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ANALYSIS OF WATER INFLOWS IN THE DONKIN-MORIEN NO. 3 TUNNEL, SYDNEY COALFIELD, NOVA SCOTIA

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ABSTRACT

The analysis of piezometric levels, water inflows and hydrochemical data at the Donkin-Morien Development Project No. 3 tunnel has revealed a flow regime characterised by discontinuity networks rather than intergranular permeability. Above chainage 420 m, water inflows were encountered from a minor aquifer unit being recharged by percolation travelling down dip from outcrop. Below chainage 420 m, the inflows become predominantly more saline, with recharge occurring either vertically or down dip from seabed, while below chainage 500 m the disappearance of the aquifer unit resulted in no further inflows being encountered. A freshwater/saltwater interface was identified in the vicinity of chainage 420 m.

INTRODUCTION

The Sydney Coalfield is located on Cape Breton Island which lies at the north-eastern end of Nova Scotia, Figure 1. During the late 1970's, an extensive drilling and geophysical programme by the Cape Breton Development Corporation, defined an offshore coal resource block in the Donkin-Morien area of the coalfield, Figure 2. Subsequent feasibility studies resulted in the definition and implementation of the Donkin-Morien Development Project.

Within the resource block five major coal seams have been identified as being potentially workable: Harbour, Hub, Phalen, Lloyd Cove and Point Aconi (the thickness varies between 1.5 and 4.5 m). The total in situ resource within the five seams is estimated to be nearly two billion tonnes.

Initially, two tunnels are being driven to intersect the Harbour Seam - tunnels No. 2 and 3. The No. 3 tunnel, a uniradial arch 7.6 m wide by 5.3 m high, has advanced a total distance of 1027 m, at a decline of 20% for the first 780 m and 10% for the final 247 m, using drill and blast methods. A 7.6 m diameter full face tunnel boring machine (TBM) manufactured by Lovat of Toronto was used to drive the No. 2 tunnel a distance of 3500 m.

After outlining the geology and hydrogeology of the Donkin-Morien mine site, the paper examines water inflows encountered during driveage of the No. 3 tunnel. Inflow locations and yields are discussed along with the results of hydrochemical and radio isotope studies.

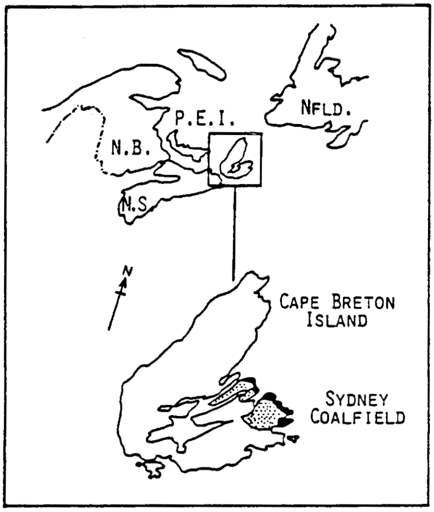

Figure 1 - Location of Sydney Coalfield

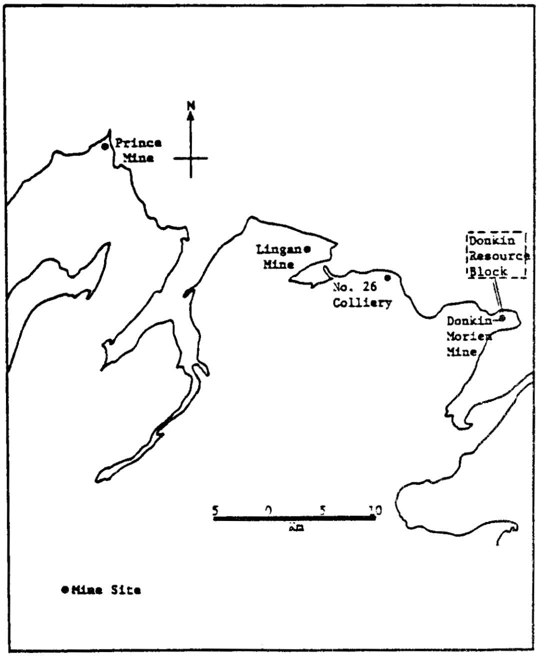

Figure 2 - Location of Donkin-Morien Resource Block

GEOLOGY

The Sydney Coalfield is located in a 2200 m sequence of strata known as the Pictou Group which is Upper Carboniferous in age (Westphalian C and D). The Donkin-Morien tunnels have been driven through Coal Measures strata which essentially consist of interbedded sandstones, siltstones, mudstones and coal seams. Lithologically, the intersected tunnel strata can be divided into eight identifiable units, Golder Associates (1981).

