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THE GROUNDWATER RESOURCES OF ST HELENA.

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1. INTRODUCTION

The three-week visit to St Helena was funded by ODA following the recommendation by Mr D Brown (ODA, Water Authority, St Helena) that the possibility of developing spring sources by horizontal drilling be investigated.

Severe water shortages occur most years in the centre of the island for a period varying between 3 and 7 months. More than half the island's population live in this area and it is here where most of the land suitable for cultivation is located. However, even in the driest periods large quantities of water are being lost to the ocean as stream flow from the major valleys. The problem can be simplified as follows: whilst there is a plentiful supply of freshwater at low elevation in the valley floors the cost of pumping this water to the centre of the island, a vertical distance of 400-500 m is prohibitive.

Mr D Brown suggested that an investigation be carried out to assess the possibilities of more efficient abstraction of upland spring flows (springs and seepages above the 500 m contour) by drilling horizontal boreholes into the water-bearing strata feeding the springs. To give some idea of the scale of the problem, the costs of bowsering water from Jamestown to the outlying districts, experiencing severe water shortages for the period November 1982-May 1983 amounted to more than £12,000 (labour and fuel costs only).

A reliable source of water would also be of considerable benefit to agricultural output and help reduce the food import bill presently costing St Helena £40,000 p.a. The details of potential benefits both for domestic and irrigation water supplies is discussed later.

The aim of this visit was threefold:

(1) To gain an understanding of the groundwater flow system and to quantify the resources.

(2) To delineate areas where horizontal drilling is most suitable.

(3) To review the potential savings and benefits from (2) above.

2. PHYSIOGRAPHY

2.1 *Location*.

St Helena lies close to the middle of the Atlantic Ocean between latitudes 15°53'57"S and 16°01'20"S and longitudes 5°38'20"W and 5°47'47"W. Ascension Island lies some 1300 km to the North West (Fig. 1) whilst the nearest mainland is Pta Albina (Angola) over 1800 km to the east. The island has an area of 121 km^2 with a maximum length (NE-SW) of 17.4 km and width of 11.4 km. Communication with the outside world is restricted to a regular (at 10 day intervals) ferry service with Ascension (a 3-4 day trip). A larger boat (RMS St Helena) owned by St Helena Shipping Co. travels between Bristol and Cape Town, calling at St Helena at approximately 6 weekly intervals. There is no air-field on the island.

2.2 *Topography.*

The island mostly lies above 200 m and rises to a height of 820 m above sea level (Mount Actaeon). A number of deeply cut and narrow valleys radiate from the central highland area of the island. The coast of the island almost entirely consists of near vertical cliffs, typically 100-300 m high, except where these are breached by the valleys. There are few flat areas and these are mostly restricted to central highland areas.

2.2 *Vegetation.*

The island can be subdivided into 3 zones on the basis of vegetation:

(1) The central upland area (above 500 m contour) where flax, grassland pasture and forest predominates.

(2) Outer and lower zone (below 500 m contour), scrub predominates.

(3) Valley margins:- along the valley margins at all elevations thick luxuriant vegetation can grow - including yams, ginger, bananas. In many cases no surface water is flowing and this type of vegetation indicates that subsurface water is available at relatively shallow depths.

3. CLIMATE

Earlier studies on the climatic conditions on St Helena have been made by Kitching (1954), Simansky (1967) and Kopec (1969).

3.1 *Rainfall.*

Rainfall varies considerably with altitude, above 500 m amsl, mean annual rainfall exceeds 660 mm whilst at sea level mean annual rainfall is less than 300 mm. Rainfall is well distributed throughout the year. The driest months are October to January whilst the wettest period is March and from June to August.

Heavy rain storms are unusual and so evaporation losses, especially at lower elevations can be considerable. The principal meteorological station is at Hutts Gate located at an altitude of 630 m amsl.

A characteristic of the climate of the centre of the island is the frequency of low cloud or mist. The mists reduce evapotranspiration and may result in significant addition to precipitation by interception.

3.2 *Evapotranspiration.*

No measurements of evaporation and transpiration have been made. Potential evapotranspiration has been computed by Kopec (1969) who estimated a mean annual rate of 1880 mm at Jamestown (sea level) and 810 mm at Hutts Gate (630 m amsl). The strong south-easterly winds increase evapotranspiration whilst the high frequency of cloud cover and mists reduce it.

Temperature varies from 14°C to 29°C in the coastal zone and in the centre of the island (600 m) from 8°C to 24°C.

4. GEOLOGY

The most comprehensive and detailed account of the geology of St Helena has been produced by Baker (1968).

There were two main centres of volcanic activity - in the north-east of the island and the later volcano in the south-west part of the island (enclosure I).

4.1 *North East Volcano.*

These rocks outcrop in the north east corner of the island and consist of basaltic lavas and pyroclastics which dip to the west at about 15-20^{o}. These rocks cover only a small part of the island and are of lesser importance in relation to the groundwater resources.

4.2 *South West Volcano.*

This volcano was much larger than the earlier north-east volcano and the resulting basalt and trachybasalt lava flows cover most of the island. There were three periods of activity - the Lower shield, Main shield and Upper shield covering a period from 6-11 m years ago. The Lower and Main shields were extruded from fissures concentrated in the Sandy Bay area (south-west of Island). The later rocks of the Upper shield were erupted in the area of the Peaks.

The lava flows and pyroclastics tend to dip radially from the Sandy Bay area at low angles. Flows are typically only a few metres thick and consists of a rubbly base, a more massive central portion and a rubbly-vesicular top (Fig. 2). Tuff layers are frequently found between the flows and are developed over a large area. Late hydrothermal activity occurred after the extrusion of the Upper shield volcanics resulting in the infilling of vesicles by secondary minerals.

5. GROUNDWATER RESOURCES

A considerable volume of water (more than 1.0 x 10^6 m^3/yr) is discharged into the ocean by the major streams as baseflow; these streams are mostly derived from groundwater (spring sources). Springs or seepages at the ground surface is a form of groundwater discharge and occurs where the zone of saturation intersects the ground surface. On the island springs were usually found to occur at the contact between a tuff band and an overlying lava flow, indicating that the tuff is an aquitard (a layer of low permeability which restricts groundwater flow) and the lava flow forms the aquifer. The stream produced would often disappear, as it crosses more permeable strata, further down the slope. For this reason, runoff (other than baseflow) except on some of the steeper, non-vegetated slopes and for short periods of time is probably negligible.

There are probably several hundred springs and seepages on the island most of which are not developed for water supply purposes.

5.1 *Aquifers.*

The aquifers, (water bearing strata) that produce the springs are likely to be of 3 types:

(1) The aquifer within the soil and unconsolidated part of the weathered mantle. The lithology of the weathered mantle was observed at a number of road cuttings and also in a 4 m deep trench cut in the hillside at the head of Lemon Valley. The weathered section (Fig. 3) showed the following sequence:

Soil	∿ 0.2 - 0.5 m thick
Highly weathered basalt - consisting of pebbles and boulders of basalt in a soft clayey matrix	0 - 6 m thick
Compact though weathered rock	Several metres thick

The aquifer within the unconsolidated rock is likely to be of low permeability and variable thickness (0 - 6 m) - being thickest below the guts of valleys. This latter point suggests that the unconsolidated rock is at least partly of colluvial origin. This aquifer may be an unreliable source of water due to the restricted dimensions of the aquifer and flows may be expected for only short periods of time after heavy rainfall. Groundwater flow direction would follow the topography.

(2) The rubbly and vesicular tops and bases of lava flows. These are potentially good aquifers; where the vesicles are interconnected with joints and fractures high permeabilities and porosities can be expected even though the aquifer is probably fairly thin (0.5 m). Such an aquifer is believed to feed Hambess spring which maintains a constant discharge throughout the year (45 m^3/d). In the centre of the island late hydrothermal activity and associated secondary mineralization has filled the vesicles and as a consequence reduced the porosity.

(3) Jointed and fractured massive basalt. Where the joints are regular and open quite high permeabilities can be expected even in the massive basalt forming the centre of the flow. Culshaw (1975) estimated the permeability of the jointed basalt flows at 7-200 m/d using an equation for the permeability of a planar array of parallel smooth cracks as given by Louis (1969) as:

$$K = g e^3 / 12 \nu b$$

where g = gravitational acceleration (9.8 m/sec^2)
e = opening of joint or fissure (0.1-0.01 cm)
b = spacing between joints (0.3 m-1.0 m)
ν = coefficient of kinematic viscosity

The porosity (or storage) of such fractured hard-rock aquifers is generally low typically 0.5-5%. It should be noted that both vesicular and jointed basalt aquifers may feed springs flowing from the weathered mantle (Fig. 4).

The vesicular and jointed basalts are referred to as 'deeper' aquifers to distinguish them from the shallow aquifer within the weathered mantle.

5.2 *Aquitards.*

The deeper aquifers are separated by thin (typically 0.2-2 m thick) tuff layers. These layers can be persistent over hundreds or even thousands of metres (Baker, 1968). In the upper catchment of Fishers Valley a number of springs are apparently flowing from the same level indicating the continuity of the red tuff aquitard. Groundwater may seep across this layer where it is thin, fissured and/or broken by tree roots.

The aquifer system can therefore be represented by a series of water-table aquifers (jointed massive basalt or fractured 'rubbly' flow tops) separated by pyroclastic (tuff layers). Groundwater flow is essentially vertically downwards until a tuff layer is encountered. Flow then occurs along this contact (groundwater flow in these deeper aquifers is therefore likely to follow the dip of the strata) until it discharges at the surface as a spring. Water then flows along the surface and/or within the weathered rock/soil before seeping to deeper layers when permeable strata is encountered (Fig. 4). It is by these means that the lower aquifers (below 500 m amsl) are thought to be recharged since direct infiltration from rainfall below 500 m amsl is not likely due to the lower rainfall and higher evaporation rates, although the lack of soil (and therefore a soil moisture deficit) may mean that during the occasional heavy storms some direct recharge would occur.

