HYDROGEOLOGICAL ASPECTS ASSOCIATED WITH BRITISH IRONSTONE MINING

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ABSTRACT

The paper discusses hydrogeological effects encountered when room and pillar mining is used on a British ironstone deposit of Jurassic age. The production cycle, mine geology and localised groundwater system are discussed and four main sources of water access to the workings identified. A mechanism of induced micro-fractures superimposed onto an existing natural network is proposed for conditions where the ironstone roof beam remains intact. Similarily, a seasonal variation in mine water yield has been determined and is related to the overall groundwater regime. Individual areas of water access to the mine workings are identified and discussed along with their mode of operational de-watering. Finally, production hazards and problems caused by water are outlined in relation to the daily mine operation.

INTRODUCTION

The object of this paper is to examine the hydrogeological aspects of the underground workings at Santon Ironstone Mine, near Scunthorpe, the problems encountered and the methods and equipment used to deal with them.

Two mines, Santon and Dragonby, separated by a large fault existed within the Frodingham ironstone during the 1950's. A plan showing the location of the Frodingham orebody is given in Figure 1. The drivage of a connecting roadway during the late 1960's, resulted in the formation of one large complex known as Santon Mine. A work force of about 100 men, produced 20,000 tons of ore per week, by room and pillar methods on a two shift loading system. Water pumped from the combined workings totals 4500 m^3 (1 million gallons) per day or 1.6 m^3 (350 gallons) per ton of ore. An additional 25-30000 tons per week of ore from nearby opencast workings, supply a total of 50,000 tons per week of iron ore to the Scunthorpe steel making complex.

PRODUCTION METHODS

The room and pillar method used at Santon, consists of drilling and blasting 6 x 6 m rooms, leaving 15 m square pillars for permanent roof support. Figure 3 shows the layout of the combined Santon and Dragonby workings. The square pillar method is favoured to maximise production rates and minimise vehicle travelling distances when loading out ore. Trials indicated that road heading machines, such as the Dosco TB600, could be successfully used, but required separate drivages to achieve a room height of 5-6 m.

Drilling operations in the headings were carried out using a twin-boom Emico Secona ATH-24 jumbo, which produced 56 holes of 4 m depth at an average penetration rate of 7m/min. 110 kg of explosives/heading with instantaneous and ½ second delayed action electric detonators, fired in a burn cut pattern, produced 250 tons of fragmented ore. In each case firing would occur at the end of the afternoon shift to allow for the dilution of fumes.

The recently blasted heading would initially be made safe before loading out, by 'trimming' crews using pneumatic picks and trimming bars to clear any loose material from the roof and sides. Similarly, any pieces on the surface of the rock pile too large to travel the conveyor, would be broken at this stage. Caterpillar 980 load-haul-dump (LHD) machines would then transport ore from the rock pile to a Hopper/Plate feeder, where it is fed onto the conveyor system. The LHD machine has a 4 m^3 capacity bucket and is capable of delivering 550 tons of ore/shift to the conveyor at speeds of up to 24 km/hr.

The setting of supports within the remaining 2 m thick ironstone roof beam would complete the production cycle. Support consisted of 19 mm diameter by 1.5 m long full column resin roof bolts, set at a maximum spacing of 2 m. Drilling and setting of the roof bolts and holes was carried out using a Tamrock roof bolting machine.

Two separate production districts were operated on an 80 hour week, two shift system, using identical production cycles. However in the Dragonby 1 East development area, conditions were complicated by water problems.

MINE GEOLOGY

The Frodingham Ironstone comprises alenticular ferruginous bed, varying in thickness from 2-11 m, which lies within the Lower Lias of the Jurassic System. The orebody dips eastwards at 1 in 50, Figure 2, and is overlain by 80 m of variable Jurassic sediment in the Santon area. A major fault (Figure 3), with a throw of 27 m divides the workings into the Santon and Dragonby districts. Some smaller faulting is found within the workings, but are restricted to throws of less than 1 m.

The geological sequence overlying the orebody is shown in Figure 4. Lower Lias with a thickness of 70 m underlies the ironstone. This comprises of blue shaley clays interbedded with thin argillaceous limestone bands. Wilson [1], refers to these strata as the Blue Lias Clays.

