface float material where the more soluble calcite components had been differentially weathered / dissolved with respect to the more durable quartz.

- (b) A north-south or north-west/south-east fracture set usually wholly infilled by amorphous quartz or pegmatic material forming thin veins. These features were the most persistent and common in the study area.

In general the vein material discussed above was not well exposed making deductions regarding the direction and degree of dip of the feature difficult or impossible.

The depth of the main weathering zone was found to vary throughout the area from a minimum of 5 meters to in excess of 65 meters at certain fracture sites. The degree of weathering was slight overall with occasional well defined thin layers of moderately to highly weathered rock, often associated with local fracturing. Whilst a pattern of weathered rock overlying fresh was generally established in the study area, at certain drilling sites on fracture structures (most notably sites 4 and 7 - refer to enclosure 2) a repeated pattern of weathered and fresh rock was found at depth - eventually becoming mainly or wholly fresh.

Textural and mineralogical differences between the types of gneiss were minimal and often subtle with variations of biolite and magnetite content being the most obvious.

A 14m zone of highly altered gneiss was encountered in G34355 and G34357 at depth with discrete layers of pure montmorillonite present. This occurrence was not observed at other sites.

3. THE GEOPHYSICAL INVESTIGATION

3.1 Introduction

Surface geophysical work was confined to electro-magnetic (E-M) surveys using the chemtron G51 instrument. In total, some 31 set-ups

or 118 individual traverses were completed (refer to Enclosures 5 to 14) the majority of the work was undertaken on the western townlands (see Enclosures 1 and 2 for traverse line locations).

The E-M work was used as an interpretive tool specifically in connection with the numerous vein-filled linear fracture systems. Its purpose and scope can be summarized as follows :-

- (i) Establishing the existence or otherwise, of conductive zones associated with the lineaments and accurately locating their position and strike.
- (ii) Using the information obtained to help select drilling sites with the most potential.

3.2 Results

The positions of the major anomaly peaks detected on each traverse line have been indicated on Enclosure 2 (marked with a cross). It is apparent that most, but not all, of the lineaments investigated produced a related E-M anomaly. Certain lineaments such as those marked B, C and D are quite consistent in this respect, while others, notably E and F give an anomalous response along part of their length only. Others give no anomalous response at all. These differences in response are essentially due to changes related to the fracture lineament itself, be it degree of fracturing and/or weathering, type and extent of vein-fill material, or its water-bearing status - all of which would affect its conductivity.

In general the line of anomalies detected in each case were approximately parallel to the strike of a nearby lineament, as in the case of D. (see Enclosure 2). Along lineament C, the anomaly peaks were practically coincident with the surface outcrops of the fracture suggesting a near vertical dip.

At the three sites where proven yields in excess of 0,4ℓ/sec are present namely sites 3, 7 and the PT-1 / PT-3 area detailed E-M work reveals a convergence of the line of anomalies relative to the surface outcrop of the veinfilled fracture. This is most clearly shown at site 3 (see inset, Enclosure 2) where a strict relationship between the east-west vein and anomalies is shown to be questionable.

An intensive E-M study at site 3, undertaken in an attempt to clarify the age relationship of the two fracture systems, gave only ambiguous results as shown in the inset of Enclosure 2.

3.3 Validity of the technique

The E-M method employed enabled a semi-quantitative assessment to be made of the linear structures investigated ^{so} such that the more promising features could be identified and others eliminated. More detailed follow-up work on the former provided valuable information on the exact position, degree and linear extent of the conductive zones so enabling drilling programme to be located at sites and on zones with the most potential for success.

The technique was especially useful in that the anomaly peak positions detected invariably did not coincide with the surface outcrop positions of the fractures and as the available field derived geological information (especially the dip of the fractures) was usually modequate, the E-M method provided the only rational scientific means of siting a borehole. The validity of taking readings every one meter (as opposed to ten meters in general) when close to the ground position of a major anomaly peak became apparent upon commencement of drilling on anomaly peak locations (see chapter 4.3 - site 3).

4. THE DRILLING PROGRAMME

4.1 Introduction

A total of 27 air percussion drilled exploration boreholes were completed at ten different sites. Casing was installed and boreholes capped in all but three instances. A total meterage of 1878 meters were drilled during the project, the deepest borehole being 152 meters (refers table 1, page 11).

The types of features investigated by the drilling programme were;

1. Well-jointed quartzite beds
2. East-west ^udroxy quartz and calcite - filled fractures.
3. North-south amorphous quartz - filled fractures.

4.2 Criteria adopted for site selection

Exploration boreholes were mainly sited where several independent pieces of evidence, be they geological, geophysical or physiographic, indicated the high potential of a site. In itself an E-M anomaly was not considered sufficient reason to warrant drilling.

TABLE 1 - EXPLORATION B/H DATA : A SUMMARY

SITE NO ON ENCL.2	EXPLORATION B/H NO.	TOTAL DEPTH (M)	CASING LENGTH (M)	DEPTH OF MAIN WATER STRIKE M(BG)	FINAL YIELD (l/s)	AQUIFER	DEPTH TO WATER LEVEL(M) BM (BD)	MAIN WEATH- ERING DEPTH (M)BG	STRATIGRA- PHIC UNIT
5	G 34342	103	0	15	SEEP	?	7,9	8	Grey gneiss
1	G 34343	100	2,45	49	0,3	Frac	1,8	11	Qtzite/ grey gn.
	G 34344	60	2,33	1	0,05	Alluv	1,0	0	"
2	G 34345	75	0	16	0,13	Frac/ weath	2,0	5	Grey gn.
	G 34346	93	0	51	0,08	"	7,5	12	"
3	G 34348	87 ⁸	9,7	55,5	1,83	Frac	12,8	66	Porph. gn.
	G 34349	86 ⁹	3,1	63	0,43	Weath	13,0	67	"
	G 34350	80,75 ⁷	6,1	33	1,72	Weath/f	13,1	72	"
	G 34351	81 ⁶	3,6	53	0,21	Weath	13,1	62	"
4	G 34352	46 ⁵	6,1	20	SEEP	W	11,9	21	Grey gn.
	G 34353	56 ⁴	1,5	11,6	"	"	11,6	49	"
	G 34354	55 ¹	1,75	14,5	SEEP	"	11,8	24	"
	G 34355	108 ³	3,0	94	0,04	W	12,9	21	"
	G 34356	152 ²	4,1	90	0,11		12,3	63	"
	G 34357	140 ¹⁵	111,8	93-100	0,09	W	12,1	19	"
5	G 34732	27,5 ¹⁶	2,3		SEEP		11		"
	G 34733	38 ¹⁷	3,2	8-12	"		11		"
6	G 34734	35 ¹⁸	4,8	21,5	"		15,7		
	G 34735	35 ¹⁹	4,3		"		15,7	13	
7	G 34736	69,5 ²⁰	2,7	31	0,48	F/W	12,5	13	Porph. gn.
	G 34737	75,5 ²¹	1,3	35	0,28	F/W	12,4	18	"
	G 34738	69 ²²	1,8	25,6	0,24	"	12,5	34	"
8	G 34739	45 ²³	3,4	33,6	0,11	W	13,4	23	"
9	G 34740	25 ²⁴	2,2	-	DRY	-	-	10	"
	G 34741	26 ²⁵	3,9	-	DRY	-	-	7	"
10	G 34813	33 ²⁶	1,3	-	DRY	-	-	21	Grey gn.
	G 34814	77 ²⁷	1,0		SEEP		23,7		

TOTALS 1878,25 187,7

TOTAL NO OF EXPLORATION B/H'S	27	> 1,5	↑ YIELDS (L/sec)	0,15 - 0,5	0,03	0
		↓			(SEEPAGE)	(DRY)
		2		13	9	3

Types of evidence and factors considered in the site selection process included -

1. The length and continuity of a fracture lineament.
2. Brecciation associated with a fracture feature.
3. The presence of a line of well-defined E-M anomalies.
4. Fracture lineaments which transected the essentially northward groundwater flow direction.
5. Incomplete vein-fill of fractures.
6. ^{The} presence of vein outcrop or 'float' specimens ^{in veins} with a well developed secondary porosity caused by the differential weathering/solution of a calcitic component.
7. The presence of well-developed jointing.
8. Areas of soft extensively burrowed ground in association with linear occurrences of 'ganna' bushes.
9. The presence of known strong boreholes on the feature under consideration.

4.3 Drilling results

A summary will be given in the following pages of the reasons for drilling at a particular site and the results obtained. Supplementary data on the following discussion can be obtained from the individual drilling logs (figures 3 to 29) and the well site schedules (ext ^Evelope no 654) Refer to enclosures 1 and 2 for both the site and individual borehole locations.

SITE 1

Two exploration boreholes G34343 and G34344 were drilled at this site. The objective in both cases was to investigate the water yielding potential of well-jointed northward-dipping quartzite beds (described in chapter 2).

No fractures or joints were intercepted within the quartzite itself, even though the boreholes were sited to coincide with the maximum joint density. Though the joint spacing (average - 27 cm) in conjunction with their high angle of dip (average - 86°) may have been contributory reasons for the failing to intercept joints, a more likely reason is the tightness of the joints, implying sealing of the joint planes at depth.

SITE 2

G 34345 was drilled at a spot where prominent north-south joints associated with an extensive vein-filled fracture to the south are present, in conjunction with an east-west highly mineralized and epidotized zone within the gneiss, with a marked fracture cleavage. Shallow groundwater occurrence at least was suspected on the basis of vegetation types present. The borehole was sited with a view to intersection jointed or fractured rock at depth.

The drilling results indicated that minor fracturing only, occurred between 12 and 20 meters depth, with associated moderate weathering, otherwise the gneiss was completely fresh. The main water strike was at 16 meters with seepage at 3,5 meters.

G 34346 was drilled 220 meters to the south and was sited to intercept a steeply westward-dipping north-south-trending partly-brecciated amorphous quartz-filled fracture. The objective was to intercept this quartz vein at about 50 meters. It was hoped that if the brecciated material itself did not yield water, then related fractures associated with the major feature might.

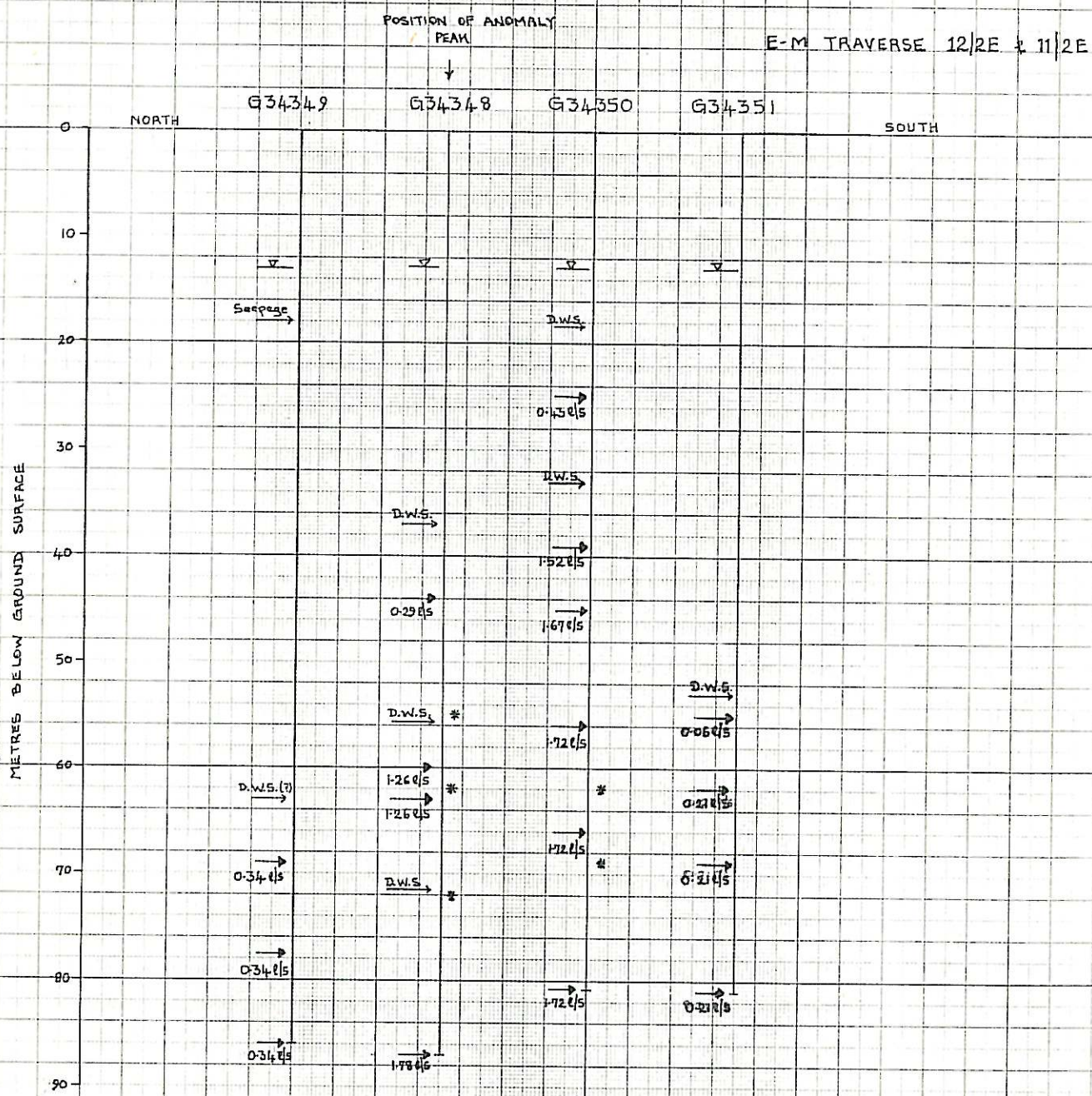
Some 38 meters of fresh gneiss were penetrated before intercepting the quartz vein at 50 meters, where a small water strike was noted (0,08 l/sec) but no significant fracturing was present.

SITE 3 (see fig. 35)

Several factors indicated that this site, selected in consultation with Mr. Vegter, might be worthwhile.

1. The feature chosen for drilling was a long (1.5 km) east-west linear fracture partially infilled with drusy quartz and calcite. The overall texture was readily apparent at several small outcrops as well in much of the surface float material in the vicinity. Hand specimens had a distinctly porous appearance through differential solution of the more calcitic areas.

FIGURE 35: SECTION ACROSS SITE 3 SHOWING
SELECTED HYDROGEOLOGICAL DATA



CONDUCTIVITY (mS/m)	72	79.1	84.5	86.0
TEMPERATURE (°C)	22	23.6	27	27.8
T. D. S. (mg/l)	465	514	550	560
pH	-	7.85	-	-

→ BLOW TEST (yield in liters/sec.)
 D.W.S. DEPTH WATER STRUCK
 * BLASTING DEPTH
 1 METRE
 VERTICAL EXAGGERATION = 8:1

2. E-M evidence, as well as surface tracing of the feature indicated that it may be related to a similar fracture on which the main municipal production boreholes were sited. A line of well-defined high amplitude anomaly peaks whose position generally corresponded to a linear occurrence of ganna bushes, was noted. Though the line of anomalies and the strike of the vein outcrop did not coincide, they both transected the northerly ground water flow of the area.

The initial exploration borehole was drilled on an E-M anomaly peak some 9 meters north of the vein feature. It revealed deep weathering (72 meters), the main water strike occurring in a two meter wide fracture zone with a considerable drusy quartz content between 55 and 57 meters. The final yield was 1.83 l/sec.

Three additional boreholes were drilled at this site in order to fully evaluate the feature. G34349 was ^{located} 1,75 meters north of the original borehole. It encountered no fracturing and had a lower yield of 0,43 l/sec. It was apparent that even over so short a distance as this, significant differences in fracturing state and yield could be expected across the feature. G34350 struck water in a well-weathered and fractured zone between 33-34,5 meters with a final yield of 1,72 l/sec.