In the southern part of the island, in the Sandy Bay catchment, the strata is dipping to the north (the strata dips radially outwards from the south so that in the other valleys, the rocks dip down the valley towards the sea - i.e. dip slope valleys) and these scarp face springs are likely to drain a smaller groundwater catchment than the corresponding dip slope sources and this may explain the more variable flows recorded by Dennis (1973) in Sandy Bay during an extended dry period.

5.3 *Spring Flows.*

Spring discharges on the island vary from more than 300 lpm to less than 1 lpm but are mostly less than 20 lpm (Table 1). Plots of spring flow versus time are a useful guide to the properties of the aquifer. The variation in flow is related to the variation in groundwater storage. In the case of thick porous aquifers where the change in storage through the year is small compared to the total storage the spring discharge will remain constant. Conversely in the case of thin aquifers of low storativity, similar to the weathered mantle described earlier, changes in storage are likely to be large in comparison to total storage and as a result the groundwater discharge is very variable. Several examples of spring discharge with time are shown in Figs. 5, 6. The example of Hambess Spring was mentioned earlier where a constant discharge is maintained throughout the year indicating the considerable storage of the basalt aquifer feeding the spring.

Most springs show a variation in flow through the year, with the dry weather flow usually amounting to between ½-¼ of the maximum discharge. Spring flows normally increase during the recharge period (June-August). Two examples are shown (Figs. 5 & 6) where an increase in flow was recorded during June (1980, 1981) shortly after a period when infiltration to groundwater was calculated to have occurred (section 6.1) - this confirms that the recharge model is broadly accurate.

Two points should be noted:

(1) Peak spring flows may not be recorded until several weeks after infiltration occurs (i.e. Luffkins Spring, Fig. 5).

(2) Small increases in spring flow occur outside the period of calculated recharge and probably correspond to a rapid component of recharge which bypasses the soil zone.

5.4 *Groundwater Flow.*

Groundwater flows from the recharge area to the points of discharge. The main recharge area on St Helena is in the centre of the island where the elevation exceeds 500 m; at lower elevations the lower rainfall and higher evaporation rates makes infiltration through soil unlikely. The absence of a continuous soil zone below 400 m (and hence the lack of a soil moisture deficit) will mean that some recharge may occur, although since the rainfall is of low intensity, infiltration will probably be limited.

The area below 500 m amsl occupies nearly 80% of the total area of the island and, even if only a small percentage of the rainfall infiltrates to groundwater it could possibly make a significant contribution to recharge. However, in this report, recharge below 500 m, was on balance, considered negligible although this may be an oversimplification.

The main groundwater 'losses' in the system are:

(1) Groundwater seepage, over a wide front, into the ocean probably at or below sea level.

(2) Springs - groundwater losses from springs can be further divided into 3 types, (a) groundwater used for abstraction, (b) groundwater feeding perennial streams that eventually flow into the ocean, (c) evapotranspiration losses from the shallow groundwater table by thick vegetation growing in the guts.

Frequently streams issuing from springs at high elevations flow overground for 10's or 100's of metres before seeping back into permeable bedrock and thus recharging lower aquifers. The groundwater system is summarised in Fig. 7.

5.5 *Groundwater Quality.*

Groundwater quality of the springs above 500 m (amsl) is good (Table 2); the electrical conductivity being generally less than 500 micromhos per cm. However at lower elevations, the water becomes more saline and highly sodic, and is less suitable for irrigation.

Late Tertiary sea level changes may have resulted in some of the island at elevations of up to 320 m being inundated with seawater (Univ. College London, 1981). If that was the case then the increasing salinity of the streams at lower elevations may be partly a result of incomplete flushing of remnant seawater trapped in the strata.

The calcium to magnesium ratio of the more saline spring waters approaches that of seawater (Table 2) possibly indicating that the increase in salinity is a result of mixing with seawater, however this is based on a very limited number of analyses and more data would be required to confirm this.

It ought to be mentioned that in fractured aquifers rapid groundwater flow through fissures can occur without natural filtering of the water. This is especially important where springs are located downstream of cesspits. Drinking water taken from springs downstream of houses should be either treated or boiled before use.

6. RECHARGE - WATER BALANCE STUDIES

It is clear that the inputs into the groundwater system must balance the outputs; a water balance equation for the island can therefore be written:-

$$R = E + A + D + \Delta s$$

where R = infiltration in the centre of the island above 500 m
E = evapotranspiration losses from springs and seepages
A = groundwater (spring) abstraction
D = groundwater component of discharge to the ocean
Δs = change in groundwater storage

6.1 *Infiltration to Groundwater.*

The following assumptions were made in the calculation of infiltration:

(1) The infiltration to groundwater only occurs when the soil moisture deficit is zero (the soil is at field capacity).

(2) Runoff (other than baseflow) was considered negligible for the upland vegetated areas.

(3) Infiltration was calculated as the difference between rainfall and evaporation (daily figures were used), once the soil moisture deficit has been reduced to zero.

(4) A root constant of 100 mm was used for the vegetation - a mixture of grassland, woodland and flax. When the soil moisture deficit exceeds the root constant the actual evaporation rate falls to 1/10 of the potential rate. The potential evaporation rate used was based on the Penman formula using an assumed reflection coefficient of 0.2.

(5) The rainfall at Hutts Gate was used to estimate infiltration above 500 m. This station (el. 630 m) tends to record lower rainfall than other stations at similar elevations.

The mists which cover the centre of the island during the wetter periods are thought to have a considerable influence on recharge. Potential evaporation rates will be reduced and interception by plants could increase precipitation. The latter process is very difficult to quantify - much of the intercepted mist may be evaporated (once the mist clears) from the vegetation canopy before reaching the ground. In this report, the rainfall, as measured at Hutts Gate, was increased by 10% to allow for mist interception.

(6) The starting point for the calculation was taken as July 1979 when the soil moisture deficit was considered to be zero. The recharge for the period June-August 1980 and June-August 1981 was calculated (Table 3).

The average annual recharge probably lies between 1.5-2.5 x 10^6 m^3/yr since the rainfall for the period September 1979 to August 1980 was below average whilst the period September 1980-August 1981 experienced slighly higher than average rainfall.

6.2 *Groundwater Discharge to the Sea.*

Groundwater discharge to streams flowing to the sea form a considerable part of the groundwater losses. Spring and stream flows have been measured earlier, Kopec (1969) and Dennis (1973). In trying to estimate the mean discharge to the ocean, the results of Dennis (1973 and Kopec (1969) were used. It should be mentioned that Kopec's measurements were made in January/February 1969 and represent dry weather flows. Dennis' measurements cover 3 periods - March 1973, July-September 1973 and November-December 1973. The former measurements represent the dry weather flow following the period March-August 1972 when above average recharge occurred. The rainfall in 1973 was considerably below average and recharge, if it occurred, was very low, therefore the latter observations probably represent near minimum flows.

In estimating groundwater discharge to streams (and hence to the sea) the location where the largest dry weather flow occurs was chosen since losses to permeable bedrock can occur even at a short distance from the sea. This is well illustrated in Lemon Valley where the dry weather flow declines over a distance of about 1 km from 90 lpm (at an elevation of about 100 m) to 12 lpm at the mouth of the valley. The groundwater losses to the sea have been estimated at nearly 1 x 10^6 m^3/yr (Table 4) or about half the average annual recharge.

No data is available to estimate the seepage losses, over a wide front, to the sea - but this could be a significant component of the water balance.

6.3 *Abstraction.*

Groundwater abstraction (from spring sources), mostly for domestic water supplies, has been estimated at about 0.4×10^6 m^3/yr (Table 5).

6.4 *Groundwater Storage.*

No estimate of changes in groundwater storage can be made as there is no water level data.

6.5 *Evapotranspiration Losses.*

Along the margins of many guts and small valleys thick and luxuriant vegetation grows indicating the existence of shallow groundwater, even when springs are not flowing.

Evapotranspiration is likely to be close to the potential rate and groundwater losses of more than 0.25×10^6 m^3/yr have been calculated assuming an area of 0.1 km^2 (0.4% of upland area) and an average daily evapotranspiration rate of 7 mm.

6.6 *Groundwater Balance.*

It must be stressed that this water balance is only approximate and errors are likely to be large. However it does show that considerable quantities of groundwater are being lost both to the sea and to evapotranspiration. Present abstraction accounts for only about 20% of the estimated recharge and so the potential for increased development of springs exists.

7. DEVELOPMENT

7.1 *Present Abstraction System.*

Less than a quarter of the average annual recharge to groundwater is presently being developed. Groundwater sources are restricted to springs - no boreholes or dugwells have been constructed on the island.

There are two types of spring intake:

(1) A surface intake essentially consisting of a concrete chamber (1 m^3) positioned so that the spring flows into the chamber and is then piped under gravity (Fig. 8).

(2) An underground intake. In this case some of the unconsolidated material around the spring is cut back and a permeable chamber filled with gravel, surrounding the outlet pipe, is placed in the excavation. The chamber is then covered over with the fill.

However these systems are not very efficient since:

(1) Seepage occurs often over a wide front - around and under the intake; leading to high evapotranspiration losses.

(2) There is frequently a problem of silting up of the intake and pipes.

These intakes cost about £500 and £2500 for a surface and underground intake respectively. During the mid 1970's some underground intakes were installed costing up to £10,000 and these have proved not totally successfull (D Brown, pers. comm.) - mostly as a result of silting up of the gravel pack.

7.2 *Domestic Water Shortage*.

Some areas (Thompson Hill, Blue Hill, Green Hill etc.) have no piped supply. These areas rely on household rain catchments and in dry weather on bowsering from Jamestown. The cost of this bowsering for 1982-1983 was £12,000 in terms of labour and fuel alone. If the cost of a bowser, (£20,000) is included with a ten-year life the cost of bowsering is increased to more than £14,000 p.a.

The supply of water to Thompson Hill and Blue Hill (1.5 and 3 m^3/d respectively) accounts for 70% of the total cost of bowsering. Such quantities ($\sim$ 1-2 lpm) may be obtained by developing existing seepages using horizontal boreholes.

