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HYDROGEOLOGY OF THE FORTESCUE RIVER ALLUVIUM

by

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HYDROGEOLOGY OF THE FORTESCUE RIVER ALLUVIUM
ASHBURTON PLAIN, CARNARVON BASIN

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ABSTRACT

Thirty-four exploratory bores were drilled to define a Quaternary alluvial aquifer along the Fortescue River on the Ashburton in the Carnarvon Basin 100 km south of Karratha. This aquifer extends over a former delta up to 15 km north west of the river and has a saturated thickness of as much as 15 m. It consists of pebbles up to 100mm diameter, similar to the present river bed gravels, and passes laterally into flood plain clay and silt. The unit rests unconformably on Precambrian banded iron formation and basalt, Cretaceous conglomerate and siltstone, and on Tertiary pisolite and limestone.

The aquifer is recharged by periodic streamflow directly from the Fortescue River which has a median annual flow of 121 x 10^6 m^3. The average annual recharge to the aquifer is estimated to be 11 x 10^6 m^3, and the storage in the aquifer is estimated to be about 130 x 10^6 m^3 based on a specific yield of 0.1. The groundwater salinity in the aquifer rises from 345 mg/L close to the river to more than 1000 mg/L near the tidal flats where there is a salt water interface. Test pumping bores at four sites demonstrated that bores screened in the gravel aquifer are capable of yields ranging up to 800 m^3/d. There is an appreciable thickness of unsaturated gravel above the water table, which could be used for artificial recharge, and pumping close to the river would allow a greater infiltration rate.

INTRODUCTION

LOCATION

The Fortescue River crosses the Ashburton Plain near Mardie Homestead in the Pilbara Region of Western Australia (Fig. 1). The nearest towns are Karratha, 110 km to the northeast, and Pannawonnica 100 km by road to the southeast. The North West Coastal Highway crosses the Fortescue River south of the investigation area, and access to the area is provided by station tracks.

PURPOSE AND SCOPE

The Geological Survey of Western Australia has carried out a number of exploratory drilling projects to locate groundwater supplies for towns along the Pilbara coast. Alluvium along the Fortescue River was recognised as having potential for large supplies of potable groundwater and this report describes the results of the exploratory drilling and test pumping of the alluvium carried out between 1983 and 1985. The investigation was jointly funded by the State and Commonwealth Governments under the National Water Resources Assessment Program.

PREVIOUS INVESTIGATIONS

A census of station wells was carried out in 1963-4 during the course of regional geological mapping (Williams, 1968) and the mound spring at Mt Salt recognised (Williams, 1965).

In 1965, exploratory bores were drilled along the Fortescue River to locate a water supply for Cliffs Western Australian Mining's proposed iron ore pelletizing plant at Cape Preston, 20 km north of the river mouth (Bradberry Associates, 1965). The investigation consisted of fifteen exploratory bores, of which six were test pumped, and proved the existence of an extensive shallow gravel aquifer. It was concluded that the aquifer could supply 3 x 10^6 m^3/a, however the plant was relocated and the groundwater resources were not developed.

The distribution of low salinity groundwater associated with the Fortescue River was mapped, based on the salinity of pastoral bores (Davidson, 1975), and a seismic survey (Lines FA, FB) was later carried out to determine the thickness of water bearing strata (Nowak, 1979).

In a survey of options for the West Pilbara water supply, serving Karratha, Dampier, Roebourne and Wickham, Dames and Moore (1979) described the potential of a lower Fortescue borefield, based on the report by Bradberry Associates (1965). Allen (1987), in a review of the groundwater in the Carnarvon Basin, has also briefly described the groundwater resources of the area.

Two petroleum exploration wells, Mardie West (135 m) and Coonga (176 m), were drilled in 1972 (Hematite Petroleum Pty Ltd, 1973), and there has also been drilling for uranium in the area (Tyrwhitt, 1978).

INVESTIGATION PROGRAM

The Fortescue Coastal Plain exploratory bores (prefix FCP) were drilled by the Mines Department Drilling Branch over a three year period using the mud-rotary drilling method. In 1983 twenty-six exploratory bores were drilled at 24 sites, including two drilled to bedrock to test low velocity material shown by the seismic survey. In 1984 the bore network was extended to the northwest with seven bores, and additional seismic lines (FC, FD & FE) were run in an attempt to define the bedrock surface (Kevi, 1984, unpublished Geological Survey report). In 1985 three further exploratory bores were drilled on seismic targets. One of these (FCP 34A) was converted to a shallow test pumping bore, and two other test pumping bores, each with an observation bore, were also drilled and pump tested.

The bores ranged in depth from 14.5 m to 75.5 m but were generally 20 m to 30 m deep (Table 1) and the aggregate depth drilled was 1128 m. The shallow exploratory bores ranged in diameter from 125 mm to 171 mm and were completed with 80 mm PVC casing (100 mm in FCP 31A) slotted over the water-bearing interval. A protective 100 mm steel casing or in line steel casing was used at the surface. The deep exploratory bores (FCP 2A, 14A, 32A) and the test pumping bores FCP 4P, 11P and 34A were 200 mm to 311 mm diameter and were completed with 155 mm diameter steel casing (200 mm in FCP 32A) and in-line 155 mm stainless steel screens. At the three test-pumping sites, an additional observation bore was drilled 20 m away from each pumping bore and constructed with 80 mm PVC casing slotted at the same depth as the screens in the pumping bore.