1) Sandstones
2) Interbedded Siltstones and Sandstones
3) Siltstones
4) Interbedded Siltstones and Mudstones
5) Mudstones
6) Carbonaceous Mudstones
7) Coal
8) Red Beds

The No. 3 tunnel was driven through a massive sandstone unit, up to 30 m thick, which varies lithologically from laminated to thickly bedded and from fine to coarsely grained. The grain size varies from 0.6 to 2.0 mm, while calcite and dolomite cement occurs in localised areas. Carbonaceous bands between 1 and 5 mm in thickness occur within the formation, as well as thin clay bands and conglomeratic layers known as 'lag' deposits. A complex series of argillaceous strata exist both above and below the massive or 'Portal' sandstone unit.

Within the tunnel, the strata sequence strikes approximately E - W with a dip of between 10 and 12° to the North. Two major joint sets have been intersected with E - W strikes and a dip to the North, along with a minor set which strikes E - W and dips at 90°. Clay gouge and water deposited iron staining is frequently seen on the joint faces.

At present, no major faults have been intersected in the tunnel driveage.

HYDROGEOLOGY

The No. 3 tunnel portal is located 300 m from the shoreline. A series of observation boreholes indicate that groundwater levels within the underlying strata and in particular the 'Portal' sandstone, lie below a ridge of high ground to the north of the Portal location at a depth of between 10 and 20 m below ground surface, Golder Associates (1981). The ground water levels indicate a phreatic surface coincident with sea level at the Northern extremity of Cape Perce, where the tunnels extend beneath the Atlantic Ocean. In the immediate vicinity of the No. 2 and 3 Portals, groundwater levels lie between 5 and 8 m below surface. No data is available concerning groundwater conditions at depth, although within the Sydney Coalfield as a whole the mine workings are dry.

Packer testing using constant head pressure techniques was carried in the first 50 m of strata in certain boreholes. This data is considered to represent a maximum value for rock permeabilities because of the influence of surface weathering and glacial disruption on the test intervals. The results indicate permeability values of between 8.0×10^{-5} and 7.0×10^{-4} cm/sec in the Portal sandstone and 10^{-5} and 7.0×10^{-5} in the mixed sediments. Additional tests carried out in both the Portal sandstone and mixed sediments give transmissivity values of between 8.6×10^{-5} and 2.7×10^{-4} m^2/sec and storativity values of between 6.2×10^{-5} and 10^{-4}. The Portal sandstone has a porosity of 5%.

Within the No. 3 tunnel, the flow regime is characterised by existing discontinuity networks (both fractures and joints) rather than by intergranular flow. In addition, the water occurrences appear to be channelled by bands of conglomeratic and clay material. It is interesting to note that only minor water inflows were subsequently experienced in the No. 2 tunnel. Since the No. 3 tunnel was driven before the No. 2, using a more disruptive driveage technique (drill and blast as compared with full face mechanised tunnelling), it appears to have acted as a primary drainage mechanism within the area. This concept is supported by the lowering of piezometric levels as the No. 3 tunnel advanced.

WATER OCCURRENCES

In the No. 3 tunnel, water occurrences were encountered as either small feeders or 'droppers' emanating from either the tunnel roof and walls or more frequently from 3.5 m holes drilled for rock bolts. Most of the feeders yielded small quantities of water and dried up within a short period of time, usually a few days or weeks. More persistent feeders were encountered in some roof bolt holes and these exhibited either constant or slowly decreasing yields (over a period of months), although the flow seldom exceeded 6 litres/min.

During tunnel development nuisance water was encountered until 311 m, when intermittent droppers started to occur, although these rapidly dried up. The first major feeder occurred at 320 m with a yield of 0.3 l/sec. Further occurrences in the form of 'droppers' continued to occur with yields up to 0.1 l/sec, although again these tended to dry up quickly.