7.3 *Horizontal Borehole*.

A plan view of a typical spring is shown (Fig. 9a). The most effective intake for such springs is thought to be a horizontal borehole of about 50 mm diameter penetrating for 20 m into the fractured compact rock (Fig. 9b). The horizontal borehole has two advantages over the present intakes namely:

(1) The weathered-unconsolidated basalt can be cased off - thus reducing the problem of silting-up. This assumes that the main aquifer is within the compact jointed basalt.

(2) The groundwater is likely to be induced along the borehole - thus preventing seepage over a wide front and the consequent large evapotranspiration losses.

To summarise, horizontal drilling into a spring is designed to make use of groundwater which is presently being 'lost' either by seepage through the soil and highly weathered rock to deeper layers or by evapotranspiration by vegetation along the gut. Water from the horizontal borehole can then be piped, under gravity, to the area where it is required.

7.4 *Agriculture*.

The main limiting factor to increased agricultural output is the lack of water. Rainfall is very variable and crop yields are as a result also variable, (in some cases crops can be completely lost). The use of supplementary irrigation would both safeguard against crop failure and increase yield. Typical farms range in size from less than 0.1 ha -0.4 ha and potatoes are the main crop. To assess the water requirements the following assumptions were made:

(1) A plot of 1 acre was used.

(2) Two crops of potatoes - the main crop February-May and subsidiary crop June-September - were considered.

(3) The 80% probability rainfall was considered.

(4) A drip irrigation system is being used.

The results given in Table 6 show that the maximum quantity of water required would be 5 lpm (7.2 m^3/d) during the month of April.

An attempt has been made to give some idea of the benefits that can be expected from irrigation (Table 7). Two levels of yield were considered and will depend on the type of soil etc. No figures for the increase in yield that can be expected for an irrigated subsidiary crop were available - although it is likely that the benefit of irrigation will be less than for the main crop since the deficit water requirement is lower (Table 6). The costs and benefits of irrigation, assuming only 1 crop is grown (the main crop Feb-May) are presented in Table 7. This shows that the gross returns on high yielding land are more than doubled if irrigation is practised. The low yielding land does not appear suitable for agriculture even when irrigated.

8. CONCLUSIONS

8.1 *Summary*.

(1) The potential for further development of groundwater exists, at present less than 25% (0.4 x 10^6 m^3/yr) of the average annual recharge is being abstracted.

(2) It appears that most of the groundwater is recharged in the upland centre of the island by direct infiltration - this is the area where the water is mostly required. Essentially the problem is one of how best to capture this water at high elevations before it is lost to the lower valleys. Groundwater flows out of these high level (> 500 m) basalt flows either as springs or as subsurface seepage through highly weathered rock and soil. It is this latter component which it is hoped to intercept by horizontal boreholes.

Little can be said about developing the groundwater storage of these aquifers since there is no data on water levels or on aquifer storativity.

(3) Existing intakes are inefficient and quite costly (up to £2,500) and in some cases during the digging out of the spring the groundwater flow was completely lost. This is thought to be a result of disturbance and fracturing of the impermeable tuff layer resulting in considerable groundwater seepage losses across the tuff.

8.2 *Recommendations.*

It is recommended that a short trial drilling programme be carried out to investigate further and confirm (or otherwise) the aquifer system suggested in this report.

Drilling would be confined to 4-5 sites:

(1) In promising locations, near existing seepages, where domestic supplies are most needed, i.e. Thompson Hill, Blue Hill, (Figs. 10, 11).

(2) In the area of High Peak where:

- (a) access is good,
- (b) potential for development of houses with small market garden plots exists,
- (c) a number of small springs and seepages not used at present occur.

It is proposed that at each site the soil and unconsolidated rock be cleared so that drilling can be started in compact but weathered rock. In the event of no water being encountered a vertical borehole would be drilled from above the site (Fig. 12) so that the detailed strata and depth to water level could be observed. A second horizontal borehole may then be drilled to intersect the aquifer delineated by the vertical borehole. Therefore at each site up to 3 boreholes may be drilled, 1 vertical and 2 horizontal. The drilling programme will be flexible depending on the results obtained in the field.

It must be pointed out that at some sites the unconsolidated rock may be the main water producing zone. Provision should be made so that the drilling equipment is capable of drilling and lining a borehole with a suitable gravel pack.

Further work to determine more accurately the major components of the water balance may be necessary (perhaps by looking at a catchment in some detail) if development of the groundwater resources beyond the initial drilling programme is envisaged.

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List of Tables.

TABLE 1. FLOW MEASUREMENTS

Spring	No*	Approx. Elevation (m. amsl)	Discharge lpm					
			Kopec (1969)	Dennis (1973) Mar-May	Dennis (1973) Jul-Sept	Dennis (1973) Nov-Dec	1980 Jan-Feb	1981 Jan
Leggs Gut	2	680	16.7	6.0	13.5	4.5	n.r.	n.r.
Luffkins	6	600	1.7	n.r.	0.6	0.15	1.0	1.0
Osbornes	11	600	12.2	n.r.	n.r.	0.45	n.r.	n.r.
Frenches Gut	5	680	4.2	7.0	n.r.	4.2	n.r.	n.r.
Broad Bottom	7	540	n.r.	4.2	8.9	8.9	n.r.	n.r.
Willow Bank	7	480	n.r.	n.r.	n.r.	n.r.	90	n.r.
Drummonds Pt.	10	220	351	182	187	177	n.r.	n.r.

* (see enclosure II)

TABLE 2. ANALYSES OF SPRING WATERS (Kopec, 1969)

Spring	Frenches Gut	Bates Spring	Wells Gut	Leggs Gut	Fishers Valley	Salt Spring	Sheep Pound Gut
Elevation (m. amsl)	680	680	680	680	320	350	280
Catchment	Lemon Valley	Fishers Valley	Fishers Valley	Fishers Valley	Fishers Valley	Ruperts Valley	Turks Cap Bay
Electrical conductivity micromhos/cm at 25°C	260	200	160	150	1840	3120	22800
Ca^{2+}	5.0	3.2	3.2	3.2	34.3	71.6	287.0
Mg^{2+}	4.8	3.4	3.8	3.4	57.6	117.0	655.0
Na^{+}	32.0	28.0	23.0	20.0	260.0	394.0	4110.0
SO_4^{2-}	2.0	7.0	5.0	<1.0	<1.0	196.0	1520.0
Cl^{-}	64.0	50.0	39.0	39.0	585	906.0	7850
HCO_3^{-}	24.0	18.0	24.0	18.0	110.0	98.0	49.0
NO_3^{-}	<0.1	<0.1	<0.1	<0.1	<0.1	2.0	8.6
Ca/Mg*	1.04	0.94	0.84	0.94	0.59	0.61	0.43

* Ca/Mg for seawater = 0.32

TABLE 3. GROUNDWATER RECHARGE.

Interval	Rainfall[1] (mm)	Months when infiltration occurs	Infiltration (mm)	Recharge[2] ($\times 10^6$ m^3)
Sept 1979-August 1980	587	June	16.2	
		July	6.1	
		August	5.8	
			28.1	0.75
Sept 1980-August 1981	847	May	-	
		June	34.0	
		July	39.3	
		August	43.4	
			116.7	3.1

1 Mean annual rainfall in the altitude range 492-656 m = 813 mm (after Simansky, 1967)
(Mean annual rainfall, Hutts Gate ∿ 760 mm)

2 Area of island above 500 m amsl = 26.6 km^2

TABLE 4. BASEFLOW DISCHARGE TO OCEAN

Catchment		Flow (m^3/d)	Comments
Sandy Bay		681	Mean daily flow
Shark's Valley		735	Dry weather flow, Kopec (1969)
Fishers Valley		336	" " " " "
James Valley		195	Measurements 1980 - 1981
Lemon Valley			
Bevins Gut	127 }	204	Dry weather flow, Dennis (1973)
Broad Bottom	77 }		" " " , Kopec (1969)
Deep Valley		145	Dry weather flow, Kopec (1969)
Powells Valley		50	" " " " "
Manati Bay Stream		50	" " " " "
Thompson Valley } Old Womans Valley }		136	Estimated based on size of catchments
Swanley Valley		91	Estimated from dry weather flows observed May 1983.
		2623 m^3/d	$\equiv$ 0.96×10^6 m^3/yr

TABLE 5. GROUNDWATER ABSTRACTION

Catchment	Annual Abstraction (x 10^6 m^3/yr)	Purpose
James Valley	0.29	Domestic
Sandy Bay	.033	Domestic + Irrigation
Fishers Valley	.075	Domestic
TOTAL	0.40	

TABLE 6. IRRIGATION WATER REQUIREMENT*

	MAIN CROP: POTATOES				SUBSIDIARY CROP: POTATOES			
	Feb	March	April	May (18 d only)	June	July	August	Sept (18 d only)
E_{To} (mm)	78	84	65	34	58	55	68	35
K_c	0.57	1.05	1.10	0.84	0.66	1.05	1.13	0.84
E_{Ta} (mm)	44	88	72	29	38	58	77	30
80% probable rainfall (mm)	29	45	18	14	42	44	37	13
Deficit (mm)	15	43	54	14	0	14	40	17
Water Requirement (lpm)	1.4	4.0	5.1	2.3	0	1.3	3.8	2.7

* Figures prepared and supplied by M Holland, ODA agronomist, St Helena.