The strata were lithologically logged during drilling to enable differentiation of thin gravel beds, and samples retained at 3 m intervals. Gamma-ray logs were run in the cased bores in August 1984. On completion, the bores were developed by airlifting to obtain a clear water sample for chemical analysis by the Chemistry Centre of Western Australia.

Pumping tests, consisting of a six-stage step-drawdown test followed by an eight-hour constant-rate test at rates of up to 1063 m^3/d, were carried out in the three test-pumping bores and the two deep exploratory bores during October/November 1985. FCP 14A could not be developed properly, as the water contained a large amount of sediment, and the maximum pumping rate was 120 m^3/d.

During 1983-5 the waterlevels in the bores were monitored at intervals of between 2 weeks and 3 months, depending on river stage and access (closer spaced measurements were made immediately following river flow). Since 1986 the waterlevels have been recorded in November each year by the Water Authority of Western Australia (WAWA). The bores have been levelled to Australian Height Datum (AHD).

Salinity-depth profiles in FCP 25-29, where there is a saltwater interface, were measured in September 1984, and repeated in August 1985 to confirm that the profiles had stabilized.

A summary of the bore data is given in Table 1 and more detailed bore completion reports are available in Commander (1989).

TABLE 1. SUMMARY OF BORE DATA

Bore name	Date drilled	Elevation casing top (m AHD)	Total depth (m)	Slotted Interval (m)	Static water level[1] (m)	Salinity (mg/L TDS)[2]	Airlift yield (m^3/d)
FCP1A	6.7.83	28.473	18	7-11	7.60	998	--
FCP2A	13-26.7.83	27.199	75.5	43.8-70.8	7.96	454	120
FCP2B	21-22.7.83	27.760	21	6-21	8.46	480	40
FCP3A	7.7.83	25.217	20	6-16	7.37	1337	15
FCP4A	11-12.7.83	24.342	25.5	6-21	6.97	537	20
FCP4P	19-20.6.85	--	20	13.9-20*	--	473	288
FCP5A	11.7.83	19.410	25.5	6-18	8.46	1715	very low
FCP6A	1-5.7.83	21.240	25	0-16.4	9.13	403	--
FCP7A	15-18.8.83	21.757	32	3.2-9.2	--	--	very low
FCP7B	30.8.83	21.583	14.5	5-11	8.57	--	very low
FCP8A	16-17.8.83	24.887	26	4.7-21.7	9.67	505	70
FCP9A	25-26.7.83	15.855	33	6-13	9.51	819	--
FCP10A	3.8.83	15.115	26	10-23	7.18	480	--
FCP11A	4.8.83	14.558	32	6-23	6.91	691	--
FCP11P	23.5-5.6.85	--	22	13-22*	--	678	178
FCP12A	17-18.8.83	17.748	35	6-27	8.46	409	100
FCP13A	18-19.8.83	19.334	20.3	7-18	8.23	486	80
FCP14A	6-12.9.83	19.605	74	50.5-73.5	8.06	480	120
FCP14B	22.8.83	20.221	30	5-19	7.03	390	120
FCP15A	277-2.8.83	19.971	20	5.5-13.5	9.13	460	--
FCP16A	23-29.8.83	--	19.5	not cased	--	--	--
FCP16B	23-29.8.83	11.894	14.5	2.4-10.4	8.75	710	15
FCP17A	24.8.83	9.985	26	5-13,18-21	7.15	793	100
FCP18A	25.8.83	8.997	25.5	4-17,21-23	6.15	742	85
FCP19A	5.8.83	12.488	29.5	4.5-22	7.58	633	85
FCP20A	8.8.83	14.737	29	4.7-22.7	8.52	640	125
FCP21A	11.8.83	14.301	28	5-17	8.05	806	100
FCP22A	9-10.8.83	16.288	29.5	5-13	9.22	601	40
FCP23A	26-27.7.83	14.826	17.5	6-12	7.07	2278	very low
FCP24A	26.8.83	9.423	21.3	4-14,18-20	6.49	832	30
FCP25A	3.8.84	6.437	20.5	5-20	4.77	7040	108
FCP26A	2.8.84	7.205	20.5	2.5-20	6.37	47040	69
FCP27A	31.7.84	6.429	20.5	5-13	5.75	16064	--
FCP28A	30.7.84	6.853	23.5	4-17	5.58	10560	14
FCP29A	24-26.7.84	7.514	30	5-10,14-20	6.06	17024	15
FCP30A	18-20.7.84	9.723	29.5	5-21	6.83	1158	216
FCP31A	16.7.84	11.978	29.5	6-19	8.07	774	28
FCP32A	27-28.6.85	32.864[3]	53	41.5-51.5	8.25	492	9
FCP32B	4.7.85	32.864[3]	18.5	3.4-12.4	8.38	345	17
FCP33A	6.6.85	22.429	44.5	11-21	8.97	550	86
FCP34A	12.6.85	21.627	44.7	13.8-20*	7.97	441	103