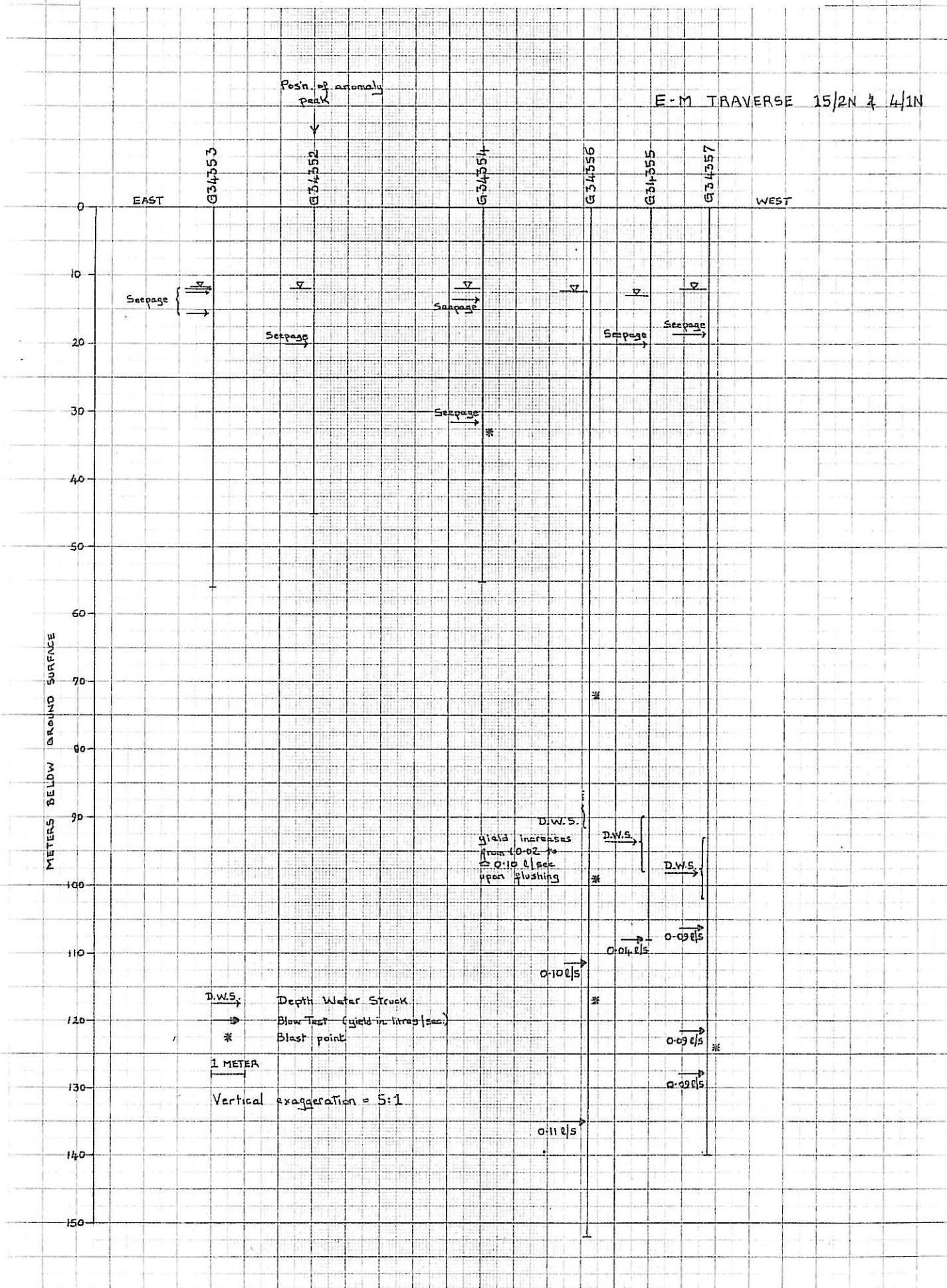
G34351, 1,75 meters to the south yielded only 0,21 l/sec. from a better-weathered zone within the gneiss.

The results obtained indicated the approach used and showed the need for additional E-M and investigatory work on other east-west structures in the vicinity.

SITE 4 (see fig. 36)

This site was specifically chosen to investigate the very long (4,5km) and prominent north-south lineament (labelled C in enclosure 2) because valuable information in the form of geophysical logs and approximate yields could be obtained from three existing boreholes at this site and used for correlation purposes.

FIGURE 36 : SECTION ACROSS SITE 4 SHOWING
SELECTED HYDROGEOLOGICAL DATA



Other factors influencing the decision to drill here were the presence of a line of prominent E-M anomalies, whose ⁵strike was indicated by ganna bushes. No outcrop was present however.

Initially three boreholes were drilled on and ^{on} either side of a selected E-M anomaly peak. No fracture development was found and only seepage water encountered. Alternating bands of weathered and fresh rock were penetrated in two of the boreholes, in contrast to the simple pattern at previous sites of weathered rock overlying fresh rock.

At the request of Mr. Vegter an additional borehole (later extended to 30) was drilled at this site revealing a similar fresh/weathered alternation. In G34355, a zone of highly-weathered material some 14 meters thick, mainly of a montmorillonite composition was encountered at 63 meters (see fig. 20). A similar weathered zone, but with a more intermittent montmorillonite occurrence was found in G34357 (fig. 22). Yields were low in these boreholes, with strikes of approximately 0,1 l/s. in the better weathered zones or at fresh and weathered contacts.

SITE 5

Three boreholes were drilled at this site. G 34342 was sited without geophysical assistance to investigate the occurrence of a marked calcrete development along joint planes, as revealed in a river bed exposure, to see if deeper-seated fracturing could be the ^{cause} ~~course~~ of the ready passage of high carbonate content waters to the surface.

G 34732 and G 34733 were sited at Mr Vegter's request on a single well-developed anomaly apparently related to the main north-south feature previously investigated at site 4.

Seepage water only was encountered in all the boreholes with depths of weathering of only 10 - 12 meters.

SITE 6

Boreholes G34734 and G34735 were drilled to investigate the extensive (3 km) north-west trending lineament marked D on enclosure 2. Extensive E-M work located a line of prominent anomalies proving the existence of a linear conductive zone related to the feature. The orientation of the lineament is transverse to the local ground-water flow direction and

it was thought the feature may be connected to the high-yielding municipal production borehole PT-1 on the basis of the geophysical evidence.

Drilling revealed weathered depths of only 14 meters. A well-weathered basic schist at shallow depths is believed to be the main ^{cause} ~~course~~ of the conductive zone. Only seepage water was struck in both boreholes.

SITE 7

This site afforded certain similarities to the previously successful site 3.

A prominent east-west linear feature of some length (marked E on enclosure 2), exhibiting a similar though less well-developed drusy quartz texture to that at site 3, had an apparently related converging line of well-developed E-M anomalies (coincident with a marked ganna bush presence and associated soft well-burrowed ground).

The fiaw-filled fracture and the line of anomalies cross near this site, but as the E-M anomaly at the point of intersection was not well defined, drilling was conducted on a better developed anomaly nearby, some 10 meters south of the fracture vein outcrop.

Three boreholes were drilled at this site across the selected anomaly peak. Consistent weathering was found to a depth of some 35 meters in G34736 and G34738, after which alternating weathered and fresh zones occurred, becoming increasingly fresher with depth. G34737 shows the same pattern, but at shallower depths (fig. 28)

The maximum yields obtained were 0,48 and 0,28ℓ/s from better weathered zones, showing minor fracturing only.

SITE 8

Lineament F (see enclosure 2) - at this site is another generally east-west trending feature cutting across the local groundwater flow direction. Though possibly related to the PT-3 fracture feature on the basis of the limited surface outcrop information available, it does not generate anomalous responses on all of the E-M traverse lines that cross it.

The vein-fill material in the vicinity is crystalline quartz and a related line of ganna bushes as well as prominent calcrete exposures are also present.

Only one exploratory borehole G34739, was drilled, sited directly on the position of the anomaly peak. The gneiss was consistently weathered to 23 meters, thereafter the rock was mainly fresh, but with occasional thin weathered horizons in ~~are~~^{one} of which a strike of 0,11 l/s was made. The comparatively low yield discouraged further investigation at this site.

SITE 9

This site was drilled on limited geological information in an attempt to intercept an east-west crystalline quartz and calcite-filled vein. No E-M anomalies were detected in connection with this vein.

The G34740, though dry, penetrated a thin but promising quartz layer, displaying a prominent drusy texture. A second borehole, G34741, was sited on all the available information to intercept this layer at depth, but without success, as the quartz vein was not encountered and this borehole was also dry. The depth of weathered material was very low (7m).

SITE 10 (see enclosure 1 for position)

This site was drilled on the basis of a line of E-M anomalies associated with a north-south trending amorphous quartz-filled vein.

Two boreholes were drilled. G34813, on a broad anomaly 6 meters west of the quartz vein, was dry. G34814 was located on an anomaly directly over the vein and penetrated it for 13 meters, but only yielded seepage water.

5. DEVELOPMENT BY EXPLOSIVE FRACTURING

5.1 Objective

~~Downhole~~
~~Downhole~~ blasting was carried out in five boreholes at two separate sites (3 and 4) during this investigation with the twin objectives of :

- (i) Determining the effect of the blasting on fractured, weathered and fresh rock, thereby assessing the effectiveness of the technique adopted and the type and amounts of explosive used.
- (ii) Attempting to improve the yields of the two strongest boreholes where the main water strikes were in fractured and weathered zones.

The ~~axis~~^{aims} were thus both experimental and practical.

5.2 The technique (see details in appendix by B.L. Venter)

Pentolite explosive was used in the blasting process because of its favourable properties namely : waterproof, stable under pressure (i.e. when submerged under water), and being a 'fast' explosive.

Individual units of pentolite have a short cylindrical appearance (see plate 5) and some 32 to 33 of these units were connected by cordtex and packed into a cylindrical plastic container (plates 6 and 7) to give a total of approximately 5 kg of explosive charge.

The cylinder containing the explosive was lowered to the required depth (plate 8) and subsequently detonated (plates 9, 10 and 11).

5.3 Results

The individual boreholes and depths at which blasting was conducted are shown in Table 2.

TABLE 2 : BLASTING DETAILS - A SUMMARY

Explorationb/h	G34348	G34350	G34357	G34356	G34354
Drilling site no.	3	3	4	4	4
Total depth (m)	87	80.75	140	152	55
Depth of casing (m)	9.7	6.1	111.8	4.1	1.75
Blasting depths (m)	55 62 72	62 69	124	72 99 117	30
Primary objective	increase yield, experimental				
Yields before blasting (ℓ/s)	1.83	1.72	0.09	0.11	0.03
Measurement method	pumped volume	blown V-notch	blown volume	blown volume	Estim.
Yields after blasting (ℓ/s)	2.9	3.16	0.05	0.10	0.03
Measurement method	pump	pumped	blown	blown	Estim
Percentage change in yield	+58	+84	-44	same	same
Yield after Galgon treatment (ℓ/s)	-	2.53	-	-	-

	G34348	G34350	G34357	G34356	G34354
Percentage change in yield	-	-20	-	-	-

It is apparent that in the originally fractured formations at site 3, where the purpose of the blasting was to increase the yield, this objective was achieved.

Additional borehole development work was conducted at G34350, the strongest of the two boreholes after blasting to see if the yield could be further increased. A solution of Calgon (sodium hexametaphosphate) of 2% by weight concentration was added to the borehole and vigorously surged for several hours. The resultant yield was found to be some 20% less than before.

An attempted blow test of G34348 after blasting and clearing of the boreholes revealed that a significant interconnection had been established between G34348 and G34350, 1.75 meters apart, in that compressed air forced down G34348 resulted in a water stream being ejected from G34350 (see plates 12 and 15). Prior to blasting, a similar blow test on G34350 did not cause this effect. The depth of the interconnection is at approximately 34.5 meters, because when both G34348 and G34350 are pumped separately, the water level in the non-pumping borehole lowers rapidly to 34.5 meters and then no further drawdown is observed. It is likely that the interconnection at 34.5 m is the only one of any significance in terms of transmitting water to the neighbouring borehole in view of this observation.

It is not clear whether the interconnection was as a direct result of the blasting exercise, or simply through a continuous process of caving (known to be substantial at this depth). The nearest blast point was some 22 meters deeper in the neighbouring borehole.

A caliper logging exercise in conjunction with other downhole logs was conducted in all of the relevant boreholes before blasting operations, but at the time of writing a later 'post-blast' set of logs are not available for comparison and discussion of the effect of the blasting process on the borehole geometry. (see report of B.L. Venter - in preparation).

With regard to the site 4 experimental boreholes, the blasting had little or no effect on the existing yields of G34356 and G34354 (see table 2) while a decrease in yield of 44% was recorded in G34357.



PLATE 5: Individual charge of Pentolite explosive



PLATE 6: Approximately 5 kg of Pentolite explosive, with cortex connection, ready for packing



PLATE 7: Packing of explosive into container



PLATE 8: Lowering the charge to the required depth in G34348, Site 3



PLATE 9: Detonation at a depth of 124 m in G34357, Site 4



PLATE 10: Detonation at approximately
30 m in G34354, Site 4



PLATE 11: Detonation in G34350 at Site 3

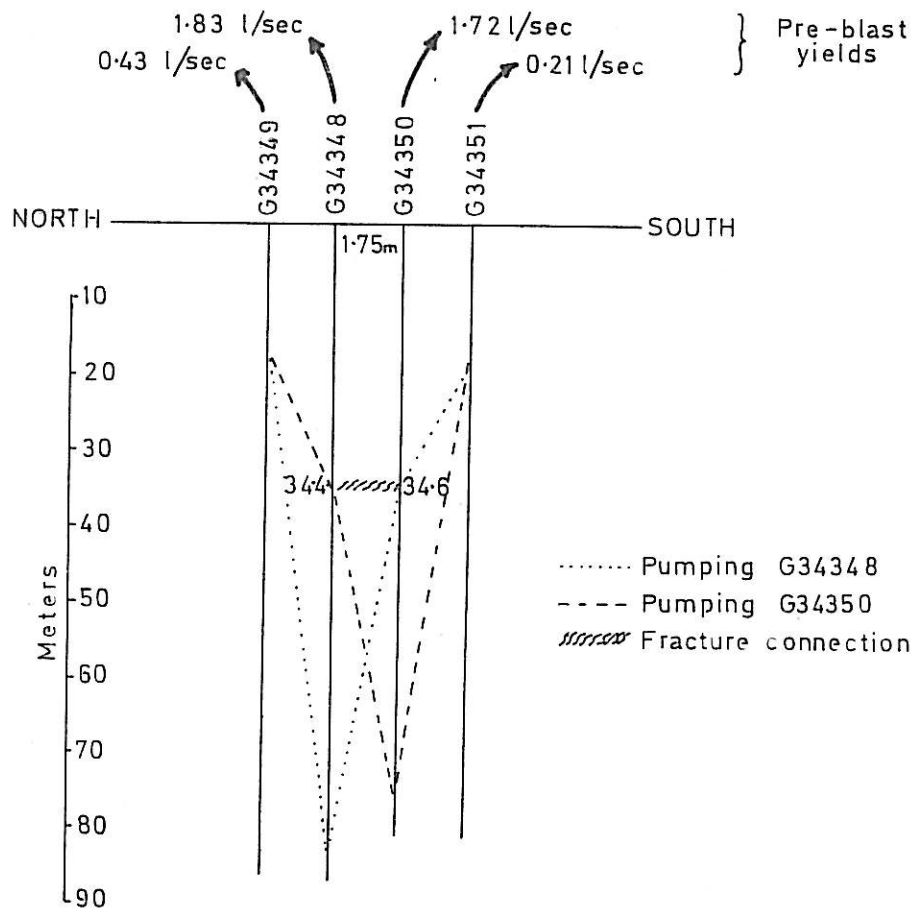


PLATE 12: Significant interconnection between two neighbouring boreholes at site 3 after blasting, as evidenced by this attempted 'blow test'



PLATE 13: Water ejected from G34350 (Left) while 'blowing' G34348. Boreholes are 1,75 m apart

FIGURE 3 : WATER LEVELS AT SITE 3
 DURING POST-BLAST PUMPING OF
 G34348 & G34350



This latter result may be explained by a suspected fracture in the casing at depth, allowing part of the 'blown' yield to escape outside of the casing.

No significant changes in water quality were noted in comparisons of pre and post blast pumped water samples.

6. HYDROGEOLOGY

6.1 Borehole yields in relation to geology and structure

A total of ten farms as well as the townlands themselves were included in the preliminary borehole survey. The quantity and reliability of the information obtained was variable and should be viewed with caution (refer to table A1). In general, the borehole distribution throughout the area is very scattered, but with notable concentrations at Pofadder town and on part of Konkoonsies (refer to Enclosure 1).

TABLE 3 - AVERAGE BOREHOLE YIELDS AND DEPTHS FOR SELECTED BOREHOLES
IN THE MAIN STRATIGRAPHIC UNITS *

STRATIGRAPHIC UNIT	NO OF B/HS	AVERAGE YIELD (l/s)	AVERAGE DEPTH (M)
Grey gneiss	11	0,59	57
Porphyroblastic granite gneiss, Comprised of	5	1,79	48
	2	4,3 -b/h's intercepting fractures	
	3	0,08	
Quartzite	1	0,76	63

* Only boreholes located within the geological area shown on Enclosure 1 and whose depths and reported yields are known, are included in this table.

Table 3, despite the smallness of the data sample, emphasises the generally low primary porosity and permeability of the igneiss and metamorphic lithologies in the area and highlights the need to intercept a favourable structure in order to obtain signifcant yields.

Boreholes not located on favourable structures are of universally low yield irrespective of the specific stratigraphic unit in question.

6.2 Porosity and permeability

The most successful exploration boreholes in terms of the yields obtained intercepted secondary 'fracture' aquifers. The quantity of water obtained from individual boreholes was directly related to the degree of fracturing and associated weathering, the porosity of the subsequent vein-fill material, the degree of infilling of the fracture by this material (affecting the permeability), as well as additional factors such as the length and orientation of the fracture feature.

Poor yields were obtained from north-south trending fractures because of the minimal fracturing encountered (if any), the extremely low porosity, of the amorphous^{ous} quartz vein material and its total infilling of the fracture zone.

More successful results were obtained on the east-west trending fractures west of the town. This can be attributed to the more porous nature of the infill material (mainly drusy quartz and differentially weathered calcite), the only partially infilled nature of the fractures as shown by the commonly occurring open space between the drusy quartz-lined walls, and the orientation of the fractures approximately at right-angles to the ground-water flow direction. thus collecting water from a larger area.

The extremely low porosity and permeability of the gneisses themselves is illustrated in fig. 3 where the water level in G34348 is some 40 meters higher than that in the pumped borehole G34350 though only 1,75 meters apart. This is a minimal drawdown in relation to the distance and pumping rates involved and demonstrates the importance of fissure flow through fractures as the main means of water transmission. Indeed, the yields of the boreholes at site 3 (fig. 3) varied in direct relation to the degree of fracturing intercepted.