Above the ironstone lies a further 45-55 m sequence of clays, also belonging to the Lower Lias. Mid-way, lies a band of ironstone known as the Pecten Bed, after the profusion of fossiliferous material found there. A thin band of sandy ferrugineous limestone, known as the Marlstone Rock, marks the junction between the Lower and Middle Lias. The nature of the Marlstone Rock varies regionally, with the development of an economic ironstone horizon, Wilson [1].

The Upper Lias, comprising 13-20 m of shales interbedded with thin mudstone and limestone bands, rests immediately upon the Marlstone Rock. This in turn is overlain by members of the Oolite Series (Inferior and Great) which comprise a variable sequence of sandstones, limestones, clays etc. The basal member is often known as the Northampton Sands or Lower Estuarine series and comprises a variable thickness of friable sandstone Wilson [1]. The Inferior Oolite Series contains the aquiferous Lincolnshire Limestone.

Superficial deposits consist of a limey sandstone (known as the Cornbrash) which in turn is overlain by a cover of sand and sandy soil.

Mineralogically the Frodingham ironstone comprises two distinct types, Whittaker [2];

1. A clay ironstone, containing limonitic ooliths in a clay matrix, with associated siderite and chamosite.

2. A limey ironstone, containing limonitic ooliths in a sideritic limestone.

Pyrite in the form of nodules is also encountered within the orebody.

THE OCCURRENCE OF MINE WATER

A daily total of 4500 m^3 of water is pumped from the combined Santon and Dragonby workings. Close examination reveals that although water occurs throughout most of the mine, its method of entry is restricted to four main sources. These are listed below and discussed separately in further detail:

1. The Entrance Portal.
2. Near Portal Feeders
3. Faults and Fissures
4. Roof Instability

1. The Entrance Portal

This water flows directly through the entrance portal from surface, along the access road and via roadside channels to the workings. Its origin is principally runoff from the localised portal surface catchment, but with a base component supplied by the superficial and near surface geology. The quantity varies with both rainfall and season, but measurements reveal 130-320 litres/min (30-70 gpm) entering during the summer months.

2. Near Portal Feeders

Along both sides of the access road from the portal towards the workings, for a distance of 200-300 m, numerous small feeders can be seen issuing from the roadway sides. The number of feeders decreases with increasing depth. Measurements indicate between 90-180 litres/min (20-40 gpm) is made by the sum of these feeders, although the quantity again varies with rainfall and season. The origin of the feeders is thought to be an aquifer horizon which is recharged by direct surface rainfall-runoff. Since a base component exists even during prolonged dry spells.

A combination of measurements and experience indicates that the combined water make from the portal and near portal feeders seldom exceeds a total of 900 litres/min (200 gpm).

3. Faults and Fissures

In general, roof conditions are extremely good and few faults or joints have been intercepted. However, water has been encountered in small quantities throughout the workings and enters in two main ways.

(a) Where workings intersect a fault, small feeders or droppers are usually associated. Three significant occurrences of this type have occurred in the Dragonby 1 East and 2 West districts and the Main Fault drivage. In each case the initial maximum flow decreased with time either to zero or a residual yield. Quantities ranged from 200-900 litres/min (50-200 gpm).

(b) The formation of rooms by blasting can result in the formation or aggrevation of the micro-fracture matrix within the overlying ironstone roof beam. This allows the interception of water flowing through the overlying strata, with the resulting formation of small feeders or droppers, which may or may not decrease with time. Water from this source was encountered in sufficient quantities in the Dragonby 1 East 5 South districts to cause production difficulties.

4. Roof Instability

In some areas of the workings, instability problems have led to the collapse of the ironstone roof beam. This has led to the formation of 'chimney' structures, which may or may not migrate upwards, due to the gradual in situ failure of the overlying strata Figure 4, Whittaker [2].

The interception of an aquifer horizon by a migrating void, can result in the direct access of water to the workings, along with accumulations of washed out material. Similarly, liquifaction of the relatively unconsolidated plug material can result in a mud flow. Both of these occurrences have been recorded in the Santon 3 West and Dragonby 1 West districts.

The near surface proximity of a void results in the formation of a surface sink hole, which can vary in size up to 30 m in depth and diameter. However, the nature of the sub-surface conditions dictate whether or not it becomes filled with water. In some cases, the Lower Lias clays have formed impermeable plugs, which restrict water flow to the workings, but allow the surface sink hole to fill with water.