E_{To} = potential rate of evapotranspiration

K_c = crop factor

E_{Ta} = $K_c \times E_{To}$ = actual transpiration by crop at that stage of development

TABLE 7. SUMMARY OF COSTS AND BENEFITS OF IRRIGATION*

Costs	Cost per acre £
Cultivations	178
Fertilizer (60 kg amm. nitrate/acre)	34
Seed	292
Blight control (4 sprays)	85
Pest control (3 sprays vs. caterpillars)	20
Ridging/Weeding (by hand)	44
Harvesting (by hand)	89
	£742

Cost of trickle irrigation system per year (Appendix 1, 2) £280
Cost of borehole per year (Appendix 2) £814

Returns

		Yield (tons per acre)			Value		
		High Value	Trash	Total	High Value[1]	Trash[2]	Total
Unirrigated	Low Yield	1.6	1.3	2.9	£ 573	£ 65	£ 638
	High Yield	3.2	2.8	6.0	£1146	£140	£1286
Irrigated	Low Yield	4.7	3.2	7.9	£1683	£160	£1843
	High Yield	8.0	8.0	16.0	£2864	£400	£3264

1 high value crop £358 per ton

2 trash valued at £ 50 per ton

Gross Margins:

Unirrigated	low yield:	loss (-£104)
	high yield:	£544 per acre
Irrigated	low yield:	£6 per acre
	high yield:	£1428 per acre

* This is based on a 1 acre plot growing potatoes as main crop (Feb-May) under high and low yield conditions (depends on soil type etc).

The table was based on information prepared by Mr T Green (ODA agronomist, St Helena).

TABLE 8. DRILLING PROGRAMME - COSTS

(No. of boreholes ∿16)

Item	Rate	Quantity	Cost
Mobilisation/Demobilisation			£ 1,000
Hire of drilling equipment + 2 man crew (includes trailer, pump, augers)	£3200/week	8 weeks	£25,600
Subsistence - 2 man crew	£20/man/day	60 days	£ 2,400
Transport to island (of equipment)	£110 per m^3 (each way)	30 m^3	£ 6,600
1 Geologist	£400/week	12 weeks	£ 4,800
Subsistence - 1 man	£20 per day	60 days	£ 1,200
Plastic casing (blank - 4" or 3")	∿ £7 per m	160 m	£ 1,120
Plastic screen (¾")	∿ £10 per m	30 m	£ 300
Fuel	£50 per day	60 days	£ 3,000
Transport of team (3 men) to and from island			£ 4,000 est.
			£50,000

Local Inputs:

(1) Labour for (a) site preparation
(b) clearing track suitable for landrover
(c) drilling operations

(2) 1 Landrover L.W.B.

(3) 1 Water bowser or compressors

Pipe from intake to point of supply c. £2 per metre 3,000 m £ 6,000

APPENDIX 1. COST OF DRIP IRRIGATION SYSTEM*

	Quantity/Acre	Rate	Cost
½" black alkyl thin wall tubing	1687 m	£0.65/m	£1097
'Even trickle'			
trickle tubing	6110 m	£0.05/m	£ 306
drippers	11,246	£0.03	£ 337
stakes	11,246	£0.04	£ 450
T-pieces	51	£0.33	£ 17
labour cost to install	8 days	£5.50/d	£ 44
			£2251

* Assumes potatoes - 80 cm row spacing, 45 cm within row. One half inch main per 3 crop rows.

Data supplied and prepared by T Green, ODA agronomist, St Helena.

APPENDIX 2. ESTIMATE OF ANNUAL COST OF IRRIGATION SYSTEM

(A) Estimate of annual cost of drip irrigation system (by T Green, ODA agronomist, St Helena).

Assume (1) Main pipes, dippers and stakes and T-pice have expected life of 12 years.

(2) Trickle tubing has life of 3 years.

(3) Farmers purchase using an Agricultural Assistance Revolving Fund loan witb interest at 6%/annum.

Potatoes:

Annual cost	= purchase price/12 (1)	=	£162
	+ purchase price/3 (2)	=	£102
	+ 6% interest charges	=	£ 16
			£280

(B) Estimate of annual cost of borehole

Cost of borehole (Approx. £5000)

Assume a 10 year life, repayment over 10 years at 10% interest

Annual payment = £814

Total annual repayment £1094

Cost of a borehole is based on the cost of the drilling programme (Table 8) and assumes that only 10 successful production boreholes out of 16 boreholes drilled.