6.3 Water strikes - depth, yields, and nature of the lithology

The highest yields were obtained from strikes in moderately to highly fractured zones extending over at least a depth of two meters.

Narrower, less well-developed zones also yielded small quantities of water however.

Water strikes within the primary (near-surface) weathered zone or subsequent weathered layers of a moderately to highly decomposed nature of low yield only were found.

The depths of water strikes are variable (see table 1)

Small strikes (see page amounts only) were usually made within the first 15 meters, while strikes in excess of 0,4ℓ/s were found at depths between 30 and 65 meters. The depth to groundwater is generally between 11 and 13 meters.

6.4 Piezometry

The piezometric surface shown in Enclosure 3 reflects the topography in a general manner, in that it slopes to the north and west. The position of the ground-water divides do not correspond with the topographic divide over most of the area however. The low number of control points used in the construction of the map, especially in key areas such as near the northern townlands ridge, limits the reliability of the map in certain respects.

With this in mind, the piezometric surface illustrated shows a general south to north direction of ground-water flow in the townlands area. The hydraulic gradient increases away from the main recharge area in the south with a gradient of approximately 1:60 near Diep en Deur. It is likely that both the direction and rate of ground-water movement will be affected by local structural controls, such as the fracture features previously discussed.

6.5 Pump tests

Short duration, limited objective pumping tests were conducted at three sites, namely: site 3, ^{to} ~~the~~ assess the effectiveness of the blasting and surging exercises in increasing the yields; SAM- 15, to obtain a reliable maximum yield figure from a reported 'strong' borehole, PT-1 to compare the specific capacity of 1982 with that of 1964, to see if there has been a decrease.

The results of the short pump tests at site 3 have been previously discussed in section 5.3. SAM 15 will be discussed in the following section (6.6).

Comparison of specific capacity data at PT-1 for 1982 and 1964 are shown in Table 4.

TABLE 4 = SPECIFIC CAPACITY OF PT-1 : A COMPARISON OF THE BEST DATA OF NIEUWOUDT (30/6/64) and Jackson (28/7/82)

TEST	TIME SINCE PUMPING STARTED (HRS)	R.W.L. METERS BELOW DATUM	DRAWDOWN IN METERS (SW)	DISCHARGE Q M ³ IN /HR (Q)	Q SW (M ³ /H\$/M)	% DECREASE BETWEEN TESTS
Nieuwoudt	1	12.10	0,93	23,64	25.42	2.7
Jackson		20.75	0,93	23,08	24,74	
Nieuwoudt	2	12.30	1,13	23,64	20,92	25,7
Jackson		21,28	1,47	22,79	15,54	
Nieuwoudt	3	12,44	1,26	23,64	18,76	35,3
Jackson		21,68	1,87	22,66	12,14	
Initial R.W.L.'S		Jackson 19,82 m Nieuwoudt 11,17 m				

It is assumed that the pump intakes were set at the same depth (no information on intake depth in Nieuwoudt's report).

From Table 4 it is clear that the current specific capacity of PT-1 for the specified pumping periods shown, is lower than in 1964 and decreases in relation to be pumping period.

Towards the end of this pumping exercise the water levels were measured at the nearby boreholes, as well as PT-3 with the following results :-

B/H	TIME SINCE START OF PUMPING (MINS)	DISTANCE FROM PUMPED B/H (M)	DRAWDOWN (METERS)
PT-1	160	0	1,72
PT -2 (A) OPEN	166	48	1,27
PT -2	169	48	1,08
PT -3	182	473	0,005

The greatest response to pumping in PT-1 is shown by PT-2(a). A good hydraulic connection along the fracture structure is inferred from the high drawdowns of PT-2 and PT-2(a) relative to the pumped borehole drawdown, despite being 48 meters distant. The small and equivocal drawdown at PT-3 is not conclusive.

6.6 SAMOEP

The farm Samoep, immediately south of the Pofadder Townlands has 21 boreholes, 15 of which were drilled by the O'Kiep Copper Company (OCC) for mineral exploration purposes (see GHP envelope no 654 for log copies).

On the basis of the farmer's information, it would appear that many of these boreholes are 'strong yielding' (3 l/s), but no exact values are available. The OCC geological logs only specifically mention water strikes for 3 of the 15 boreholes drilled, as follows :-

SAM -2	TOTAL DEPTH - 145 M Depth water struck - not recorded, Yield = not recorded, but borehole stopped because of 'excess water'. Lithology at water strike : (depending on depth struck) gneiss, quartzite or schist
SAM -10	TOTAL DEPTH - 35 m Depth water struck = 27 m Yield = 3,8 l/s (drillers estimate) Lithology at water strike : pegmatite
SAM -15	TOTAL DEPTH - 122 M Depth water struck = 24,4 m Yield = 2.3 l/s (drillers estimate) 3.8 l/s pump test max. yield. Lithology at water strike : weathered talc schist.

It is not clear if no water was struck in the other 12 OCC boreholes, or just not recorded on the log sheets.

SAM - 20 (a hand dug well situated at the farmhouse) is a pre-existing strong borehole whose yield is estimated by the farmer to be approximately 19 l/s. (It is equipped with a 19 l/s turbine pump).

The four reportedly strong yielding boreholes mentioned above occur along a broadly defined south-west / north-easterly trending line. In order to assess the accuracy of the estimated yields of the OCC geological logs, it was decided to conduct a max. yield only pump test on SAM -15. the only open strong borehole available, the others being installed with pumping equipment. The max. yield was found to be 3,8ℓ/s (65% more than the original drillers estimate).

Beacause of pump problems, the times and durations of pumping were variable, but the neighboring boreholes SAM -14 & SAM - 8 (50 meters to the north and south of SAM -15 respectively) did respond to the pumping with drawdowns of 0,16m (SAM-14) and 0.10 m (SAM 8) after approximately 1 hour.

The ground-water flow direction at Samoep is towards the north-west (approximately at rt. angles to the strike direction of the high yielding zone).

The water quality is good overall with only 4 boreholes of patently poor quality (see table 5) The total dissolved solids content varies from 1180 mg/ℓ (SAM-15) to 3275 mg/ℓ (SAM -20), though generally between 1500-1600 mg/ℓ.

In conclusion it may be said that strong yielding boreholes are known to exist on the farm (SAM -15 and SAM -20) and yet others may be inferred to exist (SAM 2 and SAM -10) but the reason for their occurrence is not known, though possibly of a structural origin as the farm is situated on a broad synform related to F3 deformation of the Namaqua Event.

7. HYDROCHEMISTRY

7.1 Water quality - general

Table A.5 (see appendix) shows that a great number of sampled boreholes have one or more chemical constituents exceeding the recommended maximum levels for drinking water as defined by Kempster et al. Table 5 summarizes the more important cases where three or more of the analyzed constituents exceed this level.

TABLE 5 - BOREHOLE SAMPLES WITH THREE OR MORE CHEMICAL CONSTITUENTS EXCEEDING THE MAX. RECOMMENDED LEVELS FOR DRILLING WHEN SUPPLIED
~~DRILLING WHEN SUPPLIED~~
 Drinking water

B/H	Ca	Mg	Na	SO ₄	CE	Nd ₃ as N	F	Sample source Service	Water use
Max Rec concs. (mg/l)	200	150	270	250	250	10	4	-	-
E-3			308	509	378		4,0	P - 10	STOCK
Ka-1			517	438	821		3,1	P - 10	STOCK
NN-4			279		374		3,5	P - 10	STOCK
Non-3	284		371	772	780		3,0	P - 10	STOCK
Non-4	227		492	545	779		3,6	P - ?	STOCK
Non-6	366		1447	1161	2193		4,1	DAM	STOCK, DOM(?)
PE-1	343		394	479	969	52	3,1	P - ?	IRRIG
PE-8	324	160	727	640	1238	29	8,9	P - 5	IRRIG
PE-14				298	348	27	3,7	P - 20	STOCK, DOMESTIC
PE-15			282		394	13	4,1	P - ?	STOCK
PT-9	309		488	496	1120		3,0	P - 50	IRRIG
PT-17	431		627	756	1218	41	2,9	P - ?	IRRIG
PT-19	856	221		487	1820	14	1,8	P - 5	IRRIG
PT-21	624	188	663	1043	1580	54	4,0	P - ?	IRRIG
PT-27				281	418	26	2,3	P - 10	IRRIG
PT-29	234		421	460	820	24	3,1	STORAGE TANK	IRRIG, DOMESTIC
G.43			773	345	1251		4,2	P - 15	NONE
G.44			731	431	1289		2,4	S - 30	NONE
G.45			546	297	918	55	4,3	S - 16	NONE
G.46			514	285	804	74	4,1	S - 30	NONE
SAM-11					459	13	2,8	P - ?	DRINK
SAM-17			351	358	723		2,6	P - ?	STOCK
SAM-19				372	450		2,5	P - ?	IRRIG
SAM-20	330		594	741	1075	13	3,0	P - ?	IRRIG

ALL CHEMICAL CONCENTRATION FIGURES ARE IN MG/L

Data taken from Appendix table A.5

* Recommended levels derived from Louw and van Wyk (see bibliography)

'sample source' abbreviation used :-

P = Pumped sample (figs. refer to duration in minutes)

? = Pumped for an indeterminate period

S = Static depth sample (number indicates the depth at which sampled - in meters)

Extremely high levels of chloride, (Cl^-), nitrate (~~NO₂~~^{NO₃} as N) and sulphate (SO_4^{--}) are present in certain of the towns boreholes, as well as PE-1 and PE-8, indicating the presence of a zone of poor quality water in the north-eastern area of the town. None of these boreholes are used for drinking water purposes however. The localized nature of the high nitrate concentrations is suggestive of a local source of contamination such as seepage from domestic sewage units, rather than an inorganic or vegetative source.

Only two of the boreholes listed in Table 5 are used for drinking water purposes, SAM-11 and PE-14. PE-14 has a moderately high nitrate content and slightly high sulphate and chloride concentrations, while SAM-11 (one of two boreholes supplying the farm Samoep) has moderately high chloride and slightly high nitrate levels.

Both the main municipal production boreholes (PT-1 and PT-3) as well as the most successful of the exploration sites (site 3) yield water of good chemical quality (see next section for discussion of fluoride content) and low total dissolved solids. Only exploration sites 1 (high Na^+ , Cl^- , SO_4^{--}) and 2 (high Na^+ , Cl^- , NO_3^- , SO_4^{--}) had water of adverse quality.

7.2 Fluoride content of the water

The question of the high fluoride concentrations of the ground water in the Pofadder area, noted by Nieuwoudt, warrants specific consideration.

Considerable controversy has arisen over the determination of a safe limit for the fluoride content for a drinking water supply and a substantial literature has been generated. The whole question is reviewed by Louw and van Wyk who, using the criteria of a level of 'dental fluorosis that is functionally and aesthetically acceptable' gave 4 ppm (approx. equivalent to 4 mg/l) of fluoride as a safe cut-off point.

They stress however the importance of several factors other than the actual fluoride concentration in the incidence of dental fluorosis including : climate and duration of exposure (both essentially referring to the amount of water consumption), the presence of high water hardness (which is thought to have a protective influence with respect to the absorption of fluoride) as well as nutritional factors.

The Pofadder drinking water supply has a total hardness of 160 mg/l (as CaCO₃) and can be classified as hard (after Sawyer and Masartey).

Concentrations of fluoride in the Pofadder area range from 1,83 mg/l (PT-18) to 8,9 mg/l (PE-8), but intermediate values occur at boreholes of known or potential use as a drinking water supply, as shown in Table 6 below.

TABLE 6 : FLUORIDE CONTENT OF KNOWN AND POTENTIAL DRINKING WATER SOURCES IN THE POFADDER AREA

KNOWN		POSSIBLE		POTENTIAL	
B/H	(F) MG/l	B/H	(F-) MG/l	B/H	(F-) MG/l
PT-1	3,12	PE-2	2,49	G34348	3,72
PT-3	2,90	PE-7	3,72	G34350	3,71
Municipal					
tap supply	3,20	PE-14	3,73	SAM-15	3,19
SAM-10	2,78	NOV-1	2,32		
SAM-11	2,81				
KA-4	3,53				

If one accepts the 'safe limit' of 4 mg/l of Louw and van Wyk, then it is apparent that all the samples listed in Table 6 fall within this limit.

No causes for the high fluoride levels are suggested, except to note that fluoride is frequently found in igneous and metamorphic rocks as a component of amphiboles and micas, replacing part of the OH-groups in the mineral structure.

7.3 Total dissolved solids (TDS)

The areal distribution of the total dissolved solids (TDS) content of sampled waters is shown in enclosure 4. The iso - TDS contours illustrated are somewhat problematical because of the low control point density on which the map is based, but show the occurrence of 'fresh water' (i.e. < 1000 mg/l) in the mid-portion of the townlands and over much of the area to the east and north-east of it.

FIG 4: PIPER WATER ANALYSIS DIAGRAM
for the
PORPHYROBLASTIC GRANITE GNEISS

1	E-3	●10	17	PT-27	●10
2	E-4	●?	18	-28	R
3	E-6	●13	19	-29	R
4	PE-1	●?	20	G-48 (i)	●?
5	PT-1 (i)	●?	21	(ii)	●?
6	(ii)	●?	22	(iii)	B
7	(iii)	●150	23	(iv)	●315
8	-3(i)	●?	24	G-49 (i)	●?
9	(ii)	●1440	25	(ii)	B
10	15	●?	26	G-50 (i)	B
11	16	●?	27	(ii)	●60
12	17	●?	28	G-735	\$
13	18	●?	29	G-736	B
14	19	●5	30	G-737	B
15	21	●?	31	G-739	\$
16	26	R			

●7 Pumped sample (duration in min)
B Air blown sample
R Reservoir/storage tank sample
S Static depth sample

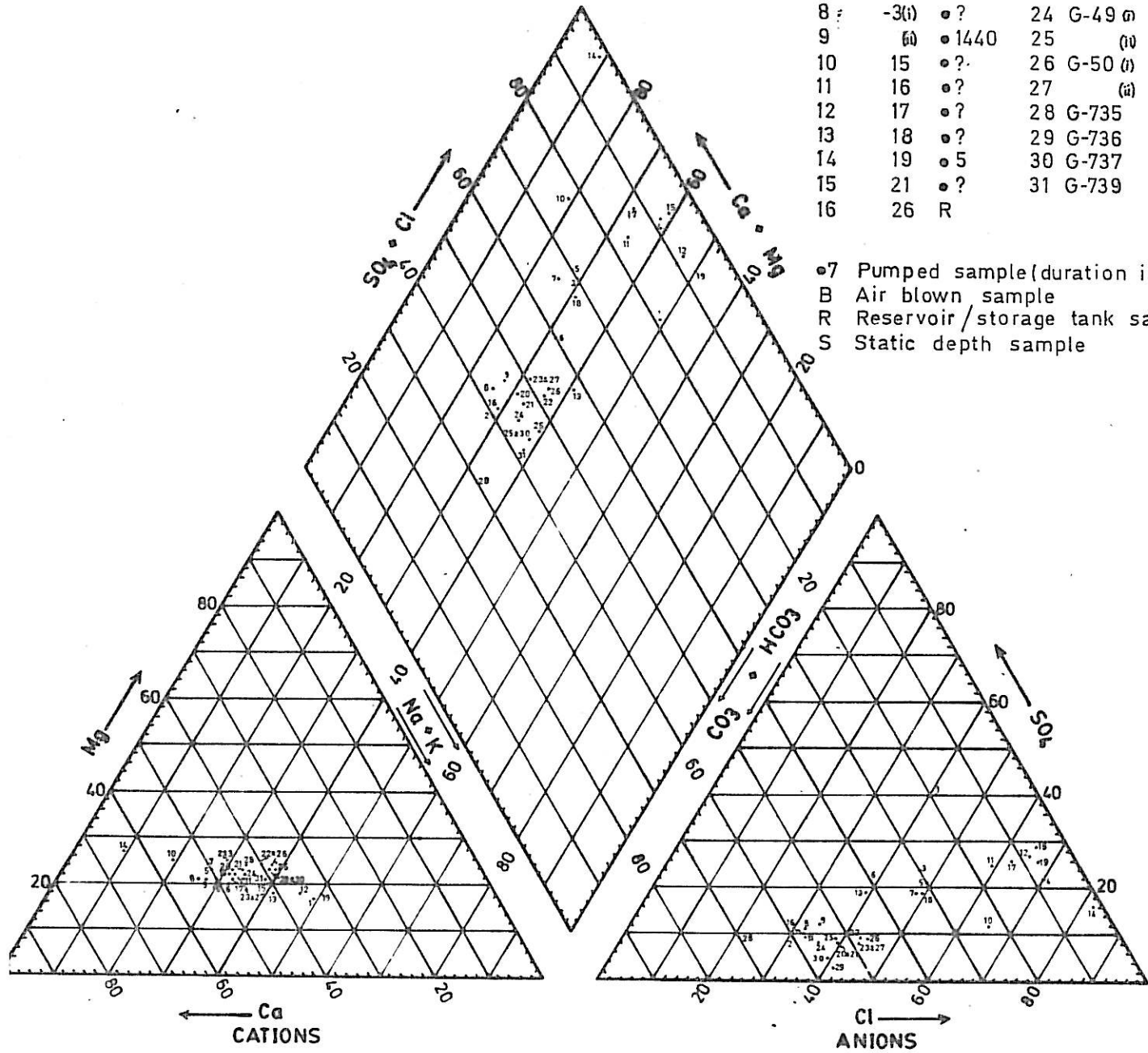


FIG: 5 PIPER WATER ANALYSIS DIAGRAM
for the
GREY GNEISS

DIAGRAM B

1	E-5	●10	12	PT-15	●?
2	Ka-1	●10	13	G-42(i)	⌘
3	PE-6	●15	14	G-42(ii)	⌘
4	PE-7	●?	15	G-43(i)	⌘
5	PE-8	●5	16	G-43(ii)	●15
6	PE-9	●10	17	G-45	⌘
7	PE-14	●20	18	G-46	⌘
8	PE-17	●?	19	G-53	⌘
9	PT-9	●50	20	G-54	⌘
10	PT-10/11	●?	21	G-56	■
11	PT-13	⌘	22	G-732	⌘