SEASONAL VARIATION IN WATER QUANTITY

A seasonal variation in the quantity of water entering the mine has always been recorded in the Santon workings. While, in the Dragonby workings, the quantity has remained remarkedly consistent except for the cummulative increase due to new production areas.

In the Santon workings, measurements indicate an average pumping rate of 2700 m^3/day (580,000 gpd) during the months April to November. During the winter months December to March, the average pumping rate increases to 6000 m^3/day (1,300,000 gpd). Twice as much water is therefore pumped from the Santon workings during the winter months than the summer. In the Dragonby workings a consistent average pumping rate of 1700 m^3/day (375,000 gpd) is maintained throughout the year.

Figure 6. shows the annual average rainfall figures (in millimetres) for the period 1941-70 at the Meteorolgical office rainfall station - West Butterwick (NGR SE 835065). The high July and August rainfall figures are due to summer thunderstorms which effect the region and produce intense rainfall of short duration. Also shown on Figure 6 is the annual average Soil Mixture Deficit (SMD) values for the area in millimetres.

The SMD value is a measure of the amount of moisture usually rainfall, which is required to return the soil to a saturated condition. A value of zero is usually present during winter (soil saturation). During spring the value rises, reaching a summer/autumn maximum (up to 150 mm), which with the onset of autumn rains returns gradually to zero. A zero SMD value indicates sufficient moisture available for soil infiltration, groundwater percolation and aquifer recharge. Therefore, throughout the summer all rainfall is either returned to the atmosphere by evapotranspiration or used to redress the SMD balance. During winter, rainfall is available for recharging underlying aquifers, which in turn will have an increased volume of water to discharge to the workings.

GROUNDWATER HYDROLOGY

The methods by which water enters the workings have already been described. However, it is important to attempt to identify the aquifer horizons from which water might be flowing, as well as the mechanism by which it enters the workings.

The principal aquifers which lie within the Oolite series are the Lincolnshire Limestone and Northampton Sands. Both are excellent sources of water supply and can yield many tens of cubic metres (thousands of gallons) per hour. In addition, the general sequences of the Inferior Oolite have been recorded by Downing et al [3] as yielding 1-2 m^3/hr (200-400 gph) to wells and boreholes.

The Upper and Lower Lias, normally considered impermeable have also been recorded, Downing et al [3], as yielding 1-4 m^3/hr (200-800 gph) to wells and boreholes. However, it should be noted that minor aquifers in the Lower Lias below the Frodingham Ironstone and known as the Hydraulic limestones, Wilson[1], are also included in the upper range of these values. Above the Ironstone, the Marlstone Rock is recorded, Downing et al [3], as yielding tens of m^3/hr, where flow is primarily via recharge along numerous fissure systems which traverse the rock.

A regional groundwater flow regime exists which trends eastwards. Aquifer recharge will occur at outcrop or via infiltration through superficial deposits. Vertical movement of groundwater will also occur between aquifers and aquitards. The presence of natural discontinuities within each stratagraphic sequence, will act as focal points for the collection and transmission of water, both laterally and vertically.

It is therefore considered that flow to the mine is principally by fissure-fracture networks within the overlying strata, rather than intergranular transmission between adjacent rock types. The extraction method results in the formation of induced fracture/fissure networks, which are then superimposed onto the existing natural flow network and allows water to enter the workings.

OPERATIONAL DE-WATERING

A schematic plan showing the system by which water is removed from the various mine districts is shown in Figure 7. It consists of a series of sumps and pipe ranges which collect and carry the water to one of two centralised storage reservoirs, from where it is pumped to surface by means of lined boreholes. At surface it is discharged directly to local water courses.

The collection system can be divided into two main parts:-

1. The Santon Main Reservoir
2. The Dragonby Main Reservoir

1. The Santon Main Reservoir

This was formed by damming the Santon 2 East district. Water is collected from five main sites within the workings and pumped to surface using two Mather and Platt 2.3 m^3/min (500 gpm) pumps. The five sites are listed below and dealt with separately.