A second major feeder was encountered at 389 m which consistently yielded over 0.1 l/sec between June and November 1982. Below 400 m, the incidence of inflows rapidly increased along with the initial yield (up to 1.4 l/sec) and the tendency to rapidly dry up. A major sequence of feeders was encountered at 445 m, with further occurrences occurring regularly until 500 m. Below 500 m, the incidence of feeders very rapidly decreased and conditions in the development area of the tunnel dried up.

Intermittent records of individual feeder yield were collected during tunnel development using 'bucket and stopwatch' methods. All water entering the tunnel was collected via a series of sumps from which it was pumped to a settling pond on surface and then discharged via a V-notch weir to a natural water course. The quantity of water discharged across the weir was calculated using manual 'spot' levels taken on a daily basis. A continuous recording device was not used.

Typical discharge values across the weir were 2 - 4 litres/sec in February 1982, rising to 11 litres/sec in June with a subsequent decrease over the summer and autumn months to between 2 and 7 litres/sec. By early 1983, the tunnel discharge had again risen to between 9 and 15 litres/sec.

PIEZOMETERS LEVELS

Piezometers were installed in two boreholes (R10 and R11) NNE and SW of the No. 3 portal location, Figure 3. The depth and stratigraphic location of the piezometers within the boreholes is given in Table 1, while their fluctuation in level between January 1982 and May 1983 is given in Figure 4.

Table 1 - Depth and stratigraphic location of the piezometers in boreholes R10 and R11, Donkin-Morien Site, N.S.

Piezometer	Borehole R10		Borehole R11	
	Depth (m)	Geological Sequence	Depth (m)	Geological Sequence
D	2.0	Glacial Till	4.0	Glacial Till
C	18.5	Mudstone	16.5	Siltstone
B	39.5	Sandstone	25.5	Sandstone
A	69.5	Sandstone	53.5	Sandstone

Water levels in the glacial till remained consistent and show evidence of seasonal variations. In the 10 - 20 m zone, the levels show a slow drawdown and rebound, suggesting a seasonal variation associated with autumn/winter recharge. Piezometers located in the 20 - 70 m zone show a marked drawdown between days 130 and 150 (chainage 250 - 350 m), which can be associated with the inflows first encountered in the tunnel. Once passed day 200 (chainage 500 m), the slow decrease stabilizes and the levels remain consistent until around day 350 (December 1982). A slow rise in levels after this date may be associated with autumn/winter recharge, although it should be noted that no apparent increase in the quantity of water yielded to the tunnel was noticed.

TIDAL INTERACTION STUDY

In October 1982, in response to concerns over possible fluctuations in the inflow rates due to tidal variations, a tidal interaction/water chemistry study was undertaken on a feeder at chainage 500 m. Figure 5 shows the oceanic tidal variations along with the chloride and sodium ion concentrations, pH and conductivity.

Examination of Figure 5 shows no immediate correlation between either the tide levels or the monitored water parameters. However, closer study suggests that a half phase lag may exist between the high tide values and the chloride and sodium ion concentrations over the 24 hour period. No discernable variation in feeder yield or total tunnel outflow (across the weir) were detected with respect to tidal fluctuations.

HYDROCHEMICAL AND RADIO ISOTOPE ANALYSIS

In September 1982, a hydrochemical analysis was undertaken on selected No. 3 tunnel inflows within a one-hour time interval, MacLeod (1982). The parameters monitored were chloride and sulphite ion concentrations, conductivity, pH, inflow rate and the geological location of clay bands. Analysis of the