● 8 Pumped sample (duration in mins.)
 ■ Air blown sample
 ⌘ Static depth sample

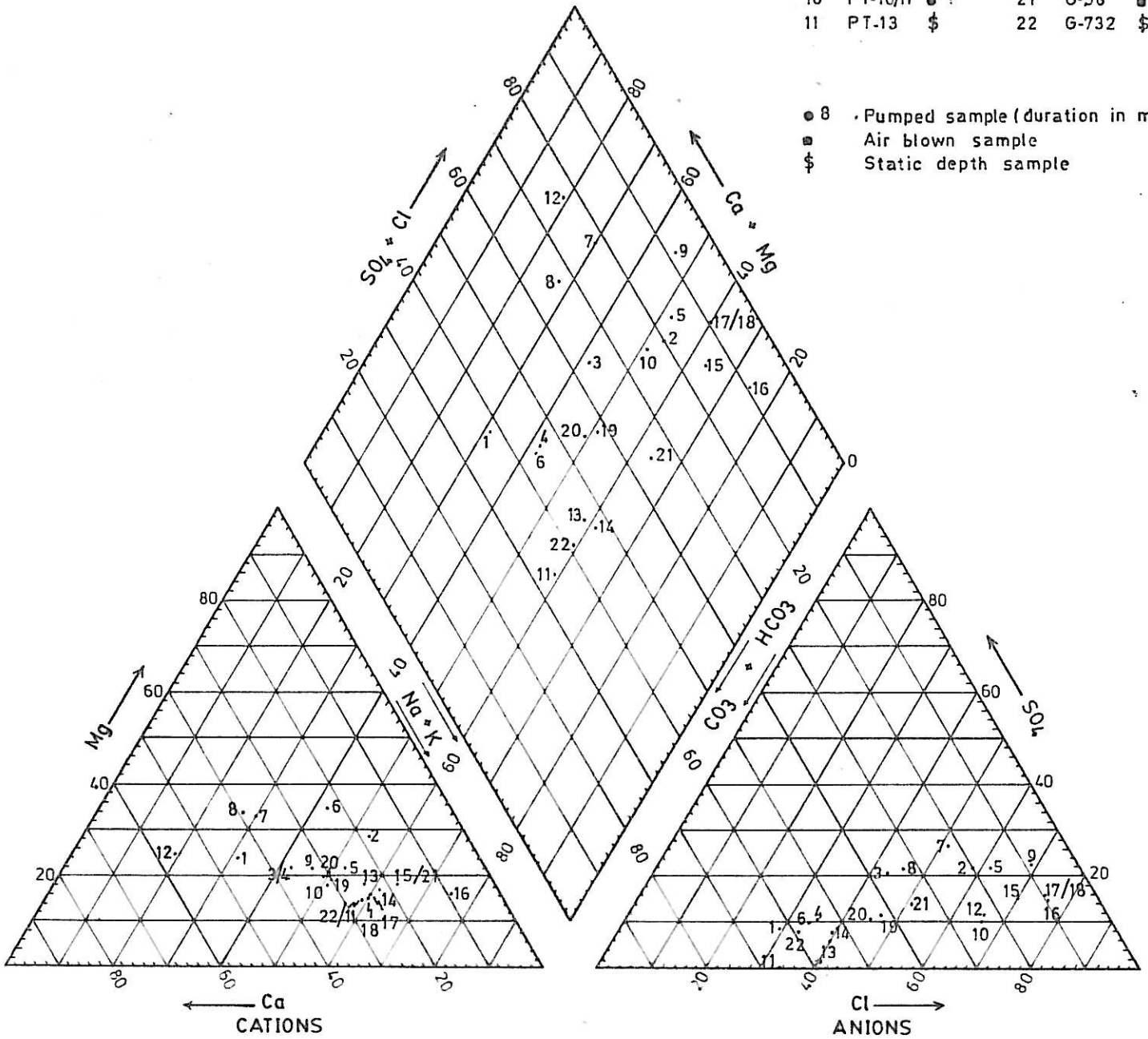


FIG: 6 PIPER WATER ANALYSIS DIAGRAM
for the
PINK GNEISS SILLIM BIOT SCHIST QUARTZITE & GRAVEL

Pink Gneiss [·]

Sillim./Biot. Schist [◦]

Quartzite [x]

Alluvial Gravel [◊]

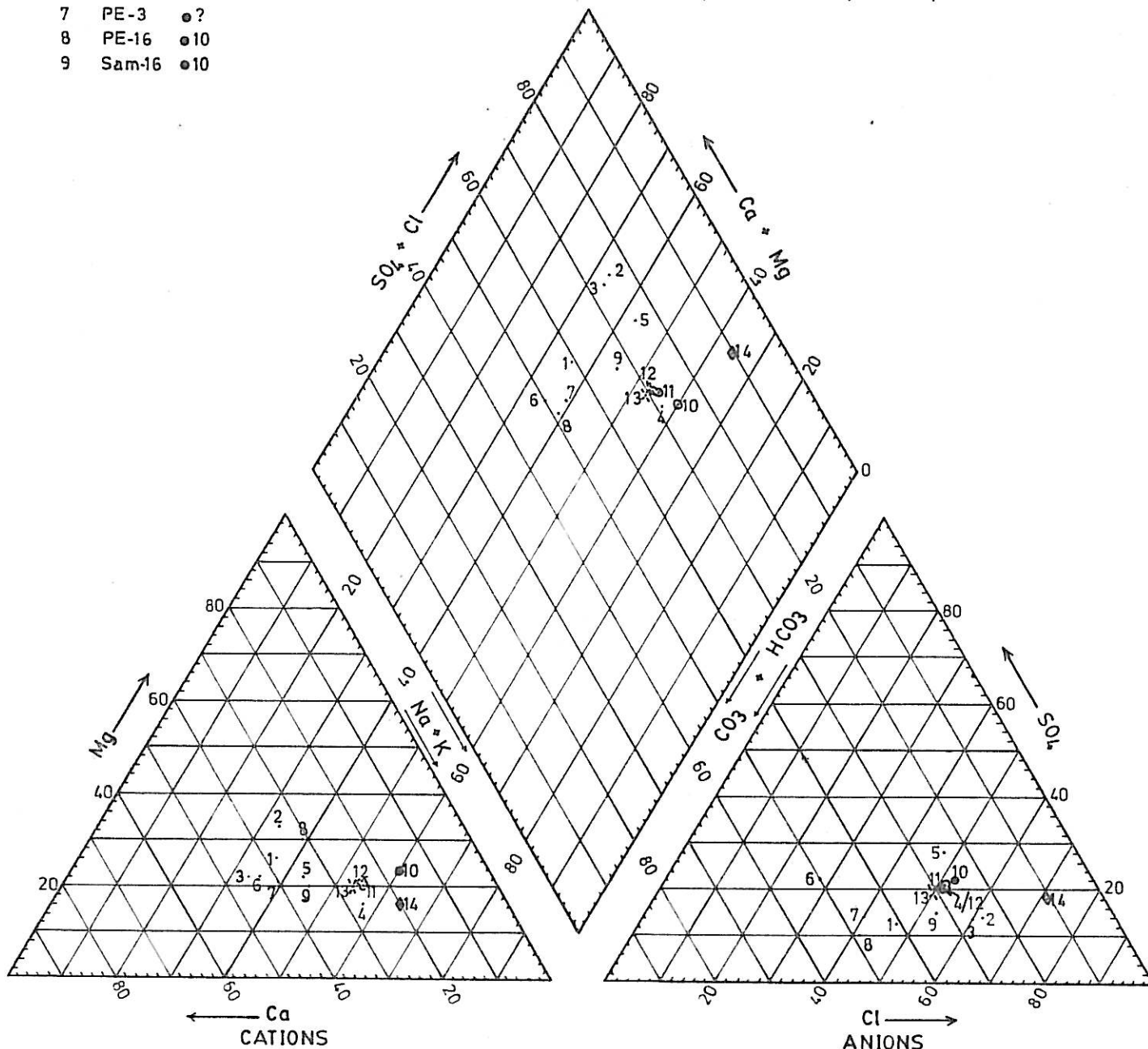
- 1 Ka-2 ●?
- 2 Ka-4 ●?
- 3 NN-1 ●?
- 4 NN-4 ●10
- 5 Nou-1 ●?
- 6 PE-2 ●?
- 7 PE-3 ●?
- 8 PE-16 ●10
- 9 Sam-16 ●10

- 10 Sam-8 \$
- 11 Sam-14 \$
- 12 Sam-15 ●90

- 13 NN-2 ●?

- 14 G-44 \$

●6 Pumped sample (duration in mins.)
\$ Static depth sample



A marked zone of high salinity water is present in the town area itself where values as high as 3 000 mg/l are common. The specific reason for this localized effect within a broad area of good quality fresh water is not known, but possible causes may include : an increase in salinity through irrigation and evaporation effects, local mineralization, contamination of groundwater from domestic sewage sources.

In the north of the survey area the TDS values are seen to increase in the downstream direction of the major drainage system, attaining its maximum value of 8477 mg/l at a spring close to the Orange River.

On the farm Samoep and over much of the area to the south and east, the water is generally of a brackish quality of between 1000 - 2000 mg/l.

No direct relationships can be discerned between the ground-water flow directions (enclosure 3) and the TDS concentrations of enclosure 4, other than in the north of the study area as previously discussed.

7.4 The Piper tri-linear diagrams

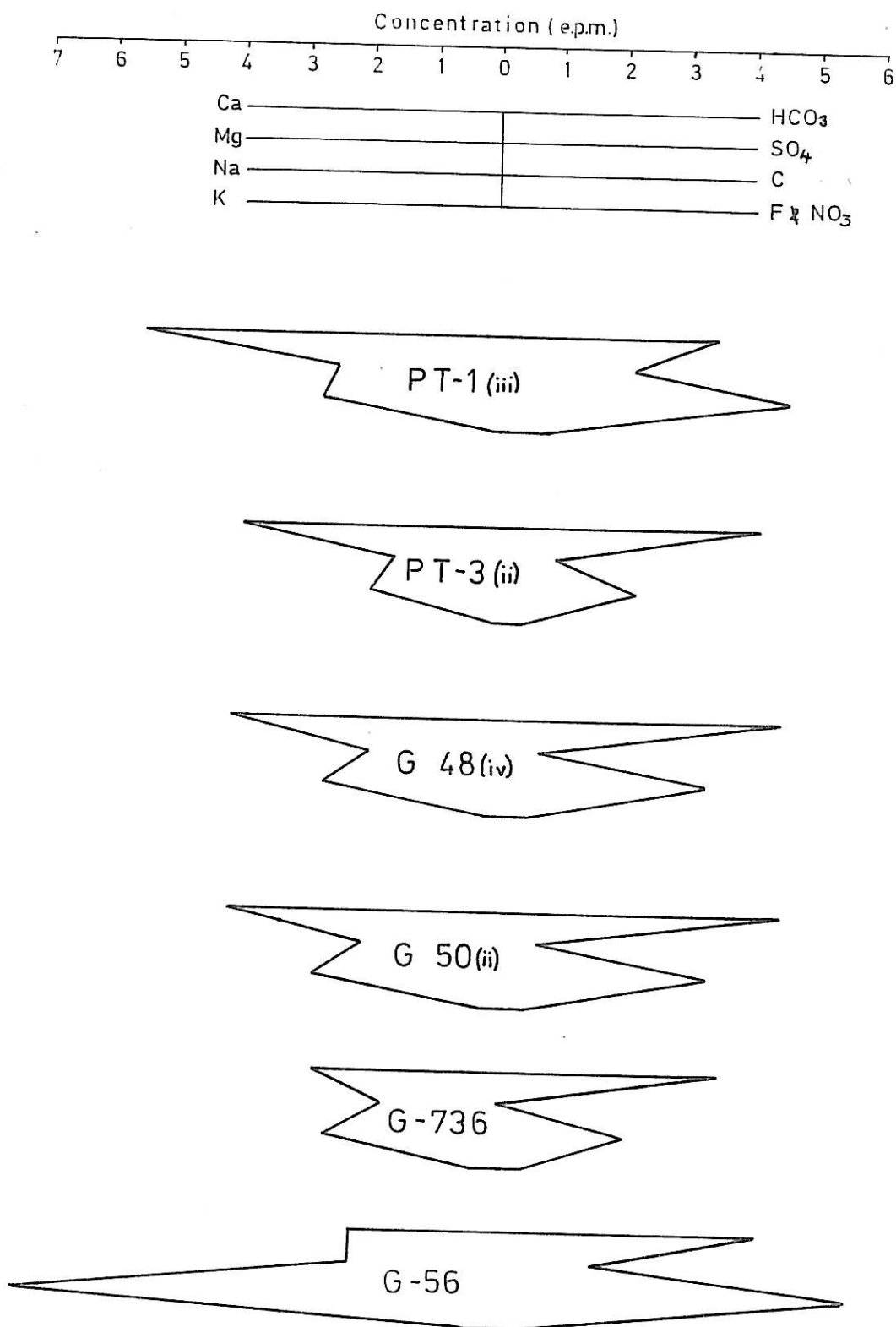
Figures 4, 5 and 6 show the relative concentrations of the major ionic components of the sampled waters expressed in the piper tri-linear format for each main stratigraphic unit.

Water sampled from the porphyroblastic granite gneiss (figure 4) generally have no dominant cation component, while the ^{an}ion components are more variable in concentration though of an overall bicarbonate to chloride character.

Most of the town water has chloride as the dominant anion, whilst the area west of the town (sites 3, 7, 8, PT-3) has bicarbonate as the main anionic concentrations.

Municipal production borehole PT-3 appears on the basis of the relative concentrations of the tri-linear plot to have greater similarities with waters of sites 3, 7 and 8 rather than PT-1 which contains a higher proportion of chloride and sulphate. The absolute similarities is evident from the ^Stiff diagrams of figure 7 however, by the similarity of the resultant shapes. The plot of G34356 (site 4) is included for contrast purposes as an example of water with a different character. The hydrochemical similarities give added weight to the geophysical evidence for a connection between certain of the east-west structures.

FIGURE 7: STIFF DIAGRAMS OF SELECTED SAMPLES



Grey gneiss waters (figure 5) have a similar overall distribution to those of the granite gneiss, but with a marked increase in the sodium proportion, which is the dominant cation. Chloride, and to a lesser extent bicarbonate form the main anionic components.

A marked sodium chloride character is evident in samples 15 to 18 (sites 1 and 2) while the discrete grouping of the site 5 analysis (no's. 11, 13, 14, 22) indicates water of a sodium bicarbonate character.

The pink gneiss (figure 6) borders between a 'no dominant ion' (mixed) type and a sodium chloride type. Samples from the schist and the quartzite have a sodium chloride character as does water derived from the alluvial gravel in which the Na Cl character is very well defined.

In none of the samples analyzed is sulphate a major anionic component.

Following the reasoning of Johnson it is apparent that there are no unequivocal 'recent recharge waters' present i.e. those of a clearly Ca/MgHCO₃ character. Johnson refers to waters plotting in the upper portion of the diamond field of the Piper diagrams (which is where most of the samples of this investigation plot) as 'static waters', presumably meaning waters with low flow ^evelocities such that they have a prolonged period of contact with the mineralogic framework and thus exhibit a tendency towards high chloride concentrations.

The higher sodium content of the grey gneiss samples compared with those of the porphyroblastic granite gneiss may be due to inherent mineralogical, differences between the two lithologies or to base exchange as the grey gneiss occurs 'downflow' of the granite gneiss with respect to the regional ground-water flow direction.

8. CONCLUSIONS

Several locations were investigated on each of the main structural features on the townlands namely; north-south fractures, east-west fractures and well-jointed beds. All of the sites were unsuccessful in terms of supplying the amount of additional ground-water required by the town to augment its existing supplies.

The investigation did succeed however in delineating the area and structure from which significant water strikes of good quality may be found, namely, the east-west fractures west of the town and in particular lineament B (see enclosure 2) which gave a maximum yield of 3.2ℓ/s at site 3.

The success at site 3 is a function of the continuity and length of lineament B, the degree of fracturing and associated weathering, the porosity of the vein material and the permeability of the fracture feature through incomplete subsequent mineralization. None of the other fracture features or jointed rock localities had such favourable characteristics.

The variation in the degree of fracturing and consequent yield across a fracture feature was clearly demonstrated at site 3 (see figure 3) and it might be expected that such variations would occur along the length of the feature also. Indeed, the variations in the magnitudes of electromagnetic anomalies measured along the strike of certain features (varying from discrete well-defined peaks to no anomaly at all) and discussed in section 3, suggests by inference similar lateral variations in fracturing, weathering, porosity and permeability. It is possible therefore that stronger yields may be obtained at other places along lineament B. The effectiveness of the structure as a fractured aquifer has been demonstrated, but at one place only. Further investigation of this feature may be worthwhile.