(a) The Entrance Portal

(b) Santon 1 West District

(c) Santon 3 West District

(d) The Main Fault

(e) Dragonby 1 West District

(a) The Entrance Portal

Water from both the portal and near portal feeders is allowed to flow via open channels at the roadside until it is collected by an open sump. It is then discharged by means of a B 80 pump and suitable pipe range to the Santon 1 West district, from where it is allowed to gravitate via open channels to a large sump in the 2 West district. A B150 pump is then used to discharge it via pipe ranges to the Santon Main Reservoir.

(b) Santon 1 West District

This water originates from throughout the Santon 1 West and 2 West districts from small feeders and roof droppers. In certain areas, contamination by a phenolic substance, possibly from nearby slag heaps, suggests a close rainfall re-charge mechanism. The water is allowed to gravitate through the districts via open channels to the large sump in the 2 West district, from where it is pumped to the Santon Main Reservoir.

(c) Santon 3 West District

This water is associated solely with the bad roof conditions and sink hole structures found in the district. It is collected behind dammed off areas and allowed to gravitate to the Santon Main Reservoir, by means of pipe ranges.

(d) The Main Fault

A feeder with a yield of about 220 litres/min (50 gpm) has been associated with this fault for many years. The water is collected by an open sump and then allowed to gravitate by pipe ranges to the Santon Main Reservoir.

(e) Dragonby 1 West District

Water from this district originates primarily from the bad roof conditions and sink hole structures, which are thought to have tapped overlying aquifer horizons. The yield is allowed to gravitate across the Dragonby 1 West District via open channels, until it is collected within a large natural hollow in the Dragonby 29 West Road. A B80 pump then discharges it via pipe ranges to the Main Fault, after which it is allowed to gravitate via pipes to the Santon Main Reservoir.

2. The Dragonby Main Reservoir

This was formed by damming a centralised section of the Dragonby 1 East district, see Figure 7. Water is collected from three main sites within the workings and pumped to the surface using two Mather and Platt 4.6 m^3/min (1000 gpm) pumps. The three sites are listed below and mentioned separately.

(a) Dragonby 2 East District

(b) Dragonby 2 West District Fault

(c) Dragonby 1 East and 5 South Districts.

(a) Dragonby 2 East District

Unstable roof conditions and the formation of sink hole structures have led to the occurrence of water on this district. Water from the affected area is collected and fed to the 3 N district via a horizontal borehole, which allows it to gravitate via open channels to a sump. A B80 pump then discharges it via pipe ranges to the Dragonby Main Reservoir.

(b) Dragonby 2 West District Fault

A feeder with a yield of about 220 litres/min (50 gpm) has been associated with this small fault (throw < 1 metre) for several years. The water is allowed to gravitate via open channels to a sump in the Dragonby 4 North district, where it is then discharged to the Dragonby Main Reservoir by a B150 pump.

(c) Dragonby 1 East and 5 South Districts

The workings run almost parallel to the dip of the orebody. All water will therefore collect in the lowest workings, unless previously intercepted. It was found that many of the 1 East and 5 South headings produced sufficient water to hinder production, but insufficient to warrant the installation of elaborate disposal facilities. Most of the water entered via small roof feeders or droppers associated with natural or induced micro-fracturing of the ironstone roof beam.

To overcome this problem, small portable Ingersol-Rand Pneumatic pumps were installed within the headings and the resultant water discharged via natural channels and pipes to a sump at the point of lowest working. A B150 pump, then discharges the water to a 1 East District sump, from which it could be subsequently pumped to the Dragonby Main Reservoir using a Mather and Platt 2.3 m^3/min (500 gpm) pump.

PRODUCTION HAZARDS AND PROBLEMS

In general, the water entering the workings only constitutes a nuisance to everyday working conditions, rather than a controlling factor on production or as a potential hazard to the work force or mine life.

The hazards and effects of the water on mining can be summarised in three sections which are listed and mentioned below:

(a) Mud

(b) De-watering Procedures

(c) Sink Holes

(a) Mud

Few of the headings made sufficient water from the small feeders or droppers to cause more than a nuisance. However, the cumulative effect of these combined with water flowing across floors and along open channels, sometimes resulted in headings and roadways becoming water logged and muddy. This in turn made travelling unpleasant and at times difficult for both men and machines. A further consequence, is the need to construct main roadways out of hard materials such as concrete, where persistent use would ultimately render passage impossible.

The formation and deposition of mud and silt in channels and pipes, results in the need for periodic cleaning and flushing of sumps and reservoir valves.