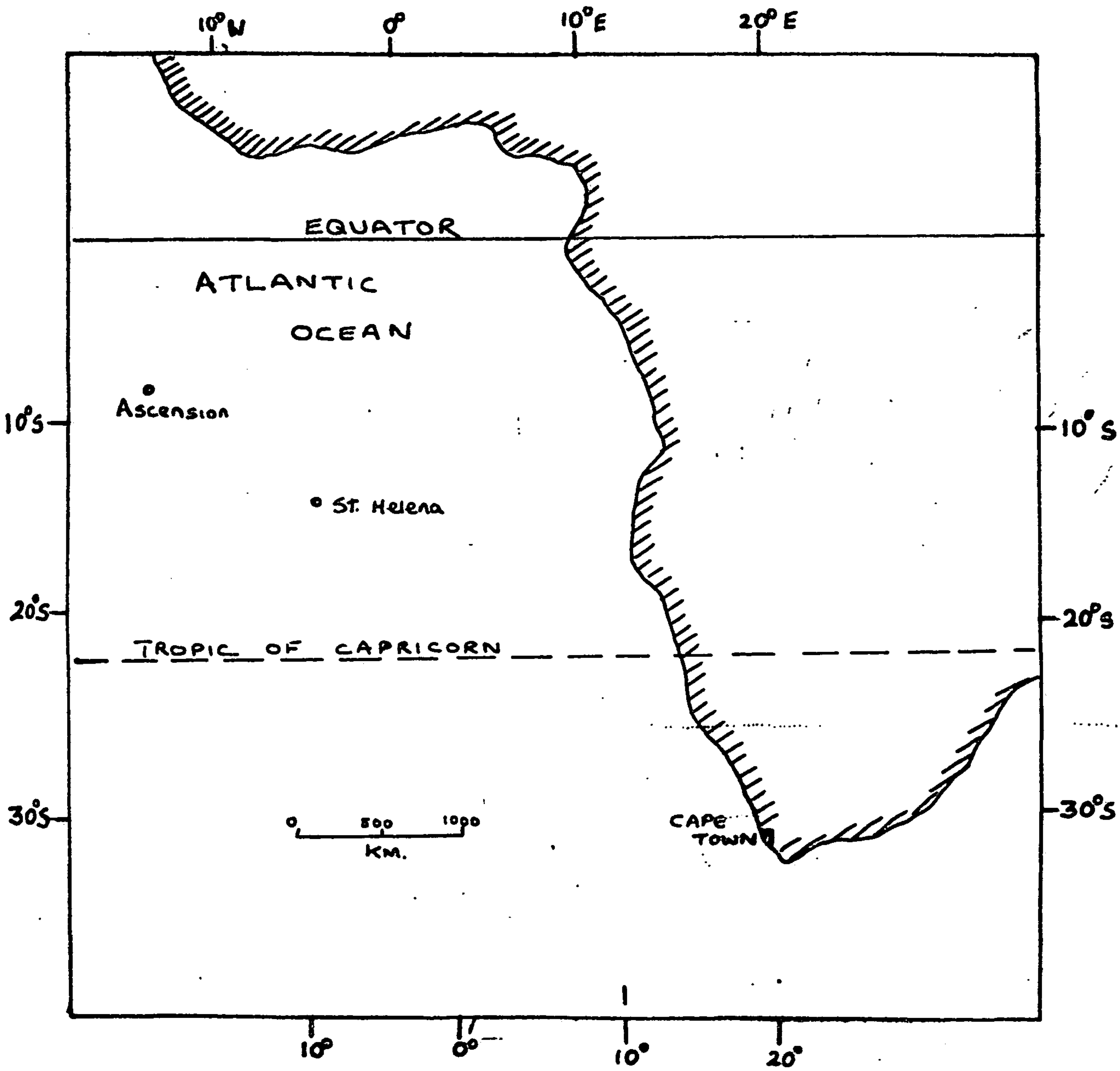


Fig1 Location Map of St Helena

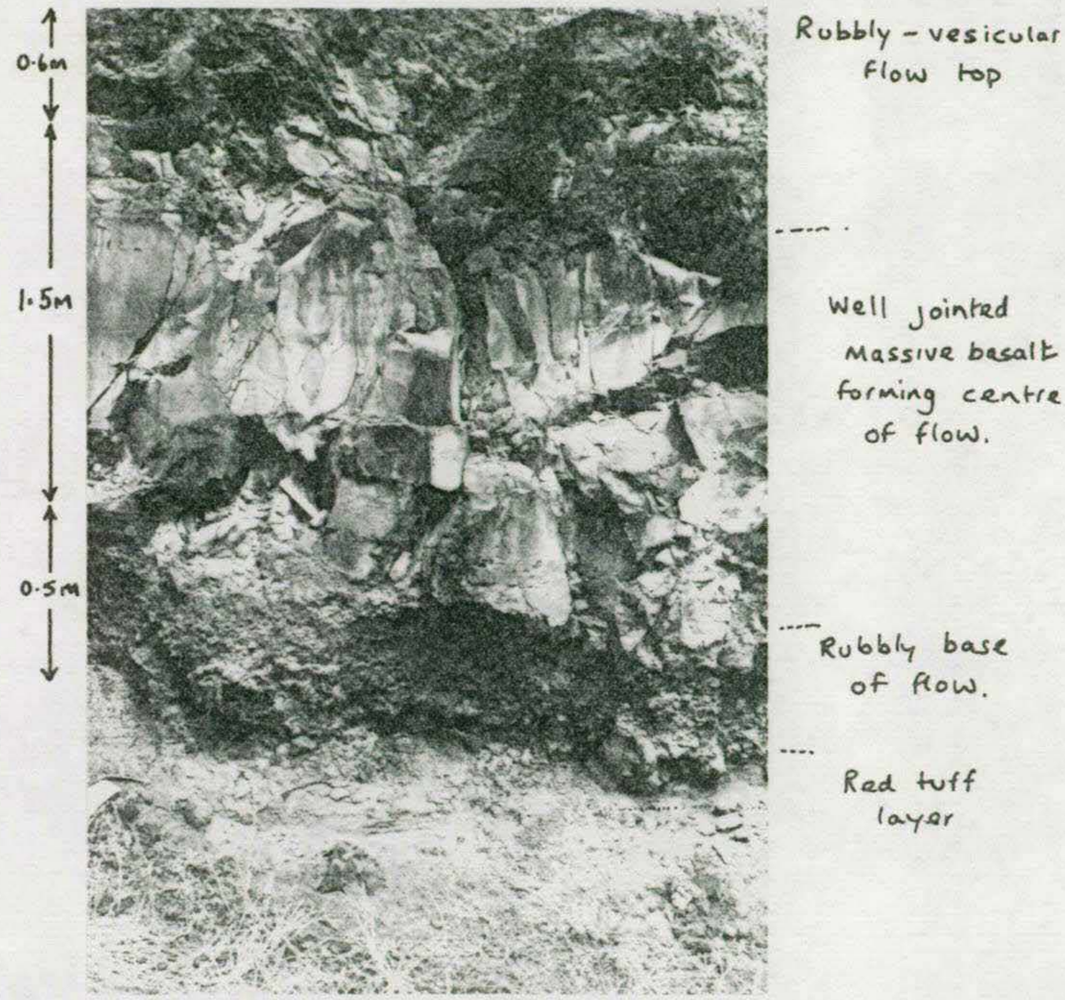
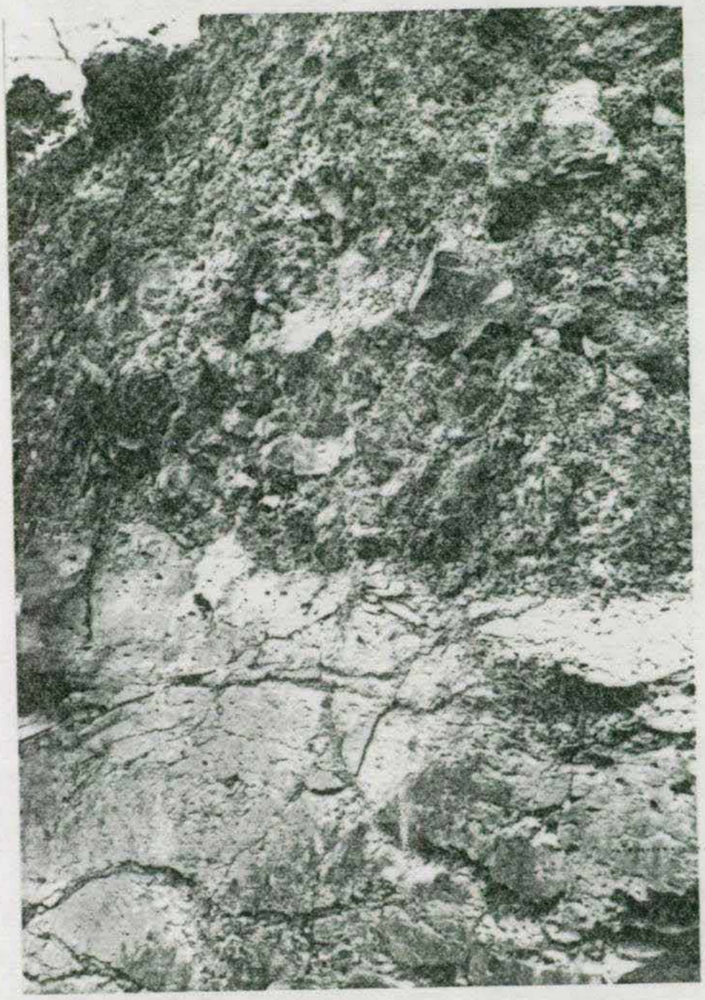


Fig 2 Section through lava flow



Highly weathered basalt (1-2m)

weathered but compact basalt

Fig 3 Section through Weathered Basalt

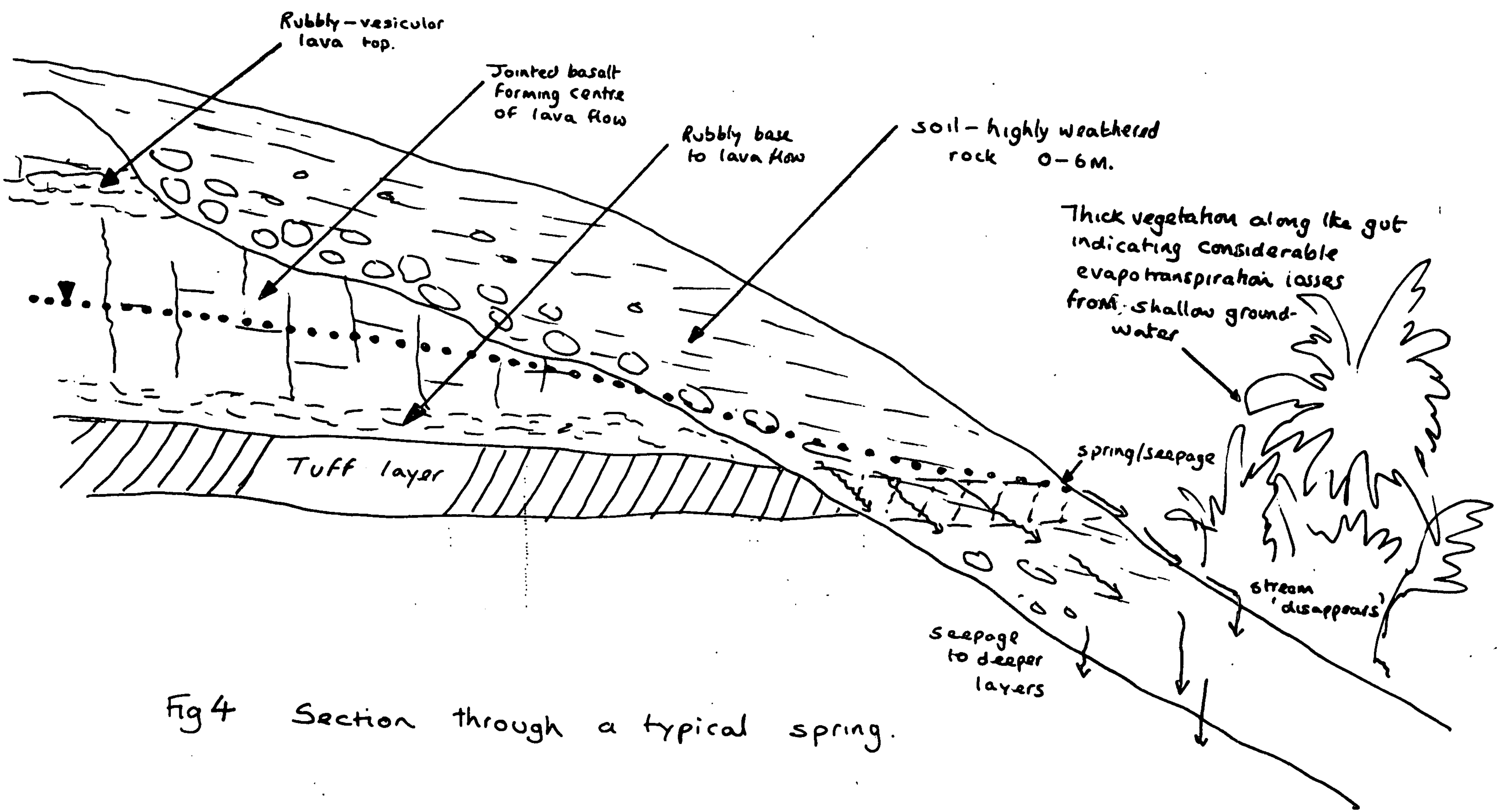


Fig 4 Section through a typical spring.