[1] 12.11.85 [2] Electrical conductivity (mS/m @ 25°C) x 6.4
[3] casing cut to same height * Screen

ENVIRONMENT

PHYSIOGRAPHY AND VEGETATION

The investigation area lies on the Ashburton Plain (Hocking and others, 1987). This is a coastal plain which rises gently inland from the Cane-Robe tidal flats, and is broken by isolated hills of Precambrian and Cretaceous bedrock. The investigation area comprises the flood plain of the Fortescue River (Fig. 1). The Fortescue River crosses the plain in a narrow channel, which is incised as much as 5 m below the general level of the plain. In the lower reaches there are several anastomosing branches.

Mt Salt (Fig. 1), a prominent bare, rounded, hill formed by a mound spring, rises to about 8 m above the tidal flats (Williams, 1965).

The surface of the coastal plain is flat and composed of cracking clay soils (gilgai) which are vegetated by mixed grasses and open shrubland or open woodland (Beard, 1975). The river banks are lined with river gums and a tree- or shrub-savannah of mixed grasses and scattered eucalypts occurs along the river. The vegetation along the river banks becomes progressively thicker downstream from the investigation area. Areas around outcrops of bedrock are covered by a veneer of gravel and are vegetated with spinifex.

North of the Mardie-Balmoral Road (the former alignment of the North West Coastal Highway) the native vegetation is overrun with mesquite. This was introduced in the early part of the century as a browse shrub after severe degradation of the natural vegetation by stock. The mesquite grew into dense impenetrable thickets after the 1945 flood, reaching its maximum extent in 1953 (Sharpe, R., 1986, personal communication), since when it has been periodically controlled by poisoning.

CLIMATE

The region is arid with hot summers and warm winters. Rainfall is infrequent and intense; it usually results from tropical cyclones and thunderstorms between December and March, and from cold fronts between May and July. The average annual rainfall is 264 mm at Mardie and 263 mm at Balmoral, but annual totals since 1885 range from 9 mm (1936) to 758 mm (1973). Potential annual evaporation is about 2500 mm. Monthly rainfalls for the investigation period at Mardie and Balmoral Homesteads are shown in Table 2.

TABLE 2: MONTHLY RAINFALL 1983-86 (mm)

Mardie (Station No.5008)

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1983	8	9	17	11	0	16	12	0	19	0	0	1	93
1984	16	80	60	14	149	0	36	6	0	0	0	25	386
1985	8	63	0	77	7	12	24	0	0	0	3	0	194
1986	22	194	19	1	0	73	6	0	9	0	0	0	324

Balmoral (Station No.5040)

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1983	10	26	7	22	0	3	9	0	8	0	3	0	88
1984	28	89	86	2	176	0	17	7	0	0	0	11	416
1985	17	36	7	67	8	9	16	0	0	0	0	0	160
1986	1	134	24	0	4	52	3	0	11	0	0	0	229

STREAMFLOW

Streamflow in the Fortescue River has been measured since 1968 at the Jimbegnyinoo Pool gauging station, 4.5 km upstream of the North West Coastal Highway bridge (Public Works Department, 1984). Annual flow has ranged from 4×10^6 m^3 (1977) to 1186×10^6 m^3 (1975), with a median flow of 121×10^6 m^3 (Fig. 2). Large floods, comparable to the Cyclone 'Joan' flood in 1975, were also recorded in 1898 (which demolished the old Balmoral Homestead near Violet Well) and in 1945.

During the investigation period there were three major flows caused by the following rainfall events: cyclone 'Chloë' in February/March 1984, frontal rain in May 1984, and cyclone 'Gertie' in February 1985. Flow persisted for several months following the flood peaks (Fig. 3).

The salinity of large flows for which multiple samples have been taken (Public Works Department, 1984) was 150 mg/L in 1973/4 and 169 mg/L in 1975/6 (Cyclone 'Joan' flood). In 1984 the field salinity of the flow at the North West Coastal Highway bridge was 100 mg/L on 9 March (about 4 days after the peak resulting from Cyclone Chloë), and had stabilized at 250 mg/L from 29 March to 1 May. In 1985, following the Cyclone 'Gertie' flood, the field salinity at the North West Coastal Highway bridge remained at about 250 mg/L from 22 February to 7 May 1985.

GEOLOGY

SETTING

The investigation area lies in the northern part of the Carnarvon Basin on the Peedamullah Shelf (Hocking and others, 1987). It is underlain by up to 90 m of gently northwest dipping Cretaceous sedimentary rocks, which are overlain by as much as 50 m of Tertiary and Quaternary sediments. The Carnarvon Basin sequence overlies a basement of Precambrian sedimentary and volcanic rocks of the Hamersley Basin.