(b) De-watering Procedures

The long term planning of new districts and there projected water yields is essential. This can be undertaken by the collection of records and detailed study of existing water occurrences. Optimum use should be made of existing reservoirs with provision for their extension and the construction of new ones. The extension of existing pipe ranges, the construction of new ones and disposal of water by natural drainage systems must also be considered. Finally, adequate pumping capacity should be envisaged at all times.

(c) Sink Holes

These constitute a special hazard, even though restricted to specific areas of the mine. Adequate provision must be made to allow drainage of these areas, even though the expected yield will fluctuate given a change in existing conditions or the formation of a new hole.

Mud flows have been recorded from these areas and need particular attention. The provision of retaining walls to prevent a mud flow from entering a working district or access road is essential. However, adequate drainage must be provided from the area both prior to and after such an event.

In summary, the drainage facilities must be sufficient to confine a mud flow should it occur, allow adequate drainage and remain sufficiently accessible for regular inspection and cleaning.

CONCLUSION

The mine water has been identified as originating from aquifer horizons contained within the overlying Lias and Oolite series. However, whether the yield is fed directly from aquifers or by a more complex rainfall-recharge - discharge process is still a matter of speculation. A mechanism of natural and induced micro-fracture networks is put forward as the means by which water primarily penetrates the ironstone roof beam. Similarly the access points within the workings have been identified and the system of mine de-watering outlined.

Finally, it is considered that had sufficient time been available, further studies on the seasonal variations in flow could have been undertaken. Similarly, the initiation of geochemical surveys could have identified the horizon of water yield, as well as its original source.