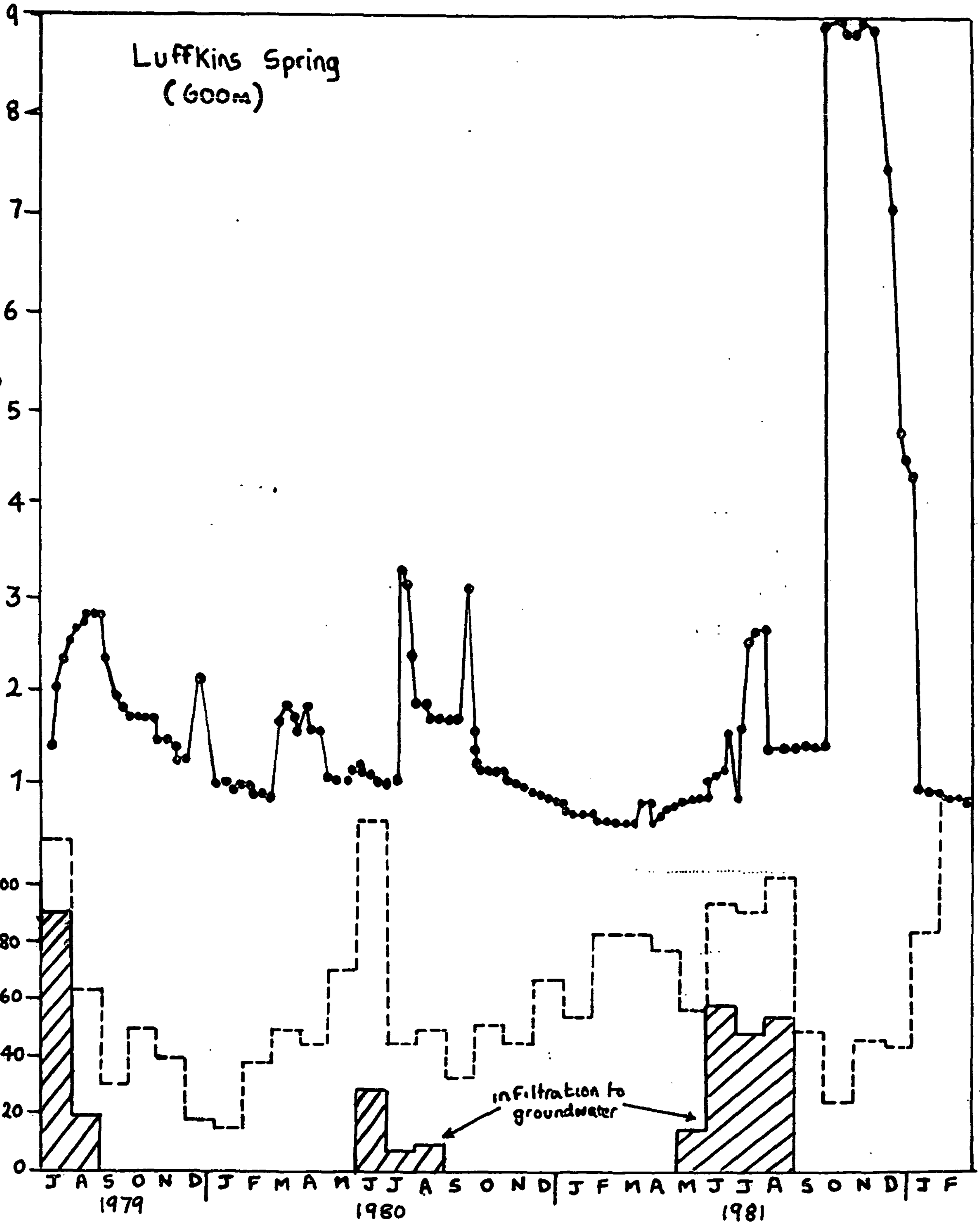


Fig 5 Seasonal Variation in Spring Discharge
- Luffkins Spring

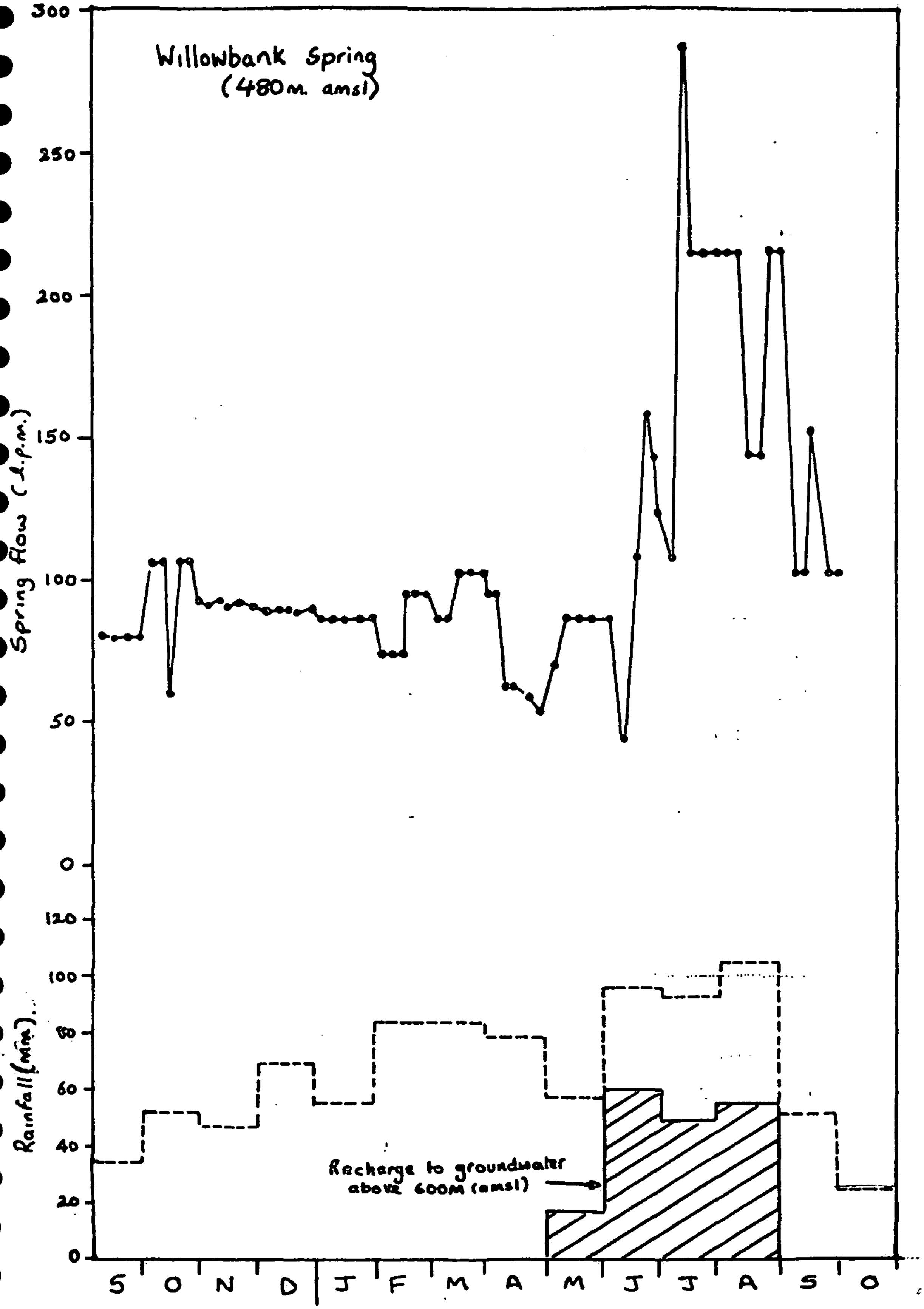


Fig 6 Seasonal Variation in Spring Discharge
— Willowbank spring

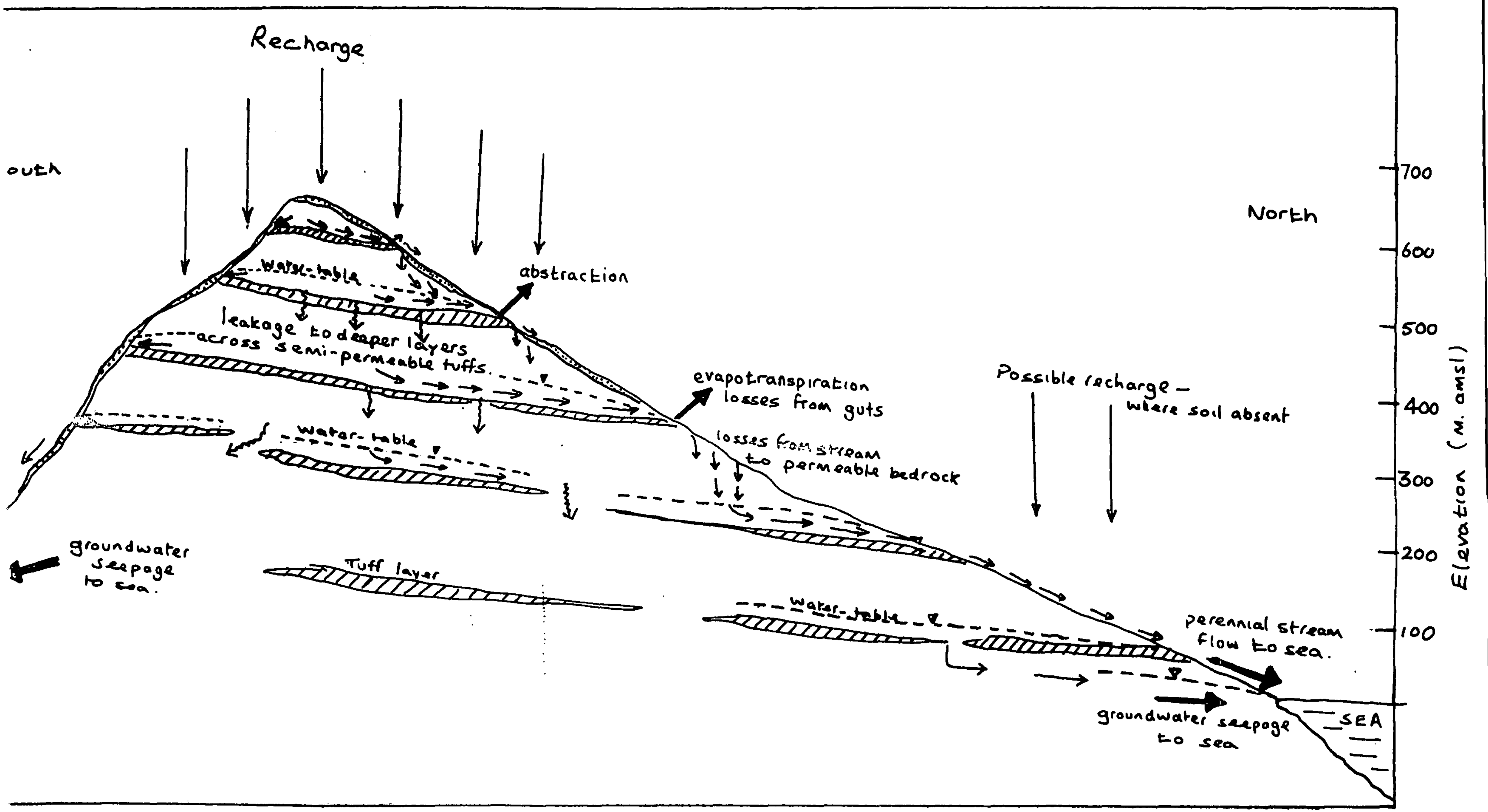
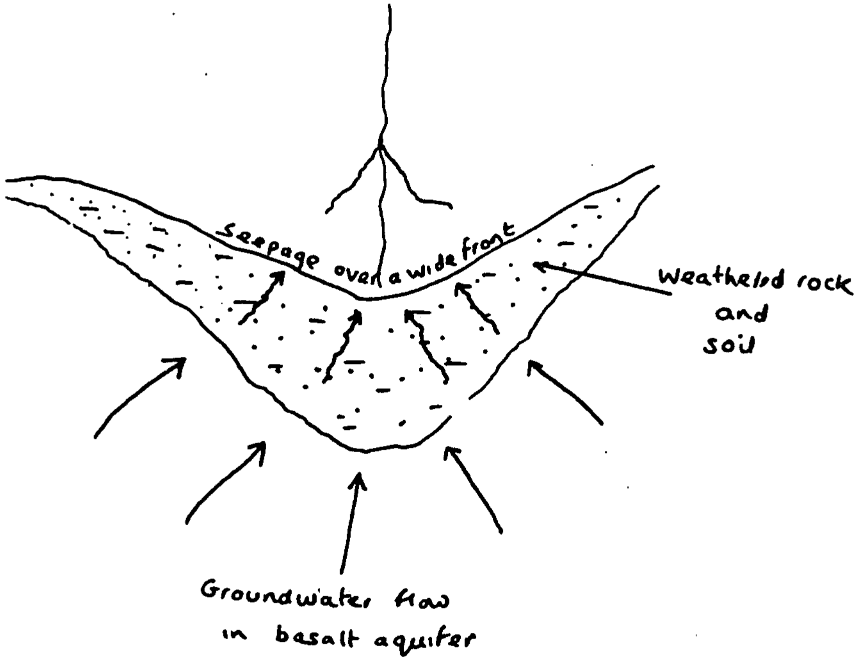
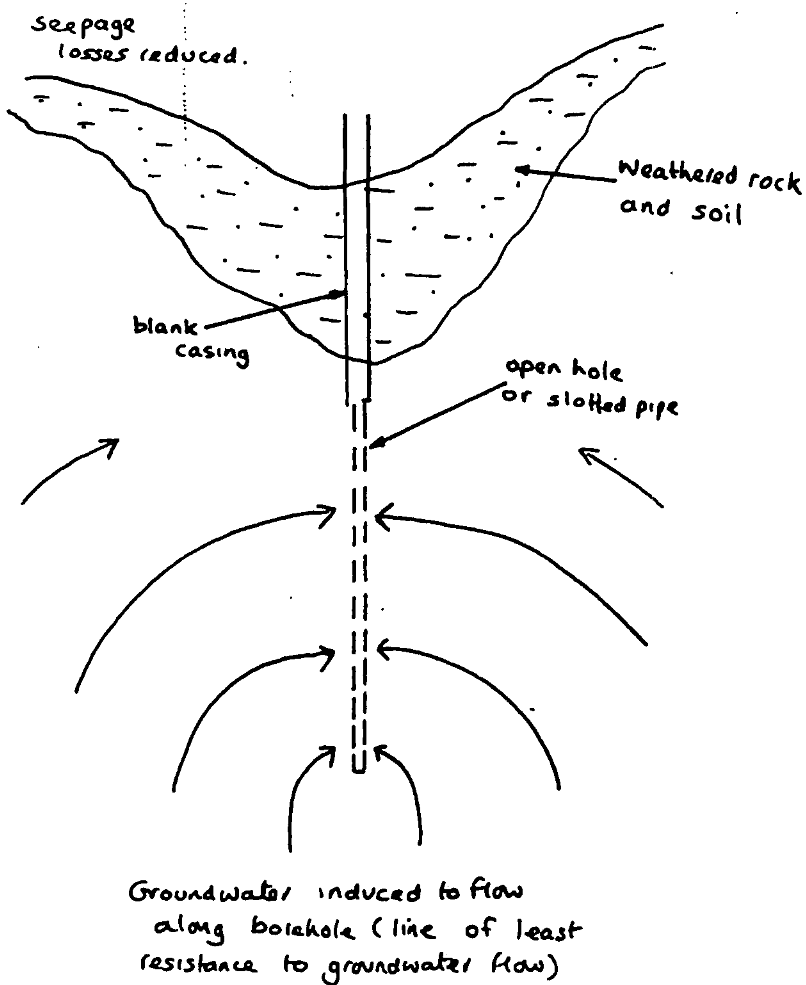