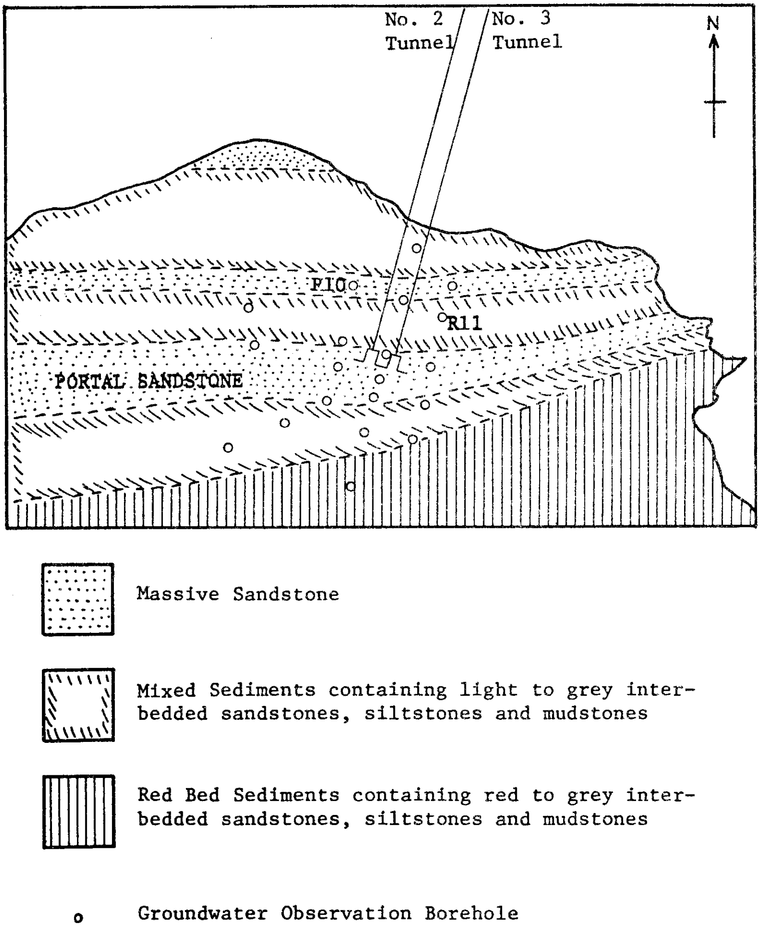

Figure 3 - Surficial geology of the Donkin-Morien mine site showing tunnel locations and groundwater observation boreholes