The stratigraphic succession in the area is shown in Table 3.

TABLE 3. STRATIGRAPHIC SEQUENCE

Time unit	Formation	Thickness (m)[1]	Lithology
Quaternary	Alluvium	30	Clay, gravel, calcrete close to watertable
------	unconformity	------	------
Tertiary Miocene	Trealla Limestone	17	Limestone, clay, marl
------	unconformity	------	------
Cretaceous	Muderong Shale	0	Shale
	Mardie Greensand Mbr		
	Yarraloola Conglomerate	23	Conglomerate, sand, clay
------	unconformity	------	------
Precambrian	Mt Bruce Supergroup		
	Brockman Iron Fm		Jaspilite, shale
	Maddina Basalt		Basalt, tuff

[1] Maximum thickness intersected during drilling

STRATIGRAPHY

Mt Bruce Supergroup

Rocks of the Mount Bruce Supergroup crop out in the hills on either side of upper reaches of the Fortescue River, and in small inliers on the coastal plain (Fig. 1). They were intersected in the deeper bores FCP 2, 14, 32, 33 and 34 (Fig. 4).

The rock types intersected are basalt (correlated with the Maddina Basalt) and chert (correlated with the Brockman Iron Formation). Ferruginised shale is common in outcrops within the investigation area.

The Mount Bruce Supergroup is of Precambrian age (latest Archaean to earliest Proterozoic) and is unconformably overlain by Cretaceous, Tertiary and Quaternary sedimentary rocks.

Yarraloola Conglomerate

The Yarraloola Conglomerate (Williams, 1968) crops out in places adjacent to the inliers of Precambrian bedrock (Fig. 1). It was intersected in the subsurface in FCP 2A, 14A and 32A (Fig. 4), but is absent in Coonga 1 and Mardie West 1 (Hematite Petroleum Pty Ltd, 1973). The formation unconformably overlies the Precambrian bedrock.

The Yarraloola Conglomerate in FCP 2A, 14A & 32A consists of granule to pebble gravel of rounded red brown siliceous ironstone, red jaspilite, grey chert, yellowish ironstained and clear quartz, dolomite and basalt, with minor beds of sand and red brown to green clay.

The formation in the subsurface appears to infill a valley incised in the Precambrian rocks by an antecedent of the Fortescue River. It is Early Cretaceous in age and was deposited in a fluvial environment. Elsewhere on the Peedamulla Shelf the formation grades laterally into the Nanutarra Formation and Birdrong Sandstone (Hocking and van de Graaff, 1978).

Muderong Shale

The Muderong Shale has been identified only in Coonga 1 and Mardie West 1 petroleum exploration wells (Hematite Petroleum Pty Ltd, 1973) where it is 93 m and 74 m thick respectively. The Fortescue Coastal Plain Bores were generally stopped in the overlying Trealla Limestone.

The formation unconformably overlies Precambrian rocks and consists of grey to green siltstone with a basal greensand (Mardie Greensand Member). It is Early Cretaceous in age.

Trealla Limestone

Sedimentary rocks correlated with the Trealla Limestone occur throughout the northern part of the investigation area. They unconformably overlie the Yarraloola Conglomerate or the Muderong Shale.

The formation consists of interbedded yellow to cream clay, soft marl, and fine grained to finely crystalline limestone.

The Trealla Limestone is a marine or lagoonal deposit of Middle Miocene age (Hocking and others, 1987).

Fortescue River alluvium

Alluvial deposits of the Fortescue River are up to 30 m thick and form an alluvial fan extending from the base of the scarp bordering the coastal plain to the coast. At the surface the sediments are mainly overbank deposits of clay and silt. Gravel bed-load deposits occur in the present river bed and in the subsurface. The Fortescue River alluvium unconformably overlies an irregular topography on Precambrian, Cretaceous, and Tertiary rocks.

The overbank deposits consist of dense red or yellow clay, and pink to white silty clay with granules and pebbles. The yellow clay is difficult to distinguish from the clay facies of the Trealla Limestone. The clay on the edge of the alluvial fan in FCP 3 and 5, and below the alluvial gravels in FCP 13 and 32, has been ferruginized and silicified. The ferruginous deposits in FCP 5 and 32 are also pisolitic.

The gravel consists of rounded pebbles of basalt, tuff, chert, jaspilite, and minor quartz, up to 100 mm in diameter, which have been derived from nearby outcrops of the Mt Bruce Supergroup. The gravel is partially cemented in outcrops near semi-permanent river pools. The basalt pebbles in the deeper gravel layers commonly have weathered surfaces, and in FCP 29A the basalt has been almost completely weathered to blue clay. Limonite coated quartz also occurs in the deeper gravel layers in 24A.

Calcrete has been formed by hydrochemical action, close to the zone of watertable fluctuation, at depths of 4-12 m below the surface. The deposits vary from carbonate-cemented fine grained sandstone to earthy limestone with rare calcite veins.