ACKNOWLEDGEMENTS

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LIST OF FIGURES

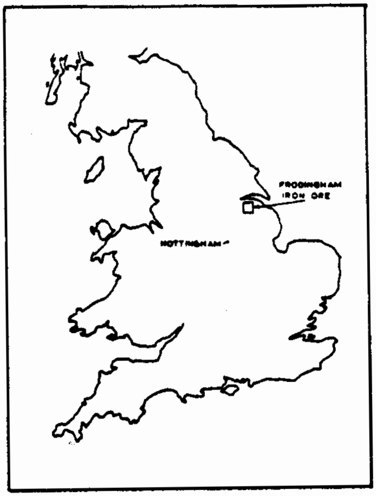

FIGURE 1 LOCATION MAP FOR THE FRODINGHAM IRON ORE WORKINGS

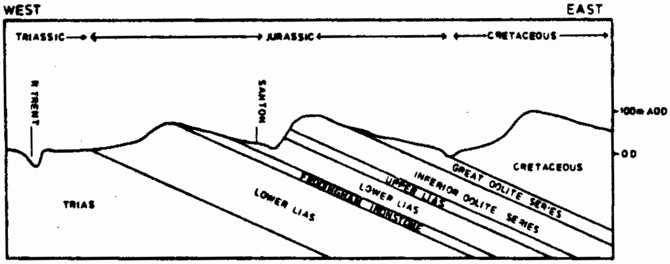

FIGURE 2 GENERALISED GEOLOGICAL SECTION ACROSS THE FRODINGHAM IRONSTONE

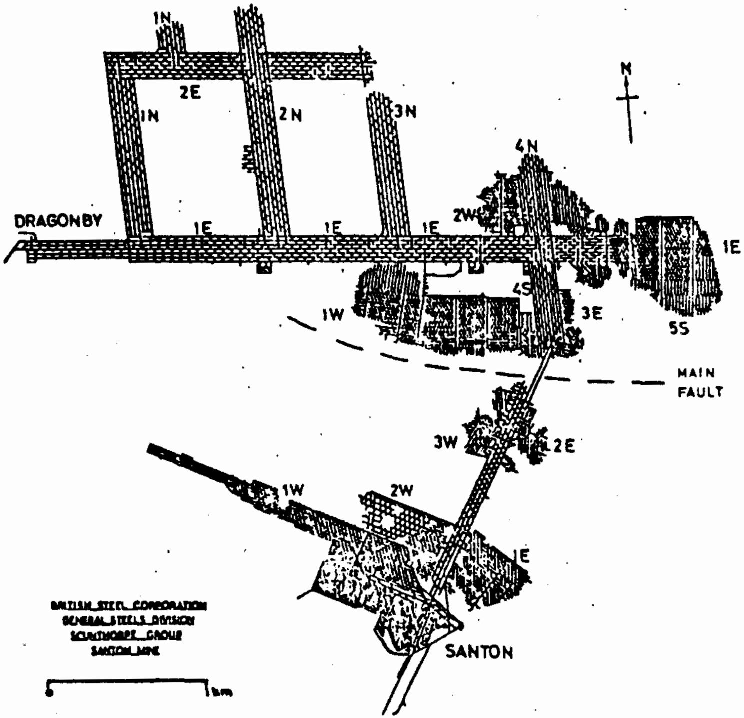

FIGURE 3 UNDERGROUND WORKINGS AT SANTON IRONSTONE MINE

GEOLOGICAL SEQUENCE		STRATA THICKNESS METRES	STRATIGRAPHIC SEQUENCE	SEQUENCE LITHOLOGY
RECENT		1 - 3	BLOWN SAND CORNBRASH	Buff Limey Sandstone
GREAT OOLITE SERIES		5 - 15	GREAT OOLITE SERIES	Mainly Clays Limestone Locally
		4 - 11	UPPER ESTUARINE SERIES	Sands and Sandy Clays With Lst. Bands, Silts and Marls
INFERIOR OOLITE SERIES		14 - 22	HIBALESTOW OOLITE LINCOLNSHIRE LST. KIRTON CEMENT STONE SANTON OOLITE	Buff and Grey Oolitic Lst. Occasional Reef Knolls Alternating Grey Calcareous Clays and Cementstones Buff Gritty Limestone - Oolitic
		0 - 7	LOWER ESTUARINE SERIES NORTHAMPTON SANDS	Sands - Locally Ferruginous
UPPER LIAS		13 - 20	UPPER LIAS CLAY	Grey Clays and Brown Shales
MIDDLE LIAS		1 - 2	MARLSTONE ROCK	Ferruginous Calcareous Sst.
LOWER LIAS		20 - 25	LOWER LIAS CLAYS	Grey Clays
		0.5 - 2	PECTEN BED	Brown Oolitic Lst. Ironstone
		25 - 30	LOWER LIAS CLAY	Dark Grey Clays
		10	FRODINGHAM IRONSTONE	Clayey Ironstone Limey Ironstone
		70	LOWER LIAS CLAYS	Shales, Clays and Limestones