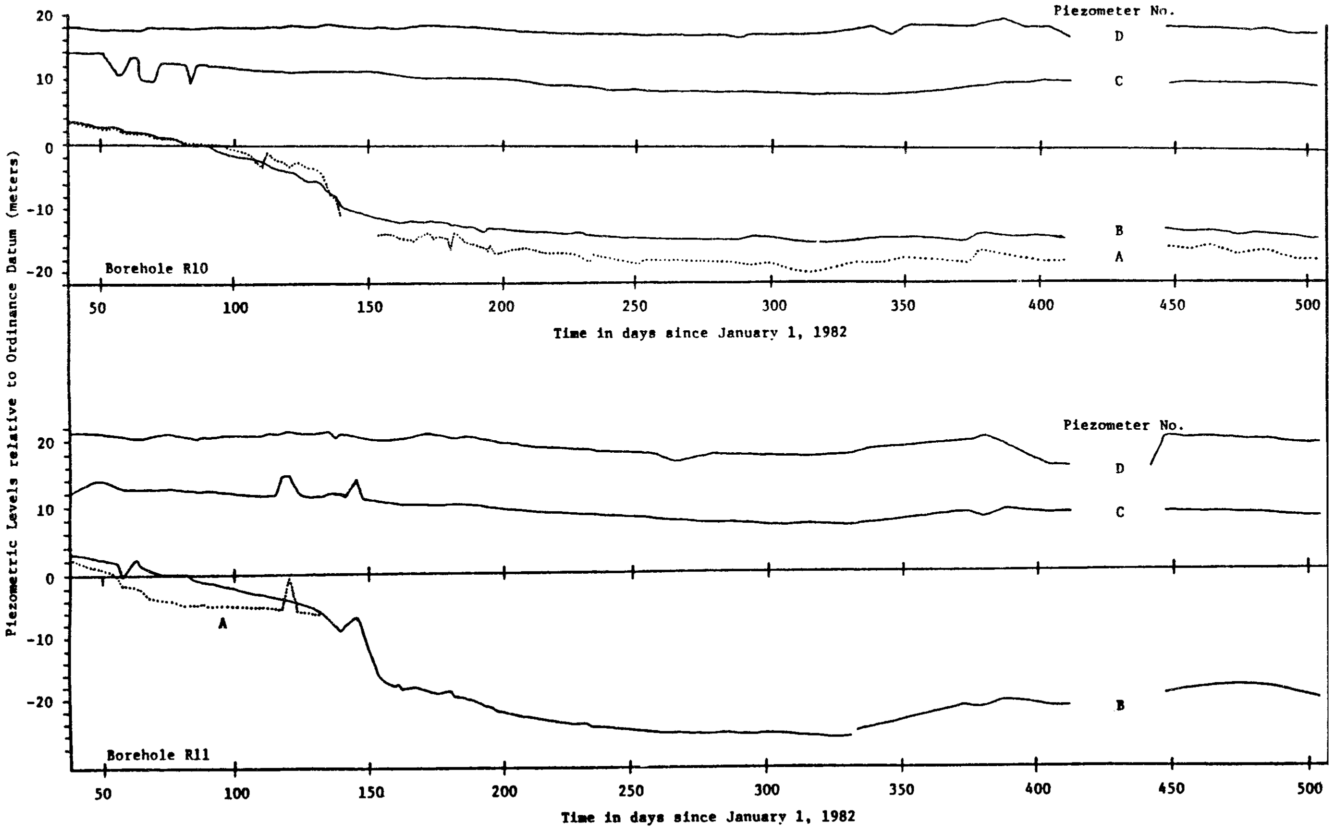

Figure 4 - Boreholes R10 and R11 - fluctuations in piezometric levels, January 1982 to May 1983