The alluvium forms an alluvial fan that has been deposited by the Fortescue River where it discharges onto the Ashburton Plain. It is considered to be of Quaternary age and is being periodically reworked by river floods.

HYDROGEOLOGY

FORTESCUE RIVER ALLUVIUM

Extent

Gravel in the Fortescue River alluvium forms a major aquifer which extends over the alluvial fan west of the river (Fig.5). The gravel contains fresh groundwater in an area of about 200 km^2 (Fig.6). The aquifer grades laterally into the overbank silt and clay which have a very much lower transmissivity.

The gravel generally occurs in one or two layers, interbedded with the overbank clay deposits (Fig.4), and has an aggregate saturated thickness of up to 15 m (Fig.6). It overlies relatively impermeable Tertiary and Precambrian rocks.

Watertable configuration

The watertable is generally between 5 m and 12 m below ground (Fig. 4), but it is subject to seasonal and annual fluctuations of as much as 6 m in bores close to the river (Fig. 7).

The watertable slopes towards the northwest, away from the river, from about 25 m AHD in the south of the investigation area to less than 1 m AHD within 2 km of the tidal flats (Fig. 8).

Recharge

Recharge to the alluvium takes place by direct infiltration through the river bed during periods of streamflow. The amount of recharge is controlled by the duration of flow, and by the available storage capacity in the aquifer near the river. Direct recharge may also occur on the floodplain since during the cyclone 'Chloë' flood, the area extending north west from Warralee Well to Corner Well (Fig.1) was inundated.

In the northwest of the area, direct recharge apparently occurs, as the watertable in FCP 18 and 27 (Fig. 7) rose following local rain in February 1986, which did not give rise to significant streamflow.

Waterlevels in bores close to the river rise rapidly when the river flows, and decline soon after the river ceases to flow (Fig. 7). With increasing distance from the river, there is a progressively greater time lag for waterlevels to rise, and for maximum groundwater levels to occur. Maximum waterlevels occur in FCP 10 & 11 (7 km from the river) eight months after the waterlevel peak in FCP 8 (adjacent to the river). The time lag demonstrates that the waterlevel rise, hence recharge, due to river flow is very much greater than that due to direct recharge from the surface.

The amount of groundwater recharge resulting from the 1984 flow (Fig. 3) was estimated by calculating the volumetric change in the saturated aquifer between March and July 1984. The increase in saturated thickness between the March and July waterlevels was estimated from the hydrographs. These were contoured and the increase in volume of saturated aquifer calculated from areal measurement (Fig.9), using an assumed specific yield of 0.1. The specific yield of disturbed samples of river bed gravel was measured to be 0.3, but a value of 0.1 is appropriate in this calculation because the gravel normally has a proportion of clay in the matrix. Based on this volume, the recharge in the area shown in Figure 9 west of the river was calculated to be 22.7×10^6 m^3. Additional recharge, not taken into account, also occurs east of the river and upstream of this area.

Storage

The total groundwater storage in the alluvial gravel can be calculated by multiplying the volume of saturated aquifer by the assumed specific yield. The volume of groundwater in storage on 12 November 1985 within the area shown on Figure 6, and based on the calculations shown in Table 4, is 126×10^6 m^3.

TABLE 4. GROUNDWATER STORAGE

Isopach interval(m) (Fig. 6)	Average thickness(m)	Area (km^2)	Volume* ($x10^6$ m^3)
>15	15	2.6	4
10-15	12.5	32	40
5-10	7.5	83	62
0-5	2.5	82	20
		Total	126

*specific yield of 0.1

Between May 1985 and the end of 1986 there was only a small river flow (Fig. 2), and waterlevels in the aquifer declined. The resultant decrease in aquifer storage between 12.11.85 and 26.11.86 west of the river, in the area shown in Figure 10, was calculated to be 11×10^6 m^3, assuming a specific yield of 0.1.

Historical waterlevel changes

Waterlevels have been measured in station wells at intervals since 1964, and the data from wells in the area are given in Table 5. Most of the lowest waterlevels that have been measured occurred in 1983-4 following a comparatively small river flow in 1983. At this time some of the wells were dry, and similar waterlevels can be inferred to have occurred after other years of low flows.

The rapid growth of mesquite north of the Mardie-Balmoral Road between 1945-53 is reported to have lowered waterlevels in local station wells by about 2m. Waterlevels susequently recovered as the mesquite was removed (Sharpe, R., 1986 pers. comm.).