Fig 7   Section through the island showing the groundwater system

Fig 8 Typical intake – the thick luxuriant vegetation around intake indicates considerable evapotranspiration losses.



(a) Typical seepage / spring



(b) Resultant groundwater flow pattern after drilling horizontal borehole.

Fig 9. Plan view of spring / seepage.

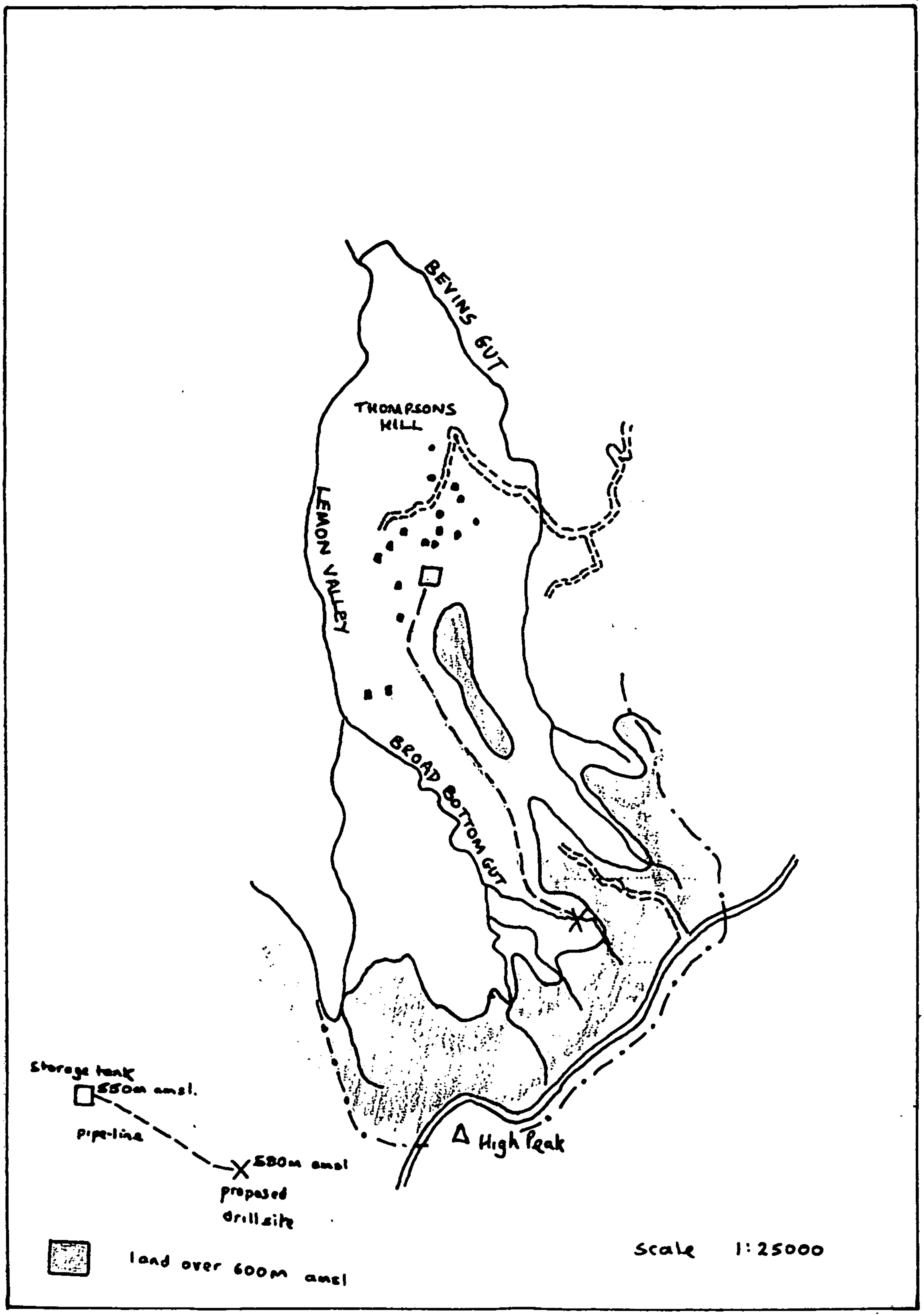


Fig 10 Proposed drilling site – Thompsons Hill area.