Insufficient reliable and accurate information is available concerning; the production status of the two main municipal boreholes PT-1 and PT-3 (ie. their maximum and sustained yields, the hydraulic parameters of the fracture feature upon which they are located and the geology at the sites (particularly the degree and depth of fracturing).

Comprehensive well and aquifer tests on these boreholes, with observation borehole construction where relevant, as well as a detailed borehole logging exercise would provide the necessary information, if difficulties pertaining to the need to maintain the continuity of the water supply to the towns storage reservoirs could be overcome. Using the information obtained, definite conclusions could be made regarding whether the boreholes are being overpumped or underpumped, together with the response of the aquifer to such pumping.

The results would help ascertain the validity of investigating other sites along lineament B.

The whole question of future action regarding fulfilling the towns water requirements hinges to a large extent on the performance and adequacy of the existing supply, concerning which little of a quantitative nature is known at present.

The validity of the E-M technique in the accurate siting of boreholes on the fracture features has been demonstrated, as has the effectiveness of downhole blasting as a development technique in fractured strata.

Both the municipal water and that at site 3 (lineament B) has been shown to be of good quality in terms of their inorganic chemical constituents.

With regard to the farm Samoep it has been established that a number of strong-yielding boreholes are present within a south-west / north-east trending zone, some 12 km south of Pofadder. It is not clear on the basis of the present information if sustainable yields of the quantities required by Pofadder are available on Samoep. A supplementary short investigation on the farm, concentrating initially on the strong yielding zone, would seem to clarify the exact quantities available and the reason(s) for the high yields on the farm.

The water quality over most of the farm is good, but the total dissolved solids content of 1100 - 1600 mg/l is at least twice that of the present Pofadder municipal supply, though still potable.

The district around Pofadder other than Samoep seem to offer little scope for development either, because of poor water quality (the Konkoonsies-Nongcaip valley) or low yields. Possible exceptions to this are the north-westerly trending faults east of the town which may warrant closer investigation.

RECOMMENDATIONS

On the basis of the information and conclusions derived from this investigation, the following recommendations are made :-

1. Consideration to be given to a short supplementary investigation concentrating on feature B between site 3 and the town boreholes (see enclosure 2) to see if higher yielding boreholes than these at site 3 (3,2ℓ/s) can be developed on this proven favourable structure.

2. With regard to the existing municipal production boreholes PT-1, PT-2 and PT-3;

- comprehensive well and aquifer tests to be conducted (step²-drawdown and constant discharge tests).

- detailed borehole logging carried out

- regular accurate water-level measurements to be taken and recorded in future using a water-level meter (not the installed air-line apparatus) to assist in performance and management evaluation in the future.

3. Samoep is considered as a potential source of supply, notwithstanding distance (12 km south of Pofadder) and water quality considerations (1100-1600 mg/ℓ), but a detailed geophysical survey, drilling and pump test programme should be undertaken, concentrating initially on the proven high yielding areas as shown by boreholes SAM2, SAM 10 (3,8ℓ/s), SAM 15 (3,8 ℓ/s) and SAM 20 (19ℓ/s).

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- explanation of sheets 2817 D (Violsdrif), 2818C and D (Goedhouse) and 1819 C (Onseepkans)

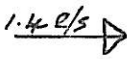
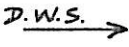
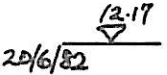
GLOSSARY OF ABBREVIATIONS USED IN THE GEOHYDROLOGICAL LOGS (FIGS. 8 - 34)

(a)	Amorphous
∧	and
Acc.	accessory
amm.	amount
assoc	associated
B	Biotite
bl.	blue
c.g.,c. grained	coarse grained
chlz	chloritized
col.	colourless
comp	component
D.d.	Dark
dec.	decrease
dis, disc	discrete
epiz	epidotized
eg.	for example
espec.	especially
F	Feldspar
f	fairly
fg	fine grained
f-mg	fine to medium grained
f.surf.,f.s.	fracture surface
gwo	general weathering only (disseminated)
HW	highly weathered
inc.	increase
maj.	majority
mat.	material
m-cg.	medium to coarse grained
mg	medium grained
mix	mixture
m-large	medium large
M.W.	moderately weathered
n.f.s.	no fracture surfaces
No.	number
not q.	not quite
occ	occasional
Opaq.	opaque
Or.	Orange
pl.	plane(s)
P. pink	Pale pink
Purp.	purple
Q.Qtz.,	quartz
sev.	several
sl.	slightly







sm.	small
substant	substantial
surf.	surface
sw.	slightly weathered
v.	very
v.c.	very coarse
v.l.	very large
v.s., v.s.m.	very small
V.S.W.	very slightly weathered
v.s.f.s.	very small fracture surfaces
wh.	white
xtal.	crystalline
yell.	yellow.

SYMBOLS USED IN THE GEOLOGICAL SYNOPSES (figs. 8 → 34)

HYDROLOGICAL:

-  "Blow test" value of yield (l/sec)
 Depth & degree of significance of water strike (eg, main, seepage)
 Rest water level (meters below datum) & date of measurement

WEATHERING STATE OF FORMATION:

- | | |
|---|-----------------------------------|
|  | Fresh (unweathered) rock |
|  | Very slightly weathered |
|  | Slightly weathered |
|  | Slightly to moderately weathered. |
|  | Moderately weathered |
|  | Moderately to highly weathered. |

GEOLOGICAL:





- | | |
|---|---|
|  | } Shadings and symbols used to emphasize lithological differences. |
|  | |
|  | Quartz |
|  | Fractures present - degree of fracturing implied by the no. & length of the symbols |
| * | Depth at which explosive was detonated. |
| q | Quartz veins present |

TABLE A.1 - POFADDER AREA BOREHOLE SURVEY DATA AUG/SEPT 1981

M - Denotes main water strike
 C - Coboop
 Nn - Namies North
 Hou - Houmoed
 Pt - Pofadder Townlands
 Ka - Kabas
 Ko - Konkoonsies
 G - Gembokvlakte
 PE - Pofadder East
 SAM - Samoep
 E - Etties
 Non - Nongcaip
 PP - Paul se puts

BOREHOLE NO	TOTAL DEPTH (M)	REPORTED YIELD (ℓ/s)	DEPTH WATER STRUCK (M)	WATER USE	B/H EQUIPMENT	TDS (MG/ℓ) FIELD
C-1	55	1.9	-	STOCK	WP	-
-2	33.5	-	-	"	P+ WP	3990
-3	61	0.25	-	DOM	WP	930
E-1	61	1.26	-	STOCK	"	1609
-2	76.2	0.03	-	"	"	-
-3	46	0.03	-	"	"	1776
-4	37	0.19	-	"	"	494
-5	37	0.32	-	"	"	450
G-1	106.7	1.14	92-106	DOM/IRRIG	P+WP	1823
-2	80	0.09	-	STOCK	WP	1896
-3	149.4	0.10	70	DOMIST	"	-
-4	128	0.28	123	DOMIST	P	-
Ka-1	-	1.3(?)	-	STOCK	WP	-
-2	-	0.32	-	"	"	-
-3	-	0.32	-	"	"	293
-4	-	-	-	DOMIST	"	618
-5	-	-	-	STOCK	"	-
Ko-1	43	1.52	31	"	"	-
-2	73	0.3	61	"	"	-
-3	76	0.35	27/65(m)	"	"	8650
-4	54	0.76	28/46	"	"	-
-5	52	0.88	49	"	"	-
-6	46	0.73	41	"	"	-
-7	33	0.19	-	"	"	SHAFT
-8	85	0.04	61	DOM	"	-
-9	131	0.57	116	DOMIST	"	-
NN-1	85.3	0.30	-	STOCK	"	1014
-2	-	-	-	"	"	1472
-3	-	-	-	"	"	1439
-4	-	-	-	"	"	1413
-5	-	-	-	"	"	1138
Non-1	76	-	-	DOMIST	P+WP	3559
-2	76	0.3	58	DOM	WP	1002

BOREHOLE NO	TOTAL DEPTH (M)	REPORTED YIELD (ℓ/s)	DEPTH WATER STRUCK (M)	WATER USE	B/H EQUIPMENT	TDS (MG/ℓ) FIELD
-3	107	0.23	90	STOCK	WP	2581
-4	134	0.09	52	DOMIST	WP	2366
-5	119	-	52	DOMIST	"	-
-6	53	0.3	-	STOCK	"	5256
Hou-1	Good	-	-	DOM	"	589
-2		-	-	STOCK	"	994
-3	Fair	-	-	"	"	746
PE-1	36	0.03	11/31	IRRIG	"	3444
-2	35	5.05	26	STOCK	P+WP	636
-3	61	2.78	43	"	P	762
-4	37	2.53	-	"	WP	1801
-5	61	0.10	49	"	"	569
-6	84	1.4	37	IRRIG	P	975
-7	31	0.77	7.3	DOM	WP	803
-8	27	1.14	18.3	IRRIG	WP	3142
-9	111	1.14	30	STOCK	"	702
-10	79	0.63	24	"	"	931
-11	91	0.03	67	"	"	504
-12	79	0.3	23	"	"	521
-13	106	1.45	28	DOM	"	1292
-14	-	0.13	-	"	"	1633
-15	34	0.78	7	STOCK	"	-
-16	40	1.89	28	"	"	531
-17	50.0	1.89	34.0	IRR/ST	"	-
-18	-	-	-	"	"	-
-19	50	1.89	34	STOCK	"	-
PP-1	91.4	0.38	57.9	"	"	647
-2	76	0.19	-	"	"	-
-3	91	0.25	58	DOM/ST	P+WP	939
-4	44.5	-	-	NONE	OPEN	993
PT-1	46	6.6	15.8/24	DOM	P(SUB)	836
-2	36.6	2.53(?)	(m)-27	DOM/ST	P(elec. Pist)	-
PT-3	77	2.0	15.8/ 58.0(M)	DOM	P(SUB)	872
-4	46	0.19	45.7	NONE	OPEN	-
-5	77	0.38	13.7	NONE	OPEN	946
-6	44	0.03	14.6	NONE	OPEN	739

BOREHOLE NO	TOTAL DEPTH (M)	REPORTED YIELD (ℓ/s)	DEPTH WATER STRUCK (M)	WATER USE	B/H EQUIPMENT	TDS (MG/ℓ) FIELD
-7	73	0.76	48.8	STOCK	WP	625
-8	-	0.76(?)	-	"	"	-
-9	-	-	-	IRRIG	"	3313
-10	-	-	-	STOCK	"	1346
-11	-	-	-	"	"	-
-12	-	-	-	NONE	OPEN	-
-13	33	-	-	NONE	OPEN	-
-30	-	-	-	NONE	HP	-
SAM-1	196.6	STRONG	-	NONE	OPEN	970
-2	144.8	STRONG	27	IRRIG	WP	1487
-3	164.6	-	-	NONE	OPEN	1377
-4	155.5	-	-	NONE	OPEN	DRY
-5	222.5	STRONG	-	NONE	OPEN	424
-6	237.7	-	-	-	-	-
-7	224	-	-	-	-	-
-8	184.4	STRONG	-	NONE	OPEN	980
-9	205.7	-	-	NONE	OPEN	1682
-10	35	73.8	27.4	DOM	WP	1488
-11	141.7	STRONG	-	DOM	WP	1495
-12	207.3	STRONG	-	NONE	OPEN	1411
-13	211	-	-	-	-	-
-14	213.4	STRONG	-	NONE	OPEN	1218
-15	121.9	3.79	24.4	NONE	OPEN	1240
-16	91.4	6.31	67	STOCK	WP	1114
-17	30.5	-	-	"	"	2322
-18	27.4	WEAK	-	"	"	922
-19	30.5	STRONG	-	ST/IRRIG	"	1614
-20	18.3	18.9	18.3	IRRIG	P+WP	3352
-21	36.6	-	-	NONE	OPEN	-

TABLE A.2

Meteorological Data

Source of data.

WEATHER BUREAU

DEPARTMENT OF TRANSPORT

PRETORIA

Station No. 247/688 POFADDER

Type of data. RAINFALL (mm) (average)

200.
from
mean
↓

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1956	21.0	4.3	58.0	1.5	4.0	3.0	3.0	0	0	0	0	65.0	159.8
1957	23.5	9.5	23.0	0	0	1.6	3.5	8.6	5.0	0.2	5.5	4.5	84.9
1958	22.0	3.0	0.7	18.1	4.3	1.0	0	0	0	2.3	0	24.2	75.6
1959	4.5	6.8	0	9.7	11.1	1.0	0	1.6	0	0.3	0	6.3	41.3
1960	0	25.8	30.1	1.9	2.8	0	0	1.8	0	0	3.5	32.6	98.5
1961	18.8	0.6	52.9	82.7	4.1	39.8	33.0	0.7	7.9	0.3	2.5	0	243.3
1962	0	38.9	1.1	0	0	2.5	4.3	16.8	0	0	10.5	0	73.9
1963	1.3	16.7	45.5	35.7	11.6	1.6	2.9	1.5	14.1	5.2	17.7	48.9	202.7
1964	0	25.0	27.4	0	0.6	7.4	0	0	27.4	12.2	0.5	0.2	100.7
1965	0.4	0	15.0	42.0	0	0	4.0	0.3	10.3	12.5	0.1	0.7	85.3
1966	5.3	6.6	5.7	6.5	0	0	0	0.1	4.4	8.8	0.1	0	37.5
1967	0.3	0.9	36.0	19.7	5.7	8.1	0	0.5	0	0.1	5.9	1.2	78.4
1968	0	0.1	34.8	0	69.9	0.3	0.7	0	1.1	10.9	17.0	0	134.8
1969	0	38.1	11.6	23.0	1.0	0.0	8.6	0	0	0	0	0	82.3
1970	-	-	-	-	-	-	-	-	-	-	-	-	-
1971	-	7.4	20.0	24.2	14.4	1.2	25.2	-	0	0	0	0	108.7
1972	63.0	0	7.0	3.5	0.6	12.0	1.2	1.0	4.5	1.0	3.0	0	96.8
1973	0	42.0	37.7	0.7	0.6	0.3	16.1	2.0	0.4	8.1	0	30.1	138.0
1974	44.9	146.2	29.7	25.4	0	9.6	0	9.6	0	0	9.1	2.9	277.4
1975	16.9	44.5	76.9	11.4	19.0	0	-	0	0	5.3	0	44.8	218.8
1976	76.8	-	-	17.4	-	7.5	25.2	2.5	0	6.6	0	-	200.8
1977	-	42.7	31.6	68.3	1.8	9.5	2.0	0.5	9.0	2.2	0.5	1.9	170.0
1978	0.7	0	13.3	8.0	0	0.3	0	0.4	5.0	0	13.4	0.8	41.9
1979	6.9	11.2	0	-	-	11.4	42.0	0	-	7.2	0	0	106.73
1980	0	4.7	22.5	0	2.5	6.6	0	11.5	21.5	0	0	2.5	71.8
1981	0	1.5	58.4	0	1.8	0	2.5	13.0	0	42.5	0	10.9	130.6
TOTAL	306.3	476.5	638.9	399.7	155.8	124.7	174.2	72.2	110.6	125.7	89.3	277.5	3060.53
AV	13.32	19.85	26.62	16.65	6.77	4.99	7.26	3.01	4.61	5.03	3.57	11.56	122.4
YEARS OF RECORD	23	24	24	24	23	25	24	24	24	25	25	24	25
*	Overall monthly average inserted into missing data months to form the total yearly rainfall indicated.												

TABLE A.3

Meteorological Data

Source of data.

WEATHER BUREAU

DEPARTMENT OF TRANSPORT

PRETORIA

Station No. 247/668 POFADDER

Type of data. EVAPORATION (mm) [CLASS 'A' - pan]

Month Year	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1957	-	-	-	-	-	93.5	109.7	145.8	208.3	292.9	382.5	449.1	1682
1958	434.1	334.8	290.8	221.5	150.1	128.0	159.5	203.2	232.2	294.9	352.6	430.5	3232
1959	406.9	339.1	278.4	192.8	117.3	123.4	129.0	166.4	255.5	299.0	401.8	445.0	3155
1960	475.0	372.4	312.4	218.4	145.0	134.1	142.7	193.0	265.7	348.0	440.4	445.0	3492
1961	433.1	410.5	305.6	202.4	121.7	96.8	116.1	153.2	207.8	285.2	351.5	406.4	3090
1962	413.0	294.6	273.6	220.0	155.4	105.2	121.4	154.9	246.4	331.2	330.2	480.1	3146
1963	394.0	362.7	286.3	185.7	125.2	99.8	98.8	176.5	236.0	274.1	341.6	411.2	2992
1964	452.1	352.0	291.8	223.0	168.1	112.3	138.2	183.6	214.9	304.8	360.7	467.6	3269
1965	433.3	358.1	318.8	-	164.1	102.6	133.1	144.0	189.7	-	376.9	408.7	2629
1966	464.1	343.9	366.0	223.8	186.9	159.0	170.2	183.1	192.0	367.5	401.6	500.9	3559
1967	483.4	400.0	292.4	180.1	161.8	103.1	148.3	182.4	236.2	271.5	362.5	423.9	3246
1968	418.5	356.7	288.8	202.9	113.7	96.4	110.6	135.2	223.4	278.2	380.1	-	2604
1969	-	314.8	-	196.1	173.1	111.8	-	197.1	248.2	343.3	423.7	486.1	2494
1970	476.8	359.1	364.7	268.8	-	-	-	-	-	-	-	-	1469
1971	-	-	388.6	253.8	202.0	152.1	131.8	-	-	365.7	-	-	1494
1972	-	-	361.3	-	173.9	171.0	-	215.8	-	-	552.0	590.2	2064
1973	620.1	482.7	373.9	279.0	179.9	194.4	227.0	285.0	378.5	458.1	539.8	-	3938
1974	466.6	353.4	319.8	228.9	-	-	156.9	175.8	247.5	342.6	-	447.8	2739
1975	-	-	-	-	-	-	-	138.9	240.1	315.4	383.2	-	1078
1976	303.9	-	-	181.8	-	-	-	-	-	-	-	-	486
1977	-	-	-	183.6	159.8	121.2	140.1	199.9	233.5	378.7	563.0	569.2	2549
1978	569.8	447.5	410.8	256.1	194.9	176.9	180.1	182.2	273.1	322.1	542.8	576.8	4203
1979	578.0	446.1	419.0	339.0	221.7	175.1	206.0	208.1	313.7	404.5	580.4	703.2	4595
1980	636.2	545.4	444.0	295.5	227.6	182.1	236.6	251.9	298.1	499.9	443.2	584.6	4645
1981	577.3	463.9	390.7	275.6	207.0	142.4	169.8	168.3	300.7	428.7	513.1	597.5	4235
AV	475.6	382.0	339.9	249.9	167.5	132.4	151.3	183.8	249.6	346.5	429.7	496.0	3584
YEARS OF RECORD	19	19	20	21	20	21	20	22	21	21	21	19	

Table Appendix A5

Chemical analyses of Groundwater samples, constituents in mg/l.