TABLE 5. WATERLEVELS IN MARDIE STATION WELLS 1964-85 (m)
(measured below surface reference)

Well name	9/64	4/65	5/65	8/65	6/74	11/79	8/83	4/84	9/84	5/85
Corner	7.0	7.41	7.36	7.19	7.10	6.51	8.66	9.18	8.60	-
Currangyry	8.5	6.33	7.01	8.07	6.90	10.1	10.19	6.20	-	6.76
Hilda	2.7	-	-	-	3.35	4.3	5.30	-	5.26	-
Lawn	3.6	-	-	-	4.25	5.03	6.31	-	6.28	-
Mulyering	9.1	9.90	9.63	8.90	7.85	10.70	10.92	10.83	-	9.05
Pilling	4.5	-	-	-	4.95	6.95	7.44	7.83	7.60	-
Secret	7.3	7.55	7.31	7.16	6.35	7.56	9.79	8.37	7.20	-
Toondy	3.3	-	-	-	3.40	5.0	5.61	5.52	5.43	-
Two Mile	5.5	-	-	-	5.75	6.51	7.25	7.49	-	-
Violet	8.5	6.94	6.70	6.92	5.80	9.08	9.67	7.12	-	-
Warralee	7.6	6.49	6.58	6.58	5.80	8.74	9.53	6.73	-	-
Wealumba	3.3	-	-	-	3.90	4.8	5.56	5.90	5.80	-
Woolawanda.	6.7	-	-	-	6.8	8.32	9.08	9.59	9.31	-
Woolie-Pdk.	5.2	4.39	4.29	-	3.6	6.20	-	4.86	-	-
Yabberoo	9.1	7.74	7.46	7.10	6.35	7.73	8.65	8.82	7.63	-

Hydraulic conductivity

Eight-hour constant rate pumping tests were undertaken on FCP 4P, 11P and 34A (Table 6). Transmissivities, derived from matching time-drawdown data from observation bores to non-equilibrium delayed-yield type curves, ranged from 380 m^2/d to 1760 m^2/d (Commander, 1989). Estimates of hydraulic conductivity in the Fortescue River alluvium, derived from the pumping tests, ranged from 63 m/d at FCP 4P to 190 m/d at FCP 11P.

TABLE 6. TEST PUMPING DATA

		Pump bore		20m Observation bore				
Bore	Pump rate m^3/d	Drawdown (8hrs) m	Sp.cap (8hrs) m^2/d	Sp.cap (30min) m^2/d*	Drawdown (8hrs) m	T m^2/d	K m/d	S
FCP4P	591	6.7	88	263	0.23	380	63	0.15
FCP11P	424[1]	1.6	265	666	0.12	1760	190	0.006
FCP34A	230	2.8	82	181	0.068	1020	170	0.038

Sp.cap=specific capacity; T=transmissivity; K=hydraulic conductivity
[1] Limited by pump, potential yield about 900 m^3/d;
* Calculated according to the method of Sheahan (1971); both specific capacities are affected by delayed yield or vertical leakage.

A pumping rate of 1690 m^3/d with a drawdown of 0.5 m was achieved by Bradberry Associates (1965) in Cliffs No.2B.

Throughflow

Groundwater in the alluvium generally flows away from the river in a northwesterly direction (Fig. 8). For a short period during streamflow, a groundwater mound builds up beneath the river bed, and there is also flow to the east of the river, which reverses when the river ceases to flow.

The throughflow, Q, across the 5 m watertable contour (between AF on Fig. 8), can be estimated from the Darcy equation:

$$Q = kbil$$

where:

k is hydraulic conductivity (m/d)
b is aquifer thickness (m)
i is hydraulic gradient (dimensionless)
l is cross section width (m)

TABLE 7. THROUGHFLOW CALCULATIONS

Section	Aquifer thickness (m)*	Hydraulic gradient ($\times 10^{-3}$)	Length (km)	Annual throughflow ($m^3 \times 10^6$) k=50m/d	k=100m/d	k=200m/d
AB	2	1.05	1.0	0.04	0.08	0.16
BC	7	1.05	2.5	0.33	0.67	1.32
CD	12	1.05	5.5	1.26	2.52	5.04
DE	7	1.05	3.5	0.47	0.94	1.88
EF	2	1.05	5.0	0.19	0.38	0.76
TOTAL				2.29	4.58	9.16

* Average aggregate saturated thickness of gravel

The aggregate thickness of saturated gravel is estimated from Figure 6, and the hydraulic gradient is based on the water table configuration in June 1985. Both can be assumed to be steady state conditions as waterlevel fluctuations are small along the 5 m watertable contour. The range of hydraulic conductivities assumed are based on the results of the pumping tests. The estimated average annual groundwater throughflow in the gravel across section AF on Figure 8, is in the order of 2.3×10^6 m^3 to 9.2×10^6 m^3 depending on the adopted hydraulic conductivity (Table 7).

Discharge

The decline in storage in a year with no recharge can be equated to the average annual discharge. Between December 1985 and November 1986 there was no streamflow and the storage depletion (Fig. 10) was estimated to be 11 x 10^6 m^3 (assuming a specific yield of 0.1). The conservative value used for the specific yield gives a minimum estimate of the annual storage depletion, but this estimate is still much greater than the minimum groundwater throughflow based on the low hydraulic conductivity of 50 m/d (Table 7). This suggests that the higher hydraulic conductivity (200 m/d) derived from the pumping tests and used in the throughflow calculations is more likely to be of the correct order of magnitude.