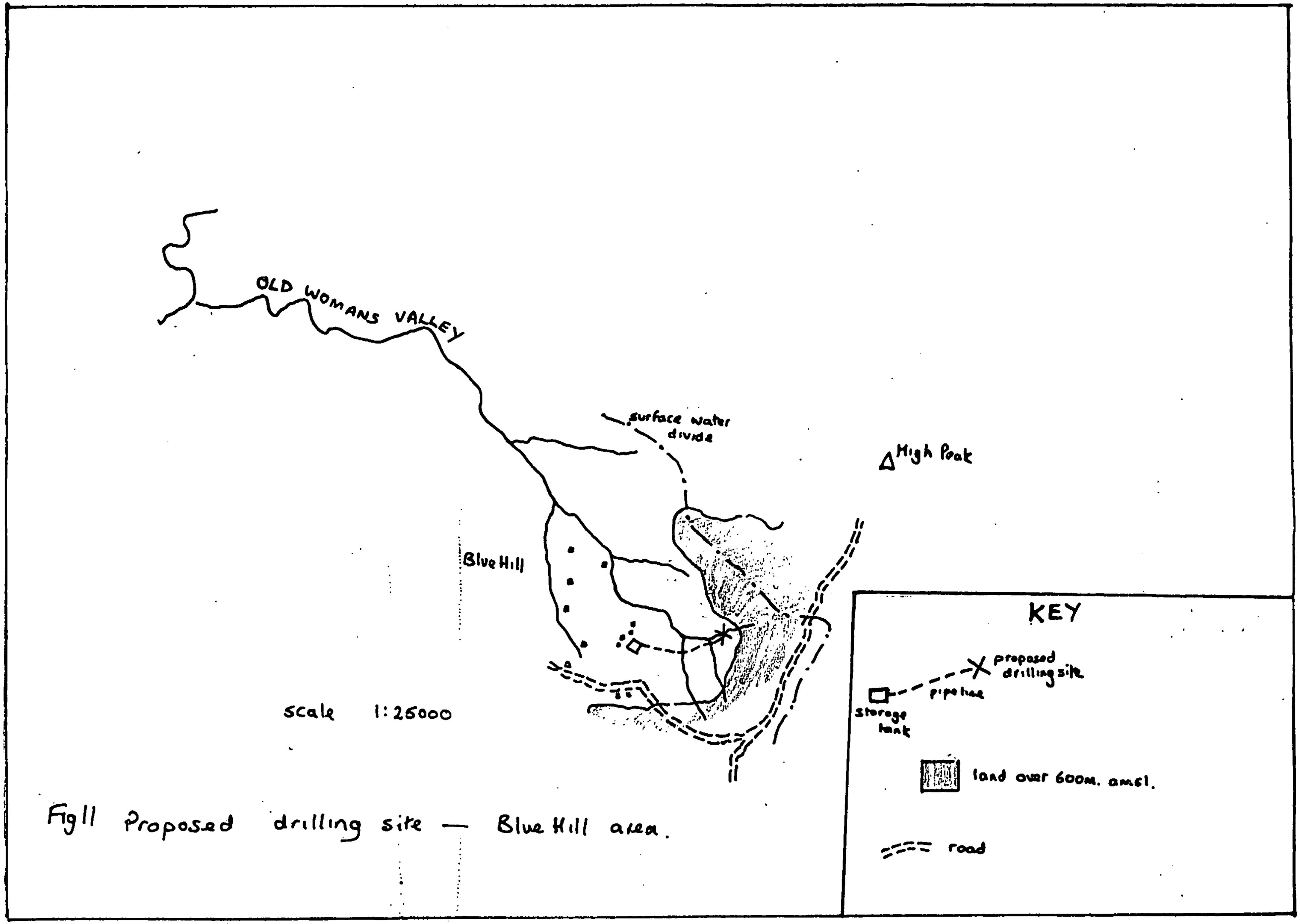


Fig 11 Proposed drilling site — Blue Hill area.

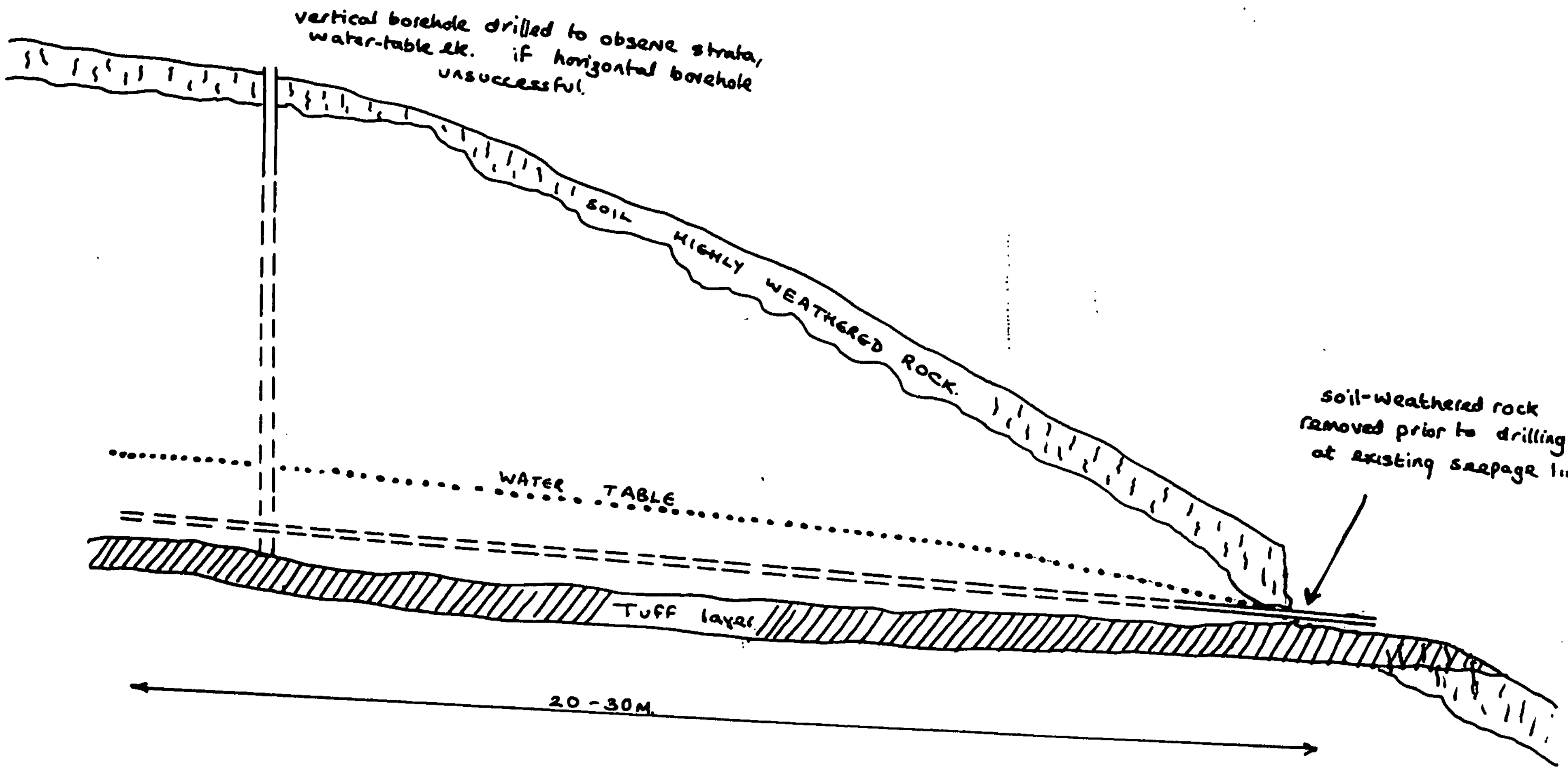
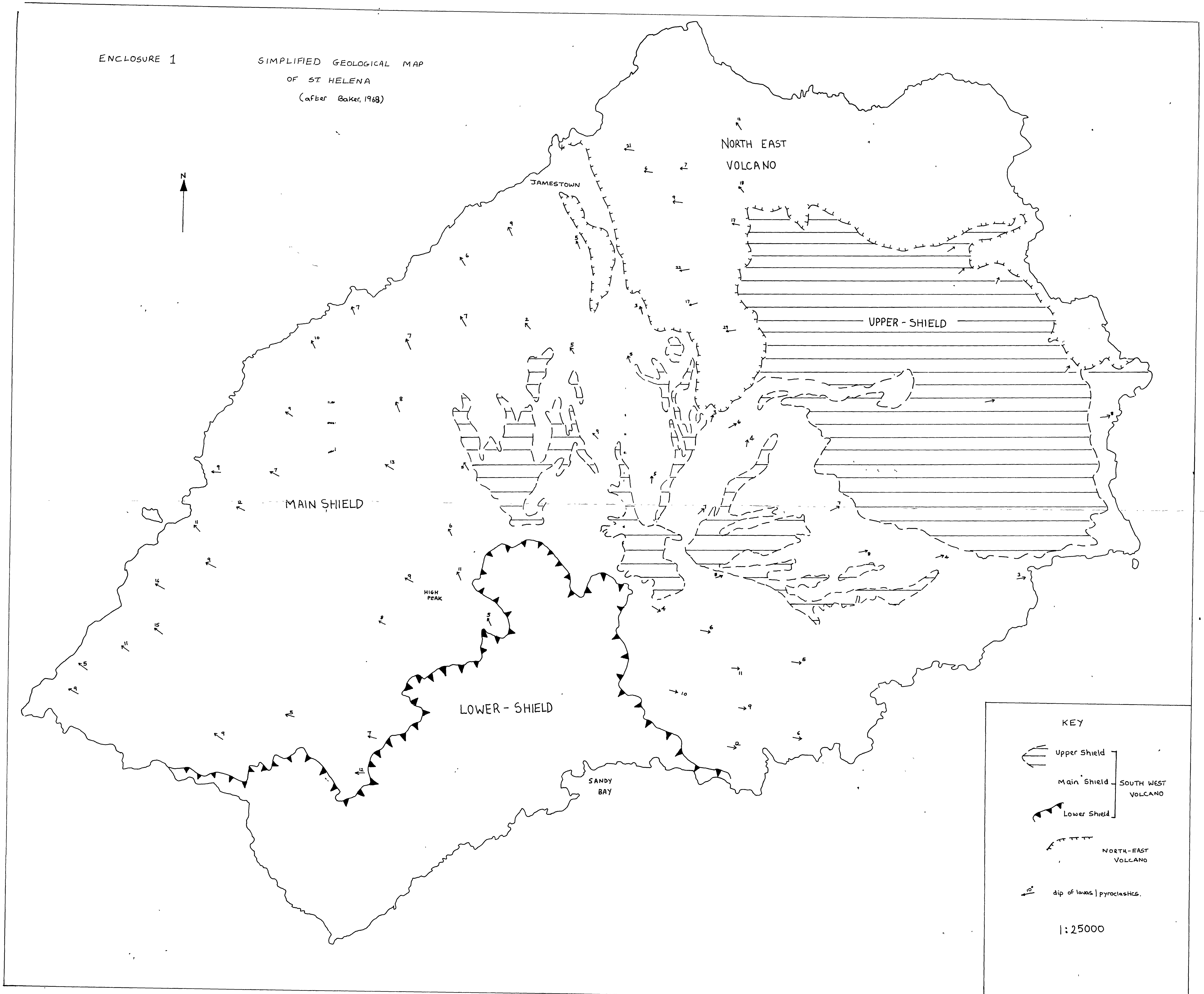


Fig 12 Sketch of proposed drilling at typical site


ENCLOSURE 1
SIMPLIFIED GEOLOGICAL MAP
OF ST. HELENA
(after Baker, 1968)
N
JAMESTOWN
NORTH EAST
VOLCANO
UPPER - SHIELD
MAIN SHIELD
HIGH PEAK
LOWER - SHIELD
SANDY BAY
KEY
Upper Shield
Main Shield
Lower Shield
SOUTH WEST VOLCANO
NORTH-EAST VOLCANO
dip of lavas / pyroclastics.
1:25000

WD/05/83/12

ENCLOSURE II