Sample location	Ca	Mg	Na	K	HCO ₃	SO ₄	Cl	Nitrate as		F	Si	P	NH ₄	PH unit	TAL as mg/l CaCO ₃	EC, mS/m		Water temperature °C	Remarks
								N	NO ₃							Lab	Field		
E-3	187.419	58.266	37.783	6.291	304.501	568.6	378.126	3.237	14.329	3.994	21.452	0.022	0.026	7.7	249.752	259.2		707	EC
E-4	72.991	24.083	51.249	5.42	277.481	33.137	71.304	2.168	9.331	3.376	13.803	0.006	0.002	7.7	227.59	74.0		281	EC
E-5	67.233	21.187	49.879	3.939	258.558	30.424	53.962	2.908	12.812	3.852	17.256	0.004	0.024	7.7	212.069	76.0		255	EC
E-6	113.382	37.186	80.199	5.617	216.625	137.33	184.906	1.863	8.247	3.286	11.198	0.012	0.048	7.9	177.733	120.0		436	EC
Ka-1	157.848	154.377	57.387	28.299	519.788	437.767	821.255	10.448	46.116	3.105	15.72	0.001	0.071	7.6	406.33	406.8		1028	EC
Ka-2	53.7	21.825	55.969	1.423	170.333	44.917	90.761	4.815	21.314	4.004	22.283	0.005	0.023	7.5	139.707	69.0		224	EC
Ka-4	66.015	38.147	71.483	2.179	143.41	63.347	181.06	5.992	26.524	3.534	19.293	0.008	0.022	7.4	117.625	99.0		321	EC
NN-1	160.523	46.733	129.966	9.607	291.124	112.011	242.432	48.172	213.238	2.55	17.443	0.004	0.015	7.4	238.78	176.0		593	NO ₃ EC
NN-2	105.962	46.398	228.854	12.288	367.32	114.831	324.182	4.392	19.442	2.645	13.393	0.001	0.002	7.6	301.276	193.0			EC
NN-4	121.361	43.13	279.404	12.7	319.07	203.687	374.444	4.643	20.553	3.455	12.198	0.117	0.025	7.8	310.913	211.2			EC
NN-5	135.66	61.358	245.135	13.56	284.533	237.223	450.002	4.209	18.632	3.034	11.723	0.002	0.016	7.7	233.374	225.3			EC
Nov-3	284.009	109.595	371.135	6.838	66.790	172.053	179.616	5.674	25.117	2.976	14.381	0.005	0.006	7.4	54.781	380.7	19		SO ₄
Nov-4	226.542	27.694	442.366	9.269	77.514	545.132	778.535	1.162	5.144	3.646	15.811	0.004	0.007	7.3	63.577	358.5	11		SO ₄
Nov-6	366.388	78.585	1446.793	19.841	143.421	1160.922	2193.42	6.017	26.635	4.061	12.443	0.005	0.018	8.0	117.634	830.5	10.5		* DRAIN SAMPLE
Nov-1	131.821	50.744	183.11	2.399	276.85	253.328	255.992	19.323	85.535	2.319	16.651	0.007	0.018	7.4	227.073	180.0			EC
Nov-3	70.13	26.784	131.443	6.068	314.759	66.678	134.958	10.836	47.967	3.168	14.795	0.002	0.021	8.3	258.165	113	160	23	EC
PE-1	343.169	132.201	394.178	14.724	220.012	478.847	988.667	51.882	229.661	3.06	21.69	0.006	0.035	7.7	180.454	445.4	415	22	Ca NO ₃ EC
PE-2	97.043	29.109	87.932	5.402	335.653	13.679	86.13	6.202	30.552	2.493	18.054	0.012	0.026	7.6	275.303	107.0			EC
PE-3	94.103	29.935	100.11	7.461	320.328	75.355	125.318	12.144	53.757	2.79	22.209	0.009	0.029	7.6	262.741	116.0			EC
PE-6	112.722	42.888	147.294	5.942	338.665	151.342	209.191	4.814	21.434	3.782	21.333	0.007	0.01	7.6	277.773	150			EC
PE-7	91.758	33.18	120.379	5.054	400.829	64.441	134.479	5.008	22.168	3.715	22.009	0.016	0.02	7.7	328.76	120	145	22	EC

2
Table
Appendix A15

Chemical analyses of Groundwater samples, constituents in mg/l.

Sample location	Ca	Mg	Na	K	HCO ₃	SO ₄	Cl	Nitrate as		F	Si	P	NH ₄	PH unit	TAL as mg/l CaCO ₃	EC, mS/m		Water temperature = °C	Remarks
								N	NO ₃							Lab	Field		
PE-8	524.44	160.49	727.63	20.346	603.226	640.359	1238.72	29.682	131.39	8.932	40.965	0.006	0.054	7.6	445.54	576	545	22	Ca, SO ₄ , NO ₃
PE-9	52.14	48.563	104.156	7.756	367.803	53.177	118.5	3.348	14.82	2.887	14.662	0.0	0.021	7.6	301.672	106.0			NO ₃ Ec
PE-14	177.904	94.113	160.401	6.935	315.29	278.67	347.902	27.635	122.329	3.729	26.426	0.009	0.056	7.2	258.574	224.0			NO ₃ Ec
PE-15	119.475	42.898	282.271	8.367	308.363	205.23	394.505	13.614	60.264	4.147	20.656	0.007	0.054	7.8	253.919	216.3			Ec
PE-16	51.458	30.875	72.688	3.599	236.344	38.272	91.394	7.859	34.789	2.036	25.12	0.036	0.028	7.3	193.866	80.9			
PE-17	134.218	69.023	102.815	7.08	344.885	174.462	247.283	7.81	34.572	2.609	24.379	0.019	0.028	7.4	280.444	163.0			
PT-1 (i)	113.643	31.741	66.163	4.913	199.642	113.179	169.125	6.253	27.680	3.197	16.616	0.01	0.02	7.8	163.746	112.5			
(ii)	714.577	18.807	56.084	3.582	184.771	75.362	92.728	2.213	9.796	3.853	16.466	0.004	0.021	7.8	151.549	79.1			Ca, SO ₄ , NO ₃
(iii)	111.519	31.735	64.844	5.235	210.22	99.29	159.136	5.504	24.364	3.119	16.012	0.007	0.014	7.7	172.436	108.0			
PT-3 (i)	81.495	19.657	41.926	4.329	255.98	40.366	67.493	3.994	17.680	3.197	15.634	0.005	0.01	7.7	209.955	72.0			
(ii)	81.15	19.431	45.938	4.513	249.824	43.94	77.896	3.017	13.355	2.898	14.427	0.006	0.0	7.6	204.906	76.0			
PT-9	309.515	128.281	488.553	18.421	232.454	496.189	1120.073	2.35	10.403	2.950	8.928	0.009	0.051	7.6	190.659	460.8	465	21.3	Ca, SO ₄
PT-10 (i)	128.57	45.0	238.55	10.566	285.167	191.003	379.031	3.5	15.423	3.324	19.79	0.011	0.01	7.9	233.894	208	205	17	Ec
PT-13	70.49	24.937	181.877	9.118	57.246	1.677	131.341	6.77	29.968	3.986	17.615	0.142	0.0	7.5	424.245	132.0			
PT-15	156.582	43.086	58.976	5.371	191.507	74.259	285.753	8.791	38.914	2.442	14.87	0.007	0.02	7.7	157.074	142.0			
PT-16	197.379	55.068	164.443	6.972	215.668	261.974	387.154	22.427	99.275	2.272	15.998	0.007	0.022	7.5	176.891	214.3			Ec
PT-17	421.35	134.2	627.59	22.307	277.922	756.936	1218.417	40.702	180.526	2.924	18.768	0.013	0.024	7.4	227.952	563.2			Ca, SO ₄ , NO ₃
PT-18	111.984	28.902	122.751	7.696	330.892	118.454	159.999	5.823	25.776	3.254	19.334	0.008	0.025	7.8	271.398	130.0			Ec
PT-19	855.984	221.536	136.988	11.18	87.042	487.345	1820.65	13.98	61.884	1.834	13.68	0.003	0.029	7.2	71.392	612.3			Ca, SO ₄
PT-21	623.92	187.73	663.387	41.148	277.167	1043.27	1580.504	54.193	239.891	4.037	30.098	0.02	0.011	7.4	227.332	658.0			Ca, SO ₄ , NO ₃
PT-26	72.162	18.265	45.114	4.354	244.225	30.749	65.545	3.131	13.86	2.803	17.132	0.005	0.018	7.9	197.853	69.9			

414

Ec

Ec

Ec

Table

Appendix A5 Chemical analyses of Ground water samples, constituents in mg/l.

500

Sample location	Ca	Mg	Na	K	HCO ₃	SO ₄	Cl	Nitrate as		F	Si	P	NH ₄	PH unit	TAL as mg/l CaCO ₃	EC, mS/m		Water temperature °C	Remarks
								N	NO ₃							Lab	Field		
PT-27	206.69	58.09	157.321	6.904	170.03	280.818	417.823	26.115	115.601	2.373	16.966	0.005	0.021	7.9	139.459	237.9			ND ₃ Ec
PT-28	84.699	24.424	60.053	4.717	173.906	82.493	130.766	5.748	25.444	3.177	15.42	0.007	0.021	7.8	142.638	92.6			ND ₃ Ec
PT-29	234.58	80.398	421.104	12.218	163.244	460.801	820.188	24.324	107.673	3.120	17.774	0.007	0.024	7.7	133.873	382.7			ND ₃ Ec
G-42	154.007	25.217	149.585	7.75	368.444	32.313	148.135	0.074	0.308	4.125	11.072	0.007	0.003	7.7	302.195	112.0			
G-43	159.14	101.288	659.609	19.056	429.17	323.323	1110.601	0.246	1.089	4.125	11.199	0.012	0.001	7.6	351.962	467.2			CP Ec
G-44	85.306	97.164	773.605	19.719	240.553	345.77	1251.79	0.436	1.930	4.151	12.456	0.007	0.073	8.0	198.942	492.8	475.0	22.8	CP Ec
G-45	203.97	100.139	730.946	22.038	338.511	421.514	1288.82	0.804	3.559	2.437	10.584	0.009	0.029	7.9	217.647	516.8			CP Ec
G-46	193.69	75.673	546.614	12.584	225.261	297.311	918.546	55.61	246.163	4.282	21.223	0.003	0.02	7.9	184.759	448.1			ND ₃ Ec
G-48	185.82	69.187	513.883	13.632	195.180	285.23	804.571	74.778	331.012	4.099	19.077	0.004	0.029	7.7	160.097	396.1			ND ₃ Ec
G-49	80.268	24.37	60.093	4.641	275.231	32.273	97.09	5.896	26.099	4.055	14.438	0.004	0.0	8.0	225.749	85.0			
G-50	78.224	24.377	63.083	5.021	275.231	30.766	95.374	6.025	26.670	3.649	14.521	0.01	0.009	8.0	225.749	85.5			
G-51	63.617	23.539	61.724	5.290	227.732	32.843	97.484	5.848	25.887	3.715	14.217	0.021	0.023	7.8	186.786	79.0			
G-52	81.933	23.829	60.293	4.81	270.731	34.977	118.285	5.091	22.536	3.700	14.539	0.017	0.053	7.8	203.694	89.5			
G-53	74.962	22.703	63.023	5.135	280.174	30.034	81.282	5.821	25.767	3.649	14.569	0.002	0.0	8.0	229.799	82.0			
G-54	60.0	21.592	64.63	7.274	246.62	31.443	80.714	5.852	25.904	3.649	8.937	0.015	0.02	7.8	202.278	76.0			
G-55	64.02	22.981	61.624	9.522	223.021	32.214	99.99	5.693	25.2	3.782	12.40	0.094	0.05	7.7	182.922	80.5			
G-56	83.712	24.529	63.148	4.987	277.335	35.638	120.669	5.366	23.753	3.712	14.436	0.009	0.041	7.8	227.47	89.5			Post-blank pumped sample after 1 hour.
G-57	66.441	24.657	121.928	7.895	270.35	59.135	147.36	7.184	31.801	3.986	16.055	0.032	0.02	7.6	224.741	108.2			
G-58	63.869	25.779	112.511	7.177	280.174	56.037	142.945	7.227	31.991	3.986	16.629	0.013	0.009	7.8	229.799	107.0			
G-59	42.309	25.546	118.657	10.926	259.487	81.011	199.323	3.652	16.166	4.204	3.749	0.014	0.057	7.8	212.831	119.3	120.5	25	

Table
Appendix A5

Chemical analyses of GROUND water samples, constituents in mg/l.

Sample location	Ca	Mg	Na	K	HCO ₃	SO ₄	Cl	Nitrate as		F	Si	P	NH ₄	PH unit	TAL as mg/l CaCO ₃	EC, mS/m		Water temperature = °C	Remarks
								N	NO ₃							Lab	Field		
S34732	42.118	14.941	104.324	6.571	287.171	30.91	71.595	5.943	26.357	4.538	15.622	0.008	0.024	7.9	235.538	76.9			
S34735	60.795	19.977	48.3	7.117	278.68	28.111	36.366	1.696	3.508	3.849	25.163	0.066	0.016	7.9	228.573	63.0			
S34736	54.795	20.146	58.543	6.674	221.674	8.483	76.435	4.957	21.943	3.370	14.128	0.054	0.086	8.0	181.817	68.4			
S34737	57.586	20.796	59.223	7.142	233.919	16.553	76.269	4.634	20.513	3.444	13.061	0.035	0.07	7.8	191.044	70.1			
S34739	67.76	20.716	66.932	6.723	275.28	31.514	70.078	5.749	25.449	3.527	14.204	0.003	0.03	7.7	225.795	76.0			
S34814	86.708	27.971	101.646	7.153	213.887	70.380	170.727	10.757	56.470	3.173	15.294	0.034	0.046	7.8	175.43	113.0			
SAM-2 (i)	86.641	54.572	267.788	14.035	292.837	209.078	404.227	6.575	28.839	3.408	10.349	0.005	0.022	7.9	240.185	211.2			EC
(ii)	111.826	58.309	278.747	15.035	331.98	251.697	388.444	5.921	26.21	3.474	10.10	0.003	0.024	7.6	272.29	221.2			EC
SAM-8	43.27	34.916	169.24	10.856	199.95	134.775	231.208	0.214	0.947	2.701	11.827	0.005	0.021	8.2	163.999	139.5			
SAM-10 (ii)	128.224	71.441	263.153	16.328	239.771	274.703	459.399	10.534	46.63	2.771	11.334	0.006	0.022	7.9	196.66	239.9			
SAM-10	142.42	65.401	240.46	15.318	334.294	277.851	414.12	8.39	37.139	2.779	11.316	0.0	0.008	7.8	265.986	230.4			EC
SAM-11	153.636	74.244	262.281	17.49	313.335	294.749	459.072	13.069	57.851	2.813	10.389	0.002	0.023	7.6	256.997	249.6			EC
SAM-14	92.9	46.961	233.167	14.395	316.448	183.372	311.806	7.774	34.442	3.282	12.068	0.005	0.013	8.0	259.551	188.3			
SAM-15	96.183	47.477	230.899	13.833	321.535	178.958	308.977	7.283	3.191	3.191	11.225	0.003	0.029	7.7	263.723	181.5			EC
SAM-16	120.954	40.448	170.472	7.808	330.977	117.246	248.219	18.514	81.954	3.160	15.277	0.007	0.028	7.5	271.484	163.1			
SAM-17	230.719	90.688	351.008	19.046	284.95	358.423	723.221	7.278	30.217	2.584	10.410	0.006	0.033	7.5	233.716	332.0			EC
SAM-18	91.64	36.828	161.11	7.744	321.754	113.76	225.571	5.826	25.789	3.606	18.472	0.002	0.042	7.8	272.105	148.0			
SAM-19	177.249	70.774	282.881	14.869	320.149	320.88	449.846	9.89	48.779	2.493	11.458	0.003	0.012	7.5	262.586	254.4			EC
SAM-20	330.509	144.31	594.678	26.632	340.45	744.02	1075.55	12.997	57.533	2.988	12.191	0.006	0.01	7.4	279.237	472.1			EC
X-1	94.228	27.187	58.806	5.044	213.636	78.756	122.708	4.653	20.597	3.197	16.11	0.01	0.01	7.9	175.214	93.0			

500
500

0.2

250 (200) 100

500 200 1000 2000

2.6 mg/l

Table A6 Chemical analyses of Ground water samples, constituents in meq/l (epm).