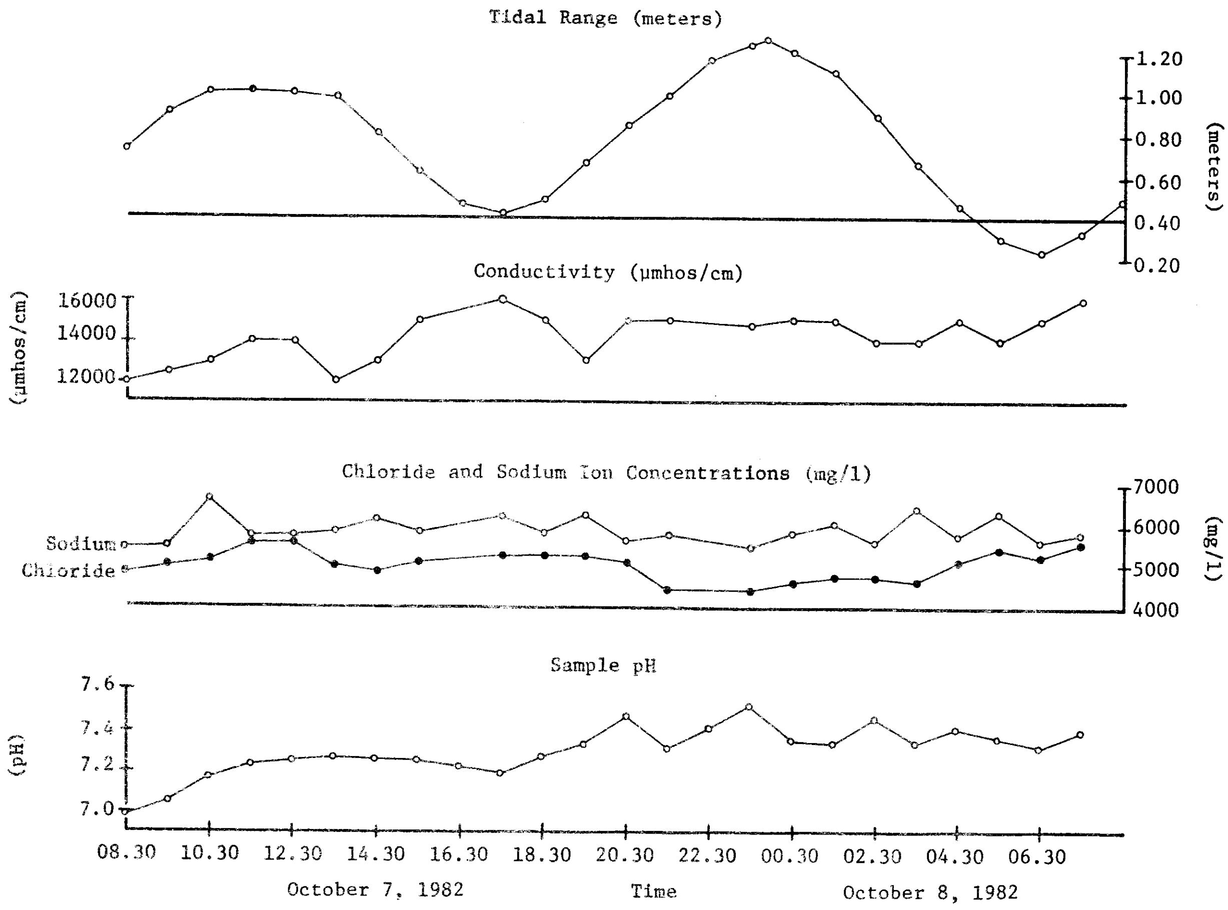

Figure 5 - Oceanic tidal variations, chloride and sodium ion concentrations, conductivity and pH for a water feeder at chainage 500 m, No. 3 Tunnel

data revealed no identifiable correlation between the chloride ion concentration and either the flow rate or the location of the clay bands. A tentative correlation appeared to exist between the chloride ion concentration and pH, whereby the pH decreased with increasing chloride.

In late 1982 and early 1983, additional hydrochemical analyses were undertaken on selected No. 3 tunnel inflows. The parameters monitored were sulphate, chloride, bicarbonate, magnesium, calcium, sodium and potassium ion concentrations as well as total metal scans. Figure 6 shows a Durov plot, Zaporozec (1972), of the No. 3 tunnel inflows. At least two distinct water types are being yielded by the feeders. Area A represents samples collected in the vicinity of chainage 400 m and indicate a freshwater component. Area B represents samples from chainage 500 m and indicate a more saline or saltwater component.

Both phases of the hydrochemical program indicate that two types of water are entering the tunnel and that the salinity increases with distance beneath the ocean. A sharp change in chemistry in the vicinity of 417 m, suggests that this may be the area of a freshwater/saltwater interface. No meaningful results were obtained from the total metal scan data.

Tritium dating was undertaken on No. 3 tunnel inflows at chainage 300 and 500 m as well as selected surface waters, Aston (1984). A direct examination of the results suggests that the feeders are discharging water that is 'modern' in age (pre 1952). However, a more detailed evaluation indicates that the data may be unreliable due to problems with the analytical technique. The resultant data should therefore only be used with extreme caution and in conjunction with additional hydrogeological and hydrochemical information.

DISCUSSION

Work in the Donkin No. 3 tunnel was undertaken to establish whether the inflows were due to:

1) the draining of discrete aquifer units.
2) the draining of aquifer units being recharged by vertical percolation from seabed.
3) the draining of aquifer units being recharged by percolation down dip from the strata outcrop.

The No. 3 tunnel inflows are not due to an intergranular flow regime, but can be characterised by either natural or induced discontinuity networks. They are closely related to a mudstone conglomerate and clay bands which are located near the top of the Portal sandstone unit. Disruption of the mudstone conglomerate by either blasting (induced fractures) or penetration with rock bolts holes resulted in either temporary or persistent feeders, which indicates that discrete aquifer units are being drained.

The mudstone conglomerate unit encountered in the region of chainage 300 m, Figure 7, coincides with the onset of both the tunnel inflows and the drawdown of piezometers located in sandstone units in the 20 - 70 m zone. A comparison of piezometer drawdown and tunnel advance, Figures 4 and 8, clearly