Discharge from the alluvial gravel is by evapotranspiration from phreatophytic vegetation in the northwest of the area, and by evaporation from the bare tidal flats. Evapotranspiration by mesquite is considerable and the effect on the watertable has been discussed (see 'Historical waterlevel changes'). A study of mesquite in an area of Arizona where the water table is 5 m deep, (similar to the northwest of the study area) found evapotranspiration rates approach the summer pan evaporation rate (Tromble, 1977). At an evapotranspiration rate of 80% pan evaporation, an area of only 5.5 km^2 is required to account for the estimated annual discharge of 11 x 10^6 m^3.

Before the advent of mesquite, it is likely that most of the groundwater discharge was to the bare tidal flats, with groundwater flow taking place over a saltwater interface (see 'Salinity').

Salinity

A lobe of low salinity groundwater, coinciding with the distribution of the gravel, extends from the Fortescue River to the tidal flats in the northwest (Fig. 11). The groundwater salinity ranges from 345 mg/L in FCP 32B to 1158 mg/L in FCP 30A in the central part of the lobe, and up to 2278 mg/L in FCP 23A on the margin of the gravel. The groundwater salinity is controlled by the low salinity recharge water from the river, which itself varies according to the characteristics of different streamflow events.

Close to the tidal flats in the northwest of the area is a saline interface at depths of between 4 and 8 m below the watertable (Fig. 12). The salinity at the watertable in the exploratory bores in this area ranged from about 1850 mg/L in FCP 27 to 18 500 mg/L in FCP 26, and the salinity of the saline groundwater below the interface ranged from 18 000 mg/L in FCP 28 to an unusually high salinity of 75 000 mg/L in FCP 26.

The groundwater salinity in most of the shallow station wells in the alluvial gravel appears to have remained relatively constant since 1964 (Table 8). However, wells abstracting groundwater from above the saltwater interface, such as Coonga, Hilda, Lawn and Toondy Wells, show relatively large fluctuations in salinity.

TABLE 8. SALINITY VARIATION IN MARDIE STATION WELLS 1964-84 (mg/L TDS, EC x 6.4)

Well name	1964 GSWA	1965 BA[1]	1974 GSWA	1979 GSWA[2]	1983 GSWA[1]	1984 GSWA[1]
Corner	535	560	440	440*	-	380
Coolanarra	552	-	690	-	-	-
Coonga	1909	-	3570	2380	1750	-
Currangyry	948	832	910	760	770	-
Garden	7678	-	9050	9800	-	-
Hilda	1875	-	1820	1150	1040	980
Homestead	800	-	760	810	-	-
Jilanjilan	1120	1344	980	1600	-	-
Lawn	1379	-	1600	1970	2100	2070
Mulyering	1121	1344	1290	1190	1152	-
Pilling	877	-	870	860*	750	890
Secret	581	704	550	550	470	505
Toondy	2368	-	3310	1600	1250	1320
Two Mile	646	-	560	550	563	-
Violet	693	672	420	460	480	-
Warralee	509	576	720	460	440	-
Wealumba	1140	-	1600	910	860	860
Woolawandawoolna	877	-	880	480	450	470
Woolie Paddock	732	896	820	720	-	-
Wool Shed	2857	-	2700	1790*	-	-
Yabberoo	796	832	760	760	710	720

1 Quoted EC x 6.4
2 Field conductivity converted to Chemistry Centre conductivity
* Standard analysis

Hydrochemistry

The groundwater in the Fortescue Coastal Plain bores shows a progressive enrichment of sodium chloride at the expense of calcium and bicarbonate with increasing total salinity (Fig. 13). Evidence of calcrete formation close to the watertable suggests that calcium bicarbonate is removed by precipitation. There is also a slight decrease in the proportion of magnesium and an increase in the proportion of sulphate with increasing salinity.

The groundwater is slightly hard to very hard (Table 9). Nitrate is present at concentrations ranging up to 5 mg/L, and fluoride concentrations range from 0.3 mg/L to 0.6 mg/L. Boron ranges in concentration from 0.2 mg/L to 0.8 mg/L and silica concentrations range from 13 mg/L to 38 mg/L. Iron was analysed only in the non-aerated samples from pumped bores where it ranged from 0.05 mg/L to 0.59 mg/L.

Temperature

The temperature of groundwater measured during the pumping tests was 31.5°C.