Sample location	Ca	Mg	Na	K	Na+K	Total cations	% Ca	% Mg	% Na+K	HCO ₃	SO ₄	Cl	NO ₃	F	Sum Cl+NO ₃ +F	Total anions	% HCO ₃	% SO ₄	% Sum Cl+NO ₃ +F	Remarks CATIONS / ANIONS %
PE-8	16.190	13.202	31.653	0.776	32.429	61.821	26.2	21.4	52.4	1.898	13.332	34.944	2.119	0.47	37.533	60.763	16.3	21.9	61.8	1.7 B5
PE-9	2.602	3.995	4.531	0.198	4.729	11.326	23.0	35.3	41.7	6.028	1.107	3.343	0.239	0.152	3.734	10.869	55.5	10.2	34.3	3.4 B6
PE-14	8.877	7.742	6.977	0.177	7.154	23.773	37.3	32.6	30.1	5.167	6.218	9.814	1.973	0.196	11.983	23.368	22.1	26.6	51.3	1.7 B7
PE-15	5.962	3.529	10.279	0.214	12.493	21.984	27.1	16.1	56.8	5.054	4.273	11.129	0.972	0.218	12.319	21.646	23.4	19.7	56.9	1.6
PE-16	2.568	2.54	3.162	0.092	3.254	8.362	30.7	30.4	38.9	3.874	0.797	2.578	0.561	0.107	3.246	7.917	48.9	10.1	41.0	5.6 C8
PE-17	6.697	5.678	4.472	0.181	4.653	17.028	39.3	33.4	27.3	5.603	3.632	6.976	0.558	0.137	7.671	16.906	33.1	21.5	45.4	0.7 B8
PT-1 (i)	5.671	2.611	2.878	0.126	3.004	11.286	50.3	23.1	26.6	3.272	2.356	4.771	0.446	0.168	5.385	11.013	29.7	21.4	48.9	2.5 A (1)
(ii)	3.721	1.547	2.44	0.092	2.533	7.8	47.7	19.8	32.5	3.038	1.569	2.616	0.158	0.203	2.977	7.574	40.0	20.7	39.3	3.0 A (2)
(iii)	5.564	2.611	2.821	0.134	2.955	11.13	50.0	23.5	26.5	3.446	2.067	4.512	0.393	0.164	5.069	10.582	32.6	19.5	47.9	5.2 (3) A
PT-3 (i)	4.067	1.617	1.824	0.111	1.935	7.619	53.4	21.2	25.4	4.196	0.84	1.904	0.235	0.168	2.357	7.393	56.7	11.4	31.9	3.1 (4) A
(ii)	4.049	1.598	1.998	0.115	2.113	7.76	52.2	20.6	27.2	4.095	0.915	2.197	0.215	0.153	2.565	7.575	54.1	12.1	33.8	2.4 (5) A
PT-9	15.445	10.552	21.252	0.471	21.723	47.72	32.4	22.1	45.5	3.81	10.331	31.598	0.168	0.155	31.921	46.062	8.3	22.4	69.3	3.6 B7
PT-10/11	6.446	3.702	10.377	0.270	10.647	20.765	30.9	17.8	57.3	4.674	3.977	10.692	0.25	0.175	11.117	19.768	23.7	20.1	56.2	5.0 B10
PT-13	3.517	2.051	7.912	0.233	8.145	13.713	25.6	15.0	59.4	8.478	0.035	3.705	0.483	0.21	4.398	12.911	65.6	0.3	34.1	6.2 B11
PT-15	7.813	3.544	2.565	0.137	2.702	14.059	55.6	25.2	19.2	3.139	1.546	8.061	0.628	0.129	8.818	13.503	23.2	11.5	65.3	4.1 B12
PT-16	9.849	4.530	7.153	0.178	7.331	21.71	45.4	20.9	33.7	3.535	5.454	10.922	1.601	0.120	12.643	21.632	16.3	25.2	58.5	0.4 A (7)
PT-17	21.524	11.039	27.297	0.57	27.867	60.43	35.6	18.3	46.1	4.555	15.759	34.372	2.912	0.154	37.438	57.752	7.9	27.3	64.8	4.6 A (8)
PT-18	5.588	2.377	5.34	0.197	5.537	13.502	41.4	17.6	41.0	5.423	2.466	4.574	0.446	0.171	5.101	12.99	41.7	19.0	39.3	3.9 A (9)
PT-19	42.714	18.224	5.959	0.256	6.245	67.183	63.6	27.1	9.3	1.427	10.147	51.36	0.998	0.097	52.455	64.029	2.2	15.9	81.9	4.9 (10) A
PT-21	31.134	15.442	28.857	1.052	29.909	76.486	40.7	20.2	39.1	4.543	21.721	44.585	3.869	0.213	48.67	74.934	6.1	29.0	64.9	2.1 (11) A
PT-26	3.601	1.502	1.962	0.111	2.073	7.176	50.2	20.9	28.9	3.954	0.682	1.849	0.224	0.148	2.221	6.857	57.7	9.9	32.4	4.7 (12) A

Table Appendix A6 Chemical analyses of ground water samples, constituents in mg/l (epm).

Sample location	Ca	Mg	Na	K	Na+K	Total cations	% Ca	% Mg	% Na+K	HCO ₃	SO ₄	Cl	NO ₃	F	Sum Cl+NO ₃ +F	Total anions	% HCO ₃	% SO ₄	% Sum Cl+NO ₃ +F	Remarks
PT-27	10.344	4.778	6.843	0.177	7.02	22.112	46.6	21.6	31.8	2.787	5.847	11.787	1.865	0.12	13.772	22.406	12.4	26.1	61.5	1.3 A (13)
PT-28	4.226	2.009	2.612	0.121	2.733	8.968	47.1	22.4	30.5	2.85	1.718	3.745	0.41	0.167	4.322	8.89	32.1	19.3	48.6	0.9 A (14)
PT-29	11.696	6.614	18.318	0.312	18.63	36.94	31.7	17.9	50.4	2.676	9.594	23.187	1.737	0.164	25.038	37.308	7.2	25.7	67.1	1.0 A (15)
S34342 (i)	2.695	2.074	6.507	0.198	6.705	11.474	23.5	18.1	58.4	6.039	0.673	4.179	0.005	0.217	4.401	11.113	54.3	6.1	39.6	3.2 B 13
(ii)	2.399	1.832	6.496	0.206	6.702	10.933	21.9	16.8	61.3	5.572	0.868	3.745	0.012	0.253	4.01	10.45	53.3	8.3	38.4	4.6 B 14
S34343 (i)	7.941	8.332	28.692	0.487	29.18	45.453	17.5	18.3	64.2	7.033	6.732	31.33	0.018	0.217	31.565	45.33	15.5	14.9	69.6	0.3 B 15
(ii)	4.257	7.993	33.652	0.504	34.156	46.406	9.2	17.2	73.6	3.975	7.199	35.313	0.021	0.219	35.563	46.737	8.5	15.4	76.1	0.7 B 16
S34344	10.179	8.237	31.796	0.564	32.36	50.776	20.1	16.2	63.7	5.548	8.985	36.358	0.057	0.128	36.543	51.076	10.9	17.6	71.5	0.6 C 14
G34345	9.665	6.225	23.778	0.322	24.1	39.99	24.1	15.6	60.3	3.612	6.19	25.912	3.971	0.225	30.108	39.99	9.2	15.5	75.3	0.0 B 17
G34346	9.272	5.691	22.324	0.349	22.703	37.666	24.6	15.1	60.3	3.199	5.938	22.697	5.339	0.216	28.252	37.389	8.6	15.9	75.5	0.7 B 18
G34348 (i)	4.005	2.005	2.614	0.119	2.733	8.743	45.8	22.9	31.3	4.511	0.672	2.739	0.421	0.213	3.373	8.556	52.7	7.9	39.4	2.2 A (20)
(ii)	3.903	2.005	2.744	0.128	2.872	8.78	44.5	23.8	32.7	4.511	0.641	2.691	0.43	0.192	3.313	8.465	53.3	7.6	39.1	3.7 A (21)
(iii)	3.174	1.936	2.685	0.135	2.82	7.93	40.0	24.4	35.6	3.733	0.684	2.75	0.448	0.196	3.364	7.781	48.0	8.8	43.2	1.9 A (22)
(iv)	4.088	1.960	2.71	0.123	2.833	8.881	46.0	22.1	31.9	4.47	0.728	3.337	0.384	0.196	3.897	9.095	49.2	8.0	42.8	2.4 A (23)
G34349 (i)	3.741	1.868	2.742	0.131	2.873	8.482	44.1	22.0	33.9	4.592	0.625	2.293	0.416	0.192	2.901	8.118	56.6	7.7	35.7	4.5 A (24)
(ii)	2.994	1.776	2.811	0.186	2.997	7.767	38.5	22.9	38.6	4.042	0.655	2.277	0.418	0.192	2.887	7.584	53.3	8.6	38.1	2.4 A (25)
G34350 (i)	3.195	1.890	2.681	0.243	2.924	8.009	39.9	23.6	36.5	3.655	0.671	2.821	0.406	0.199	3.426	7.752	47.1	8.7	44.2	3.3 A (26)
(ii)	4.177	2.018	2.747	0.128	2.875	9.07	46.1	22.2	31.7	4.546	0.742	3.404	0.383	0.195	3.982	9.27	49.0	8.0	43.0	2.2 A (27)
G34353	3.315	2.028	5.304	0.202	5.506	10.849	30.6	18.7	50.7	4.431	1.231	4.157	0.513	0.210	4.88	10.542	42.0	11.7	46.3	2.9 B 19
G34354	3.187	2.121	4.894	0.199	5.093	10.401	30.6	20.4	49.0	4.592	1.167	4.032	0.516	0.21	4.758	10.517	43.7	11.1	45.2	1.1 B 20
G34356	2.111	2.101	7.337	0.279	7.616	11.828	17.8	17.8	64.4	4.253	1.687	5.623	0.261	0.221	6.105	12.045	35.3	14.0	50.7	1.8 B 21

Table Appendix A6 Chemical analyses of Groundwater samples, constituents in mg/l (epm).

Sample location	Ca	Mg	Na	K	Na+K	Total cations	% Ca	% Mg	% Na+K	HCO ₃	SO ₄	Cl	NO ₃	F	Sum Cl+NO ₃ +F	Total anions	% HCO ₃	% SO ₄	% Sum Cl+NO ₃ +F	Remarks cations % ANIONS %	
S34732	2.102	1.229	4.538	0.168	4.706	8.037	26.2	15.3	58.6	4.707	0.644	2.02	0.424	0.239	2.683	8.034	58.6	8.0	33.4	0.0	0.222
S34735	3.034	1.645	2.101	0.182	2.283	6.962	43.6	23.6	32.8	4.568	0.585	1.026	0.121	0.203	1.35	6.503	70.2	9.0	20.8	6.6	A 25
S34736	2.734	1.657	2.547	0.171	2.718	7.109	38.5	23.3	38.2	3.633	0.177	2.156	0.354	0.177	2.667	6.497	55.9	2.7	41.4	9.4	A 29
S34737	2.874	1.711	2.576	0.183	2.759	7.244	39.1	23.3	37.6	3.818	0.345	2.152	0.321	0.181	2.664	6.827	55.9	5.1	39.0	7.6	A 30
S34739	3.381	1.704	2.912	0.172	3.084	8.169	41.4	20.8	37.8	4.512	0.656	1.977	0.41	0.186	2.573	7.741	58.3	8.5	33.2	5.5	A 31
S34814	4.327	2.301	4.422	0.183	4.605	11.233	38.5	20.5	41.0	3.506	1.465	4.816	0.211	0.167	5.894	10.865	32.3	13.5	54.2	3.4	
SAM-2 (i)	4.323	4.489	11.649	0.359	12.008	20.82	20.7	21.6	57.7	4.8	4.353	11.403	0.465	0.179	12.047	21.2	22.7	20.5	56.8	1.8	
(ii)	5.580	4.796	12.125	0.384	12.509	22.885	24.4	20.9	54.7	5.441	5.24	10.958	0.423	0.163	11.564	22.245	24.4	23.6	53.0	2.9	
SAM-8	2.159	2.812	7.362	0.275	7.64	12.671	17.0	20.7	60.3	3.277	2.806	6.522	0.015	0.142	6.679	12.762	25.7	22.0	52.3	0.7	C 10
SAM-10/11	6.398	5.877	11.447	0.418	11.865	24.14	26.5	24.3	49.2	3.93	5.723	12.96	0.752	0.144	13.858	23.511	16.7	24.4	58.9	2.7	
SAM-10	7.107	5.38	10.446	0.372	10.852	23.339	30.4	23.1	46.5	5.315	5.785	11.682	0.599	0.146	12.427	23.527	22.6	24.6	52.8	0.8	
SAM-11	7.666	6.107	11.409	0.447	11.856	25.629	29.9	23.8	46.3	5.136	6.137	12.95	0.933	0.148	14.031	25.304	20.3	24.3	55.4	1.3	
SAM-14	4.636	3.863	10.143	0.363	10.511	19.01	24.4	20.3	55.3	5.187	3.818	8.796	0.555	0.173	9.524	18.529	28.0	20.6	51.4	2.6	C 11
SAM-15	4.80	3.905	10.044	0.354	10.398	19.103	25.1	20.5	54.4	5.270	3.726	8.716	0.520	0.168	9.404	18.440	28.6	20.3	51.1	3.8	C 12
SAM-16	6.036	3.325	7.503	0.20	7.703	17.064	35.4	19.5	45.1	5.425	2.441	7.002	1.322	0.166	8.47	16.356	33.2	14.9	51.9	4.3	C 9
SAM-17	11.513	7.446	15.269	0.487	15.756	34.729	32.1	21.5	45.4	4.67	7.462	20.402	0.52	0.136	21.058	33.19	14.1	22.5	63.4	4.6	
SAM-18	4.573	3.029	7.008	0.198	7.206	14.808	30.9	20.4	48.7	5.437	2.368	6.363	0.416	0.19	6.969	14.774	36.8	16.0	47.2	0.2	
SAM-19	8.845	5.822	12.325	0.38	12.685	27.352	32.3	21.3	46.4	5.247	7.763	12.620	0.706	0.131	13.527	26.537	19.8	29.2	51.0	3.1	
SAM-20	16.492	11.871	25.868	0.681	26.549	54.912	20.0	21.6	48.4	5.58	15.428	30.341	0.928	0.157	31.426	52.434	10.7	29.4	59.9	4.7	
X-1	4.702	2.236	2.558	0.129	2.687	9.625	48.9	23.2	27.9	3.501	1.64	3.462	0.332	0.168	3.962	9.103	38.5	18.0	43.5	5.7	

GROUNDWATER SAMPLES, REFERENCE LIST : POFADDER AREA

Farm name	Borehole No.	Geological formation	date	Time	Latitude	Longitud	REMARKS.
EYTES	3	Granite	27-7-82	1130			pumped - 10 mins
	4	"	27-7-82	1010			pumped - sev. hrs
	5	"	27-7-82	1045			pumped - 10 mins
	6	"	27-7-82	1235			pumped - 13 mins
KABAS	1	"	30-7-82	1000			pumped - 10 mins
	2	"	28-7-82	1545			pumped - sev. hrs
	4	"	28-7-82	1615			pumped - sev. hrs
NAMIES NORTH	1	"	30-7-82	1600			pumped - sev. hrs
	2	"	27-7-82	1615			pumped - sev. hrs
	4	"	27-7-82	1540			pumped - 10 mins
	5	"	20-7-82	1257			pumped - 10 mins
NONGCAP	3	"	28-8-81	-			pumped - 10 min
	4	"	28-8-81	-			pumped - ?
	6	"	28-8-81	-			dam sample
NOUZEES	1	"	29-7-82	1624			pumped - sev. hrs
	3	"	20-4-82 24-7-81	1403 1355			pumped - 10 mins
"POFADDER	1	"	20-4-82	1110			pumped - sev. hrs
EAST"	2	"	8-5-82	0830			pumped - indet.
	3	"	8-5-82	0845			pumped - indet.
	6	"	27-4-82	1720			pumped - 15 mins
	7	"	20-4-82	1150			pumped - sev. hrs
	8	"	20-4-82	1140			pumped - 5 mins
	9	"	28-7-82	1235			pumped - 10 mins
	14	"	28-7-82	1310			pumped - 20 mins
	15	"	28-7-82	1345			pumped - sev. hrs
	16	"	28-7-82	1305			pumped - 10 mins
	17	"	28-7-82	1330			pumped - sev. hrs
		"					

Table 19 - continued

GROUNDWATER SAMPLES, REFERENCE LIST

Farm name	Borehole No.	Geological formation	date	Time	Latitude	Longitud	REMARKS.
"PEFADDER"	1	Granite	26-3-82 4-12-81 28-7-82	1010 1210	(i) pumped - (ii) pumped - (iii) pumped -		for 3 hr. 25 min
"TOWNLANDS"	3	"	22-4-82 14-5-82	1520 0900	(i) pumped - (ii) pumped -		sev. hours 24 HOURS
	9	"	20-4-82	1330	pumped -		50 mins
	10/11	"	20-4-82	1235	pumped -		sev. hrs (exact blh indetermin)
	13	"	2-4-82	1115	static sample -		25m
	15	"	27-7-82	1350	pumped -		sev. hrs
	16	"	27-7-82	1405	PUMPED for		sev. hours Mission pump unit.
	17	"	27-7-82	1420	pumped -		sev. hrs
	18	"	27-7-82	1435	pumped -		sev. hrs
	19	"	27-7-82	1450	pumped -		5 mins
	21	"	30-7-82	0844	pumped -		sev. hrs.
	26	"	17-8-81	-	Hospital raised		storage tank
	27	"	17-8-81	-	pumped -		10 mins
	28	"	17-8-81	-	Raised storage		tank
	29	"	17-8-81	-	Raised storage tank		pumped - sample
	G 34342	"	2-4-82 28-11-81	1150 -	(i) static sample -		25m (ii) static sample - ?
	G 34343	"	2-4-82 7-11-81	1045 -	(i) static sample -		59 m. (ii) pumped - 15 mins
	G 34344	"	4-12-81	-	static sample -		(30m?)
	G 34345	"	4-12-81	-	static sample -		16m
	G 34346	"	4-12-81	-	static sample -		30m.
	G 34348	"	9-3-82 23-3-82 23-3-82	1340 1500 1404	(i) pumped at 84m - (ii) pumped at 60m - (iii) Blown at 82.0m -		5 1/4 HRS
	G 34349	"	10-3-82 4-3-82	1200 0900	(i) pumped at 84m - (ii) Blown at 69m -		
	G 34350	"	12-3-82 24-6-82	1500 0937	(i) Blown at 80.8m - (ii) Pumped at 77.2m -		1 Hour.
	G 34353	"	26-3-82	1515	static sample -		28m
	G 34354	"	26-3-82	1530	static sample -		28m
	G 34356	"	19-5-82	1340	'Blown' at		111.5m -
	G 34732	"	29-7-82	1314	static sample -		19m
	G 34735	"	29-7-82	1330	static sample		from 18m.