FIGURE 4 GEOLOGICAL SECTION AT SANTON MINE

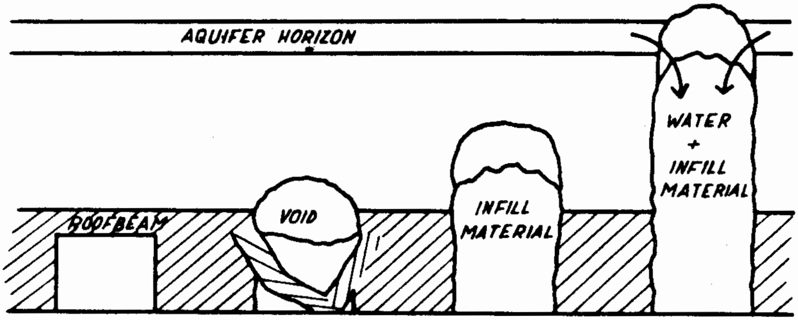

Fig. 5

FORMATION AND MIGRATION OF 'CHIMNEY' STRUCTURES OR SINK HOLES

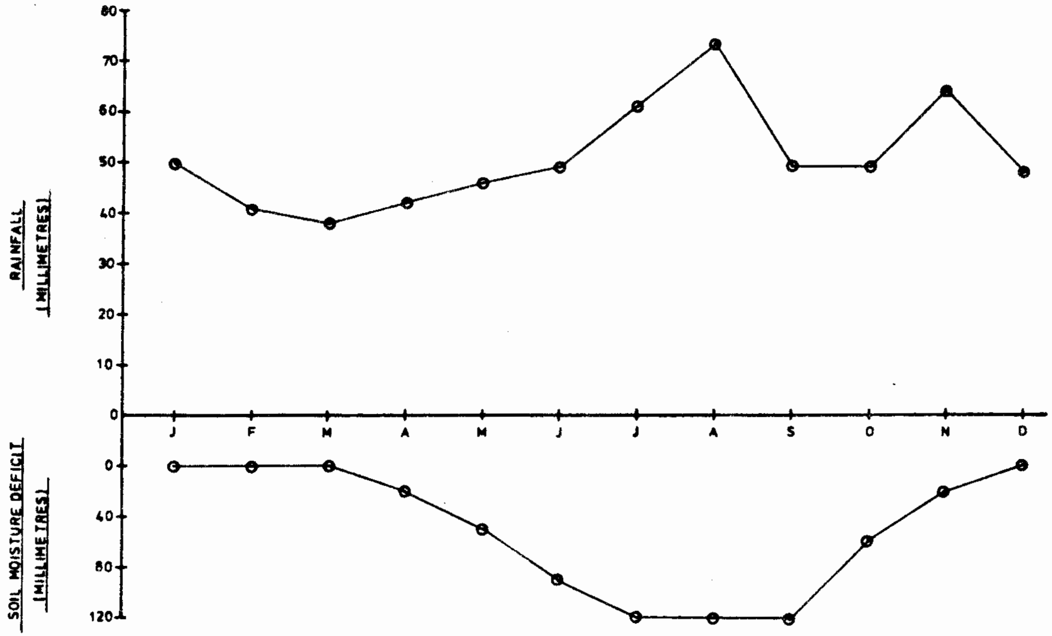

FIGURE 6 ANNUAL AVERAGE RAINFALL (1941-70) MET. OFFICE STATION WEST BUTTERWICK AND SOIL MOISTURE DEFICIT (SOUTH HUMBERSIDE) VALUES

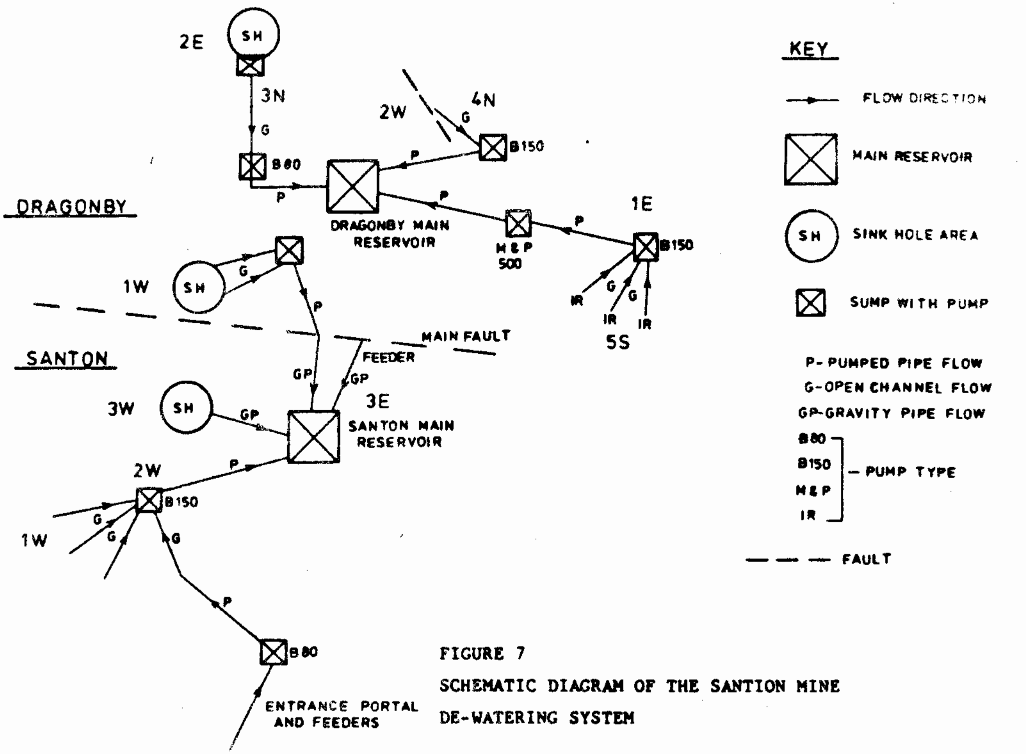

FIGURE 7

SCHEMATIC DIAGRAM OF THE SANTION MINE DE-WATERING SYSTEM