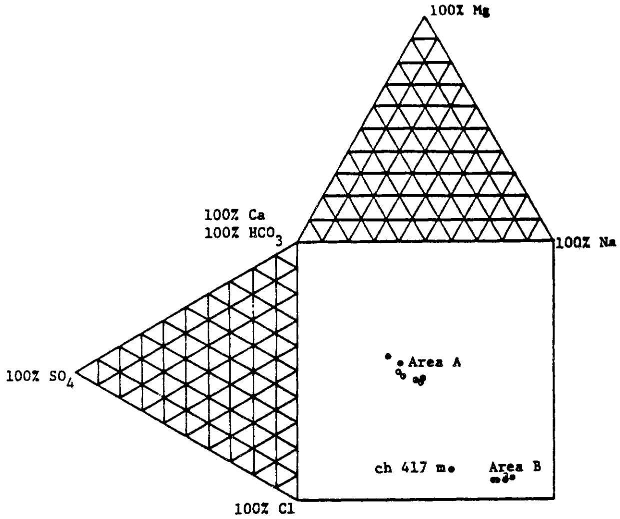

Figure 6 - Durov plot of the Tunnel No. 3 inflows

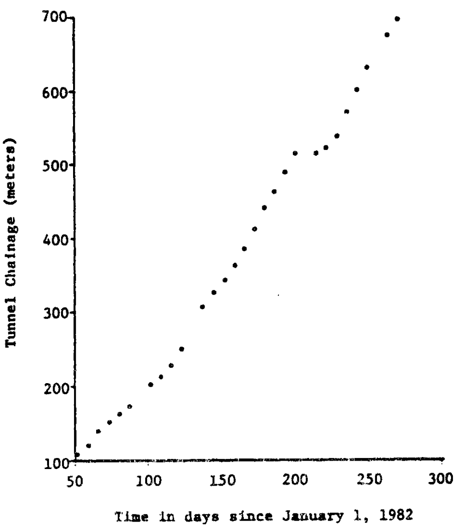

Figure 8 - Tunnel No. 3 advance from January to October 1982

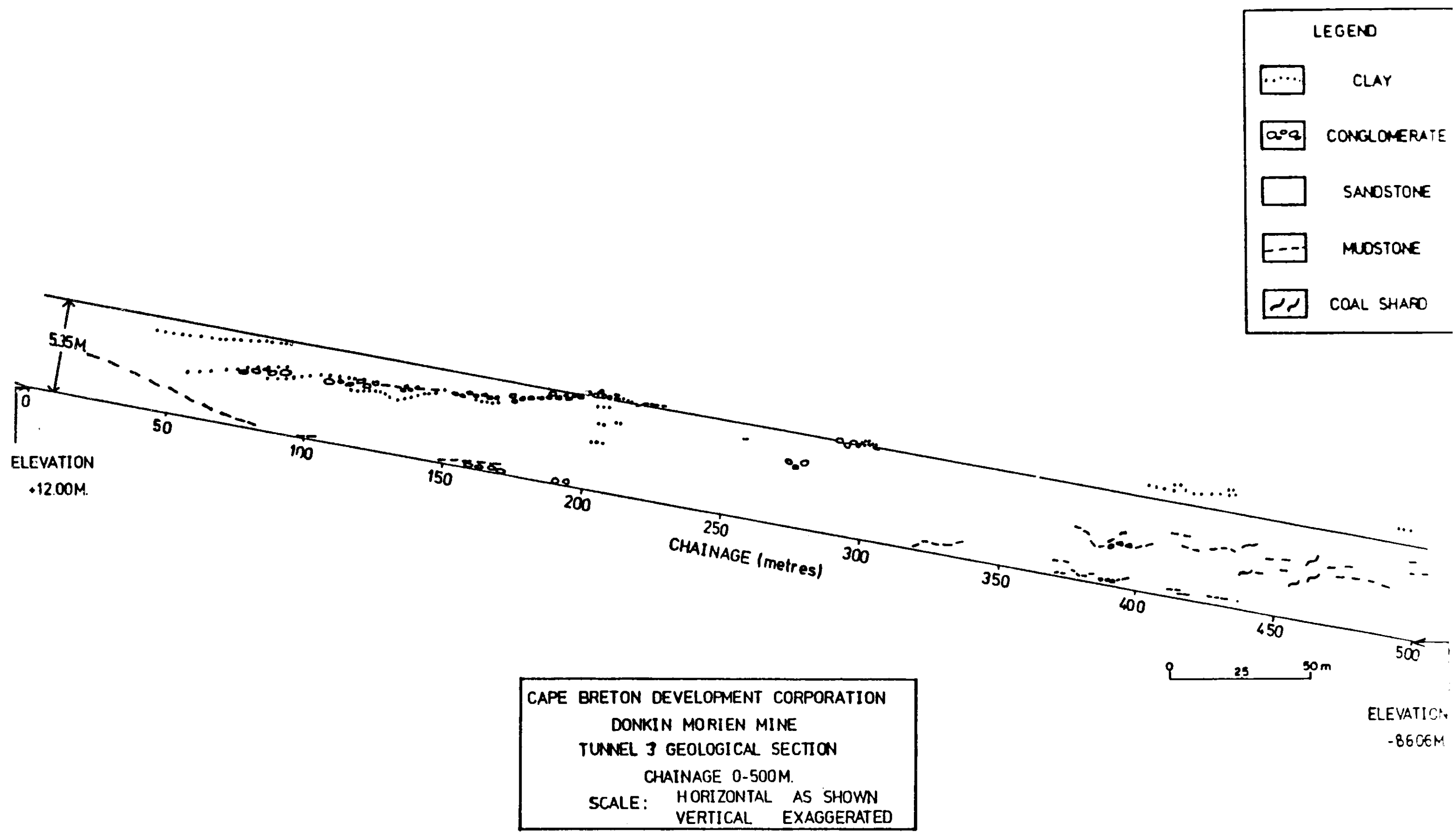

Figure 7 - Tunnel No. 3 geological cross-section showing the **location of the mudstone conglomerate band**

shows that the two are closely related and that a hydraulic connection must exist between the 20 - 70 m sandstones and the mudstone conglomerate band.

Hydrochemical data indicates that at least two distinct water types are being discharged to the tunnel: a freshwater component to 400 m and a saline component around 500 m, with a freshwater/saltwater interface in the region of 420 m. Radio isotope data suggests that all the feeders are discharging water that is 'modern' in age.

Piezometer levels, Figure 4, indicate that seasonal variations in groundwater levels within the lithological units are occurring and that percolation/ recharge from outcrop must therefore also be occurring. The concept of recharge from outcrop is reinforced by a freshwater component identified in the hydrochemical analyses.

Near surface groundwater levels across the mine site appear to form a phreatic surface with the ocean, which suggests that tidal variations should be visible. However, no definite evidence for these can be found in the tunnel inflow data, although a tentative correlation is suggested by one 24 hour study of ion concentrations. It is thought that tidal fluctuations would undergo 'damping' due to transmission through the various lithological units and that the monitoring frequency of both the piezometers and inflows was in-insufficient to determine these effects. No variation was visible in the tunnel outflow data due to the 'sump and pump' arrangement used to remove the water.