PLATE 12: Significant interconnection between two neighbouring boreholes at site 3 after blasting, as evidenced by this attempted 'blow test'



PLATE 13: Water ejected from G34350 (Left) while 'blowing' G34348. Boreholes are 1,75 m apart



PLATE 10: Detonation at approximately 30 m in G34354, Site 4



PLATE 11: Detonation in G34350 at Site 3



PLATE 8: Lowering the charge to the required depth in G34348, Site 3



PLATE 9: Detonation at a depth of 124 m in G34357, Site 4

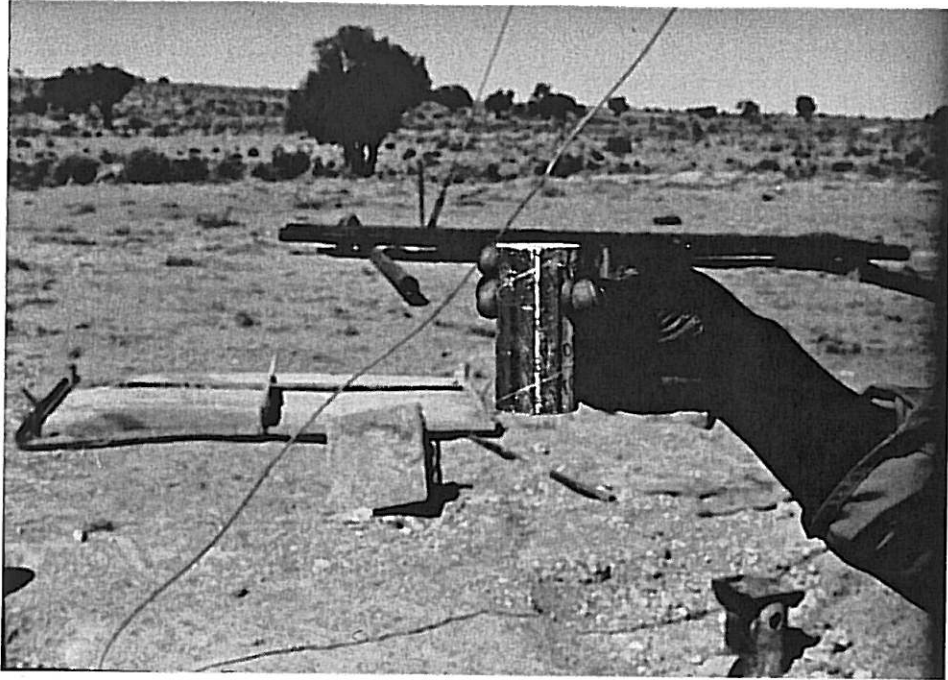


PLATE 5: Individual charge of Pentolite explosive



PLATE 6: Approximately 5 kg of Pentolite explosive, with cortex connection, ready for packing

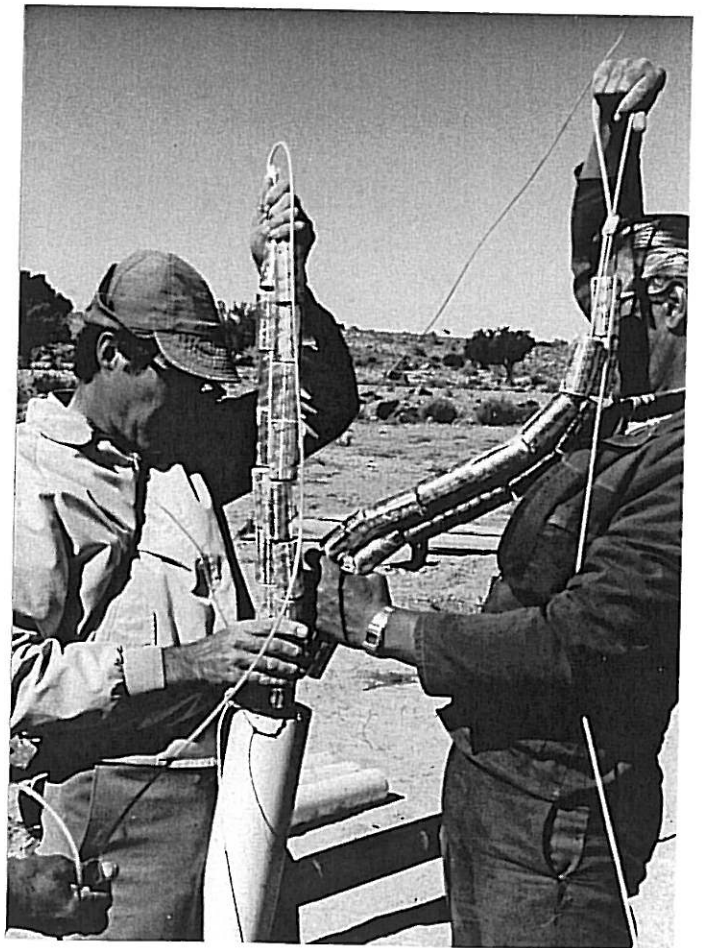


PLATE 7: Packing of explosive into container

FIG: 2 - POFADDER AVERAGE MONTHLY RAINFALL
POTENTIAL EVAPORATION & TEMPERATURE

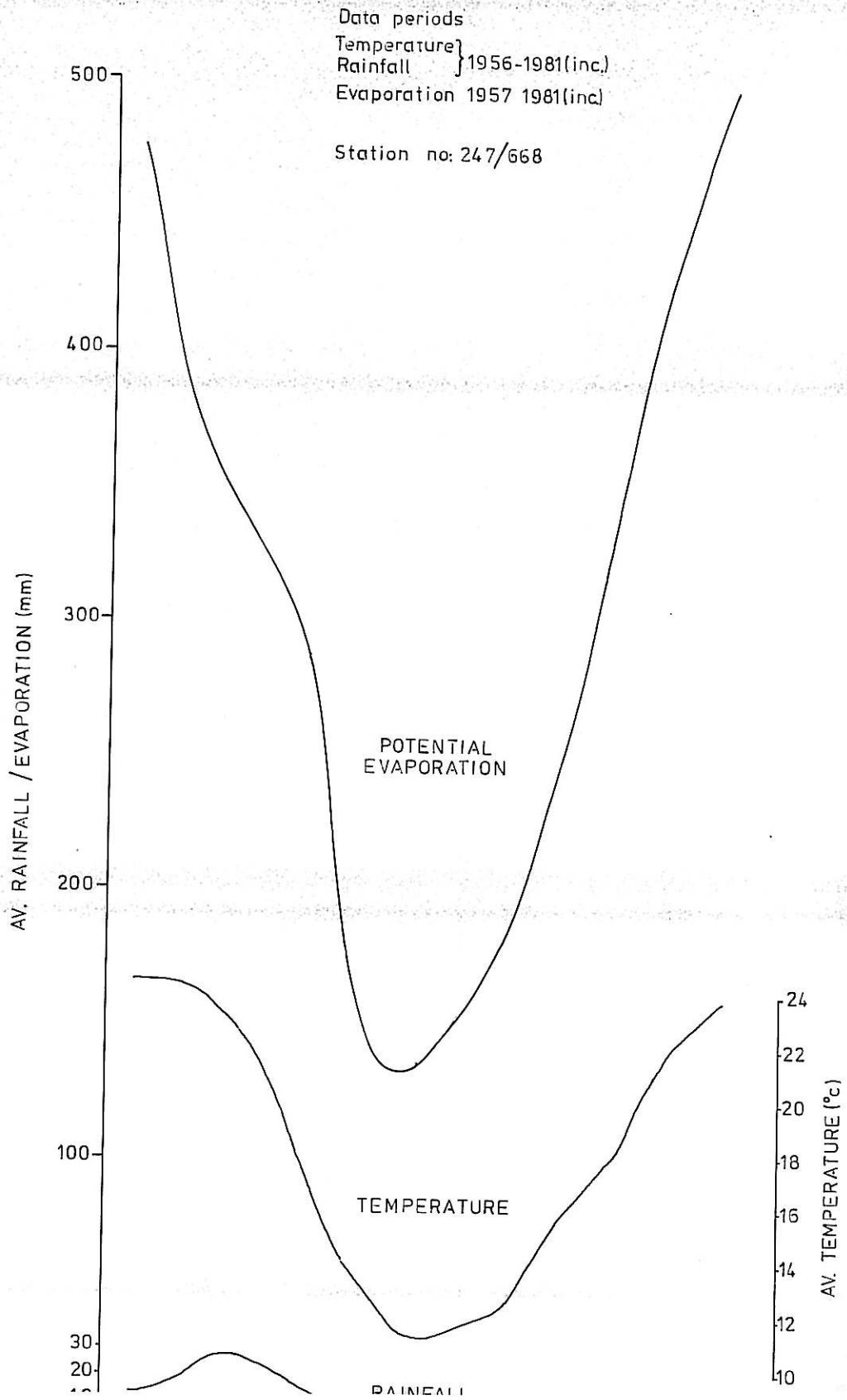


FIGURE 7: STIFF DIAGRAMS OF
SELECTED SAMPLES

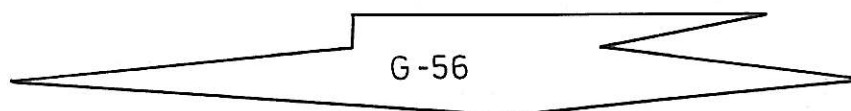
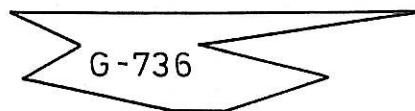
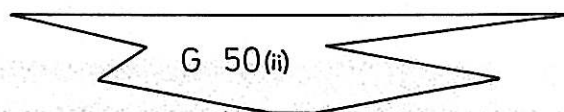
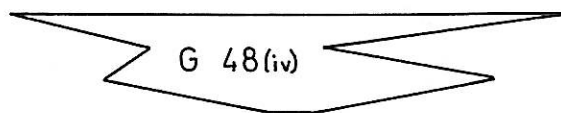
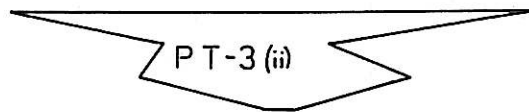
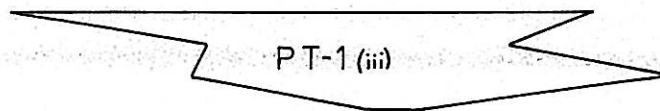
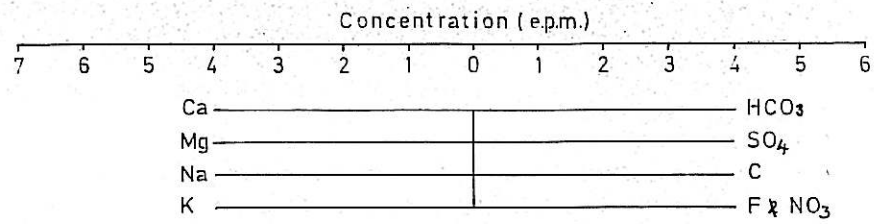
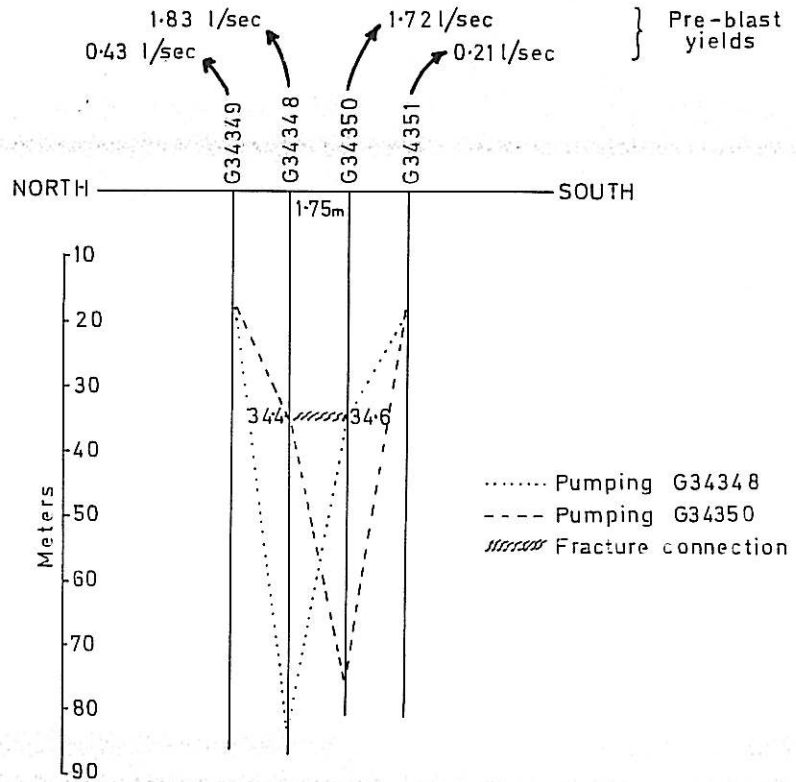


FIGURE 3 : WATER LEVELS AT SITE 3
 DURING POST-BLAST PUMPING OF
 G34348 & G34350



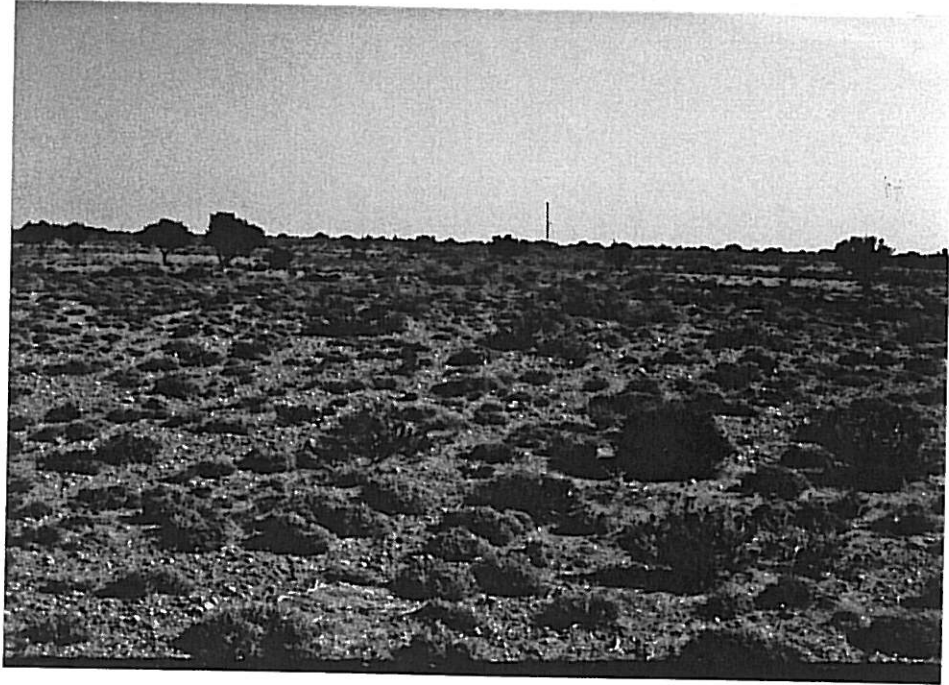


PLATE 4: Lineament B (see enclosure 2) looking west towards Site 3. Note abundant float material from vein and the presence of ganna bushes