It is concluded that inflows experienced to chainage 420 m were of two types: temporary inflows resulting from the drainage of discrete aquifer units within the mudstone conglomerate/overlying strata and persistent inflows resulting from the initial draining of an aquifer which is subsequently recharged by percolation occurring down dip from outcrop. Insufficient data exists to identify any particular lithological unit responsible, although the piezometer data indicates that a hydraulic connection does exist between the 20 - 70 m zone sandstones and the mudstone conglomerate. Below 420 m, the inflow water becomes more saline in nature and because of persistent feeders at chainage 500 m, it is thought that significant percolation either vertically or down dip from seabed must be recharging discrete aquifer units in the vicinity of the mudstone conglomerate.

Below chainage 500 m the cessation of inflows can be attibuted to the disappearance of the mudstone conglomerate from the vicinity of the Portal sandstone roof.

CONCLUSION

The Donkin-Morien No. 3 tunnel acts as the primary drainage mechanism in the area, where the flow regime is characterised by discontinuity networks rather than intergranular permeability. Water inflows were encountered between chainage 300 and 500 m, and occurred when a mudstone conglomerate unit close to the roof of the Portal sandstone became disrupted. Inflows to the tunnel seldom exceeded 6 litres/min and only constituted a nuisance to tunnelling operations.

Analysis of piezometric, inflow and hydrochemical data revealed that above chainage 420 m, persistent feeders occurred where an aquifer unit was being recharged by percolation travelling down dip from outcrop. Below 420 m, the inflows became predominantly more saline, with recharge occurring either vertically or down dip from seabed. A freshwater/saltwater interface was identified in the vicinity of chainage 420 m. Finally, no evidence concerning the effect of tidal variations on the tunnel inflows could be found.

ACKNOWLEDGEMENTS

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