TABLE 9: CHEMICAL ANALYSES OF GROUNDWATER

Total Hardness) Total Alkalinity

Bore Name	Sample No	Lab. No.	Sample Date	pH	E.C. mS/m	TDS 180	T.H. $CaCO_3$	T.A. $CaCO_3$	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	SiO_2	B	F	Fe	Mn
						....mineral matter in mg/L....																
FCP1A	65638	6965	11.07.83	8.0	156	889	430	325	79	56	163	11	<2	397	243	100	1	37	0.4	0.5	-	
FCP2A*	65639	6966	25.07.83	8.2	71	417	160	141	28	21	82	7	<2	172	107	51	2	33	0.2	0.5	-	
FCP2A*	85905	2284	17.07.85	8.4	71	410	154	140	27	21	82	7	4	163	102	51	2	34	0.2	0.5	0.05	<0.02
FCP2B	65640	6967	25.07.83	8.2	76	444	210	179	42	26	76	7	<2	218	100	56	2	26	0.5	0.4	-	
FCP3A	65641	6968	12.07.83	8.2	209	1190	540	252	72	87	213	14	<2	308	439	125	5	76	0.4	1	-	
FCP4A	65642	6969	15.07.83	7.9	84	496	230	206	43	30	88	7	<2	251	112	61	1	28	0.3	0.5	-	
FCP4P	85906	2285	23.07.85	8.5	74	420	186	175	35	24	75	6	7	199	89	57	3	28	0.2	0.4	0.17	<0.02
FCP5A	65643	6970	21.07.83	7.3	268	1600	660	279	131	81	315	13	<2	340	496	348	2	46	1.3	1.0	-	
FCP6A	65644	6971	05.07.83	7.8	63	365	170	161	30	22	64	6	<2	196	74	45	<1	26	0.2	0.5	-	
FCP8A	65645	6972	18.08.83	7.7	79	458	220	192	44	28	79	7	<2	234	104	53	<1	26	0.8	0.3	-	
FCP9A	65646	6973	11.08.83	8.1	128	759	350	290	64	46	138	8	<2	354	196	93	1	36	0.4	0.5	-	
FCP10A	65647	6974	12.08.83	7.9	75	436	200	167	37	27	74	6	<2	204	103	57	2	28	0.2	0.3	-	
FCP11A	65648	6975	12.08.83	8.4	108	618	320	184	61	40	95	7	6	212	186	82	3	32	0.2	0.4	-	
FCP11P	85907	2286	06.08.85	8.4	106	590	296	184	56	38	92	7	5	214	168	80	3	32	0.2	0.4	0.59	<0.02
FCP12A	65649	6976	22.08.83	7.9	64	377	180	158	35	23	60	6	<2	193	80	50	<1	26	0.2	0.3	-	
FCP13A	65650	6977	22.08.83	7.9	76	461	220	232	44	27	78	6	<2	283	84	50	<1	30	0.8	0.3	-	
FCP14B	65651	6978	23.08.83	7.8	61	360	170	155	33	22	56	6	<2	189	75	48	<1	25	0.2	0.3	-	
FCP15A	65652	6979	09.08.83	7.8	72	427	180	189	36	22	82	5	<2	230	85	52	1	29	0.2	0.4	-	
FCP16B	65653	6980	29.08.83	8.5	111	643	290	203	53	39	114	8	6	235	188	82	2	33	0.4	0.4	-	
FCP17A	65654	6981	25.08.83	8.2	124	720	340	200	61	45	126	8	<2	244	224	94	5	35	0.3	0.4	-	
FCP18A	65655	6982	26.08.83	8.5	116	673	310	194	56	41	123	9	6	224	205	81	4	36	0.3	0.5	-	
FCP19A	65656	6983	15.08.83	8.2	99	567	270	180	53	34	96	7	<2	219	155	79	2	31	0.2	0.4	-	
FCP20A	65657	6984	16.08.83	8.2	100	580	300	227	59	36	90	7	<2	277	144	71	1	33	0.2	0.4	-	
FCP21A	65658	6985	17.08.83	7.9	126	724	370	200	72	46	114	7	<2	244	219	109	3	32	0.3	0.4	-	
FCP22A	65659	6986	16.08.83	7.9	95	555	270	242	52	33	94	7	<2	295	122	66	<1	33	0.2	0.5	-	
FCP23A	65660	6987	08.08.83	9.9	356	2150	77	591	11	12	678	167	175	365	573	325	4	25	0.8	0.9	-	
FCP24A	65661	6988	29.08.83	8.2	130	725	350	196	66	45	125	8	<2	239	237	82	4	38	0.3	0.5	-	
FCP25A	65680	2032	06.08.84	7.7	1100	6480	1840	326	249	297	1770	36	<2	398	3420	461	5	43	-	0.5	-	
FCP26A	65681	2033	02.08.84	7.4	7350	62700	20300	225	2320	3540	16700	136	<2	215	37600	2200	1	34	-	<0.1	-	
FCP27A	65682	2034	01.08.84	7.6	2510	16200	3690	335	378	669	4680	89	<2	409	9220	937	3	42	-	0.7	-	
FCP28A	65683	2035	31.07.84	7.7	1650	10300	1920	395	208	340	3170	93	<2	482	5360	815	1	52	-	0.7	-	
FCP29A	65684	2036	27.08.84	7.7	2660	16700	1870	402	399	213	5560	163	<2	491	10000	33	<1	39	-	0.3	-	
FCP30A	65685	2037	08.07.84	8.1	181	1020	455	212	82	61	183	9	<2	259	376	134	3	38	-	0.6	-	
FCP31A	65686	2038	18.07.84	8.2	121	720	297	230	58	37	138	7	<2	281	197	110	1	35	0.3	0.5	-	
FCP32A*	85901	2280	04.07.85	8.1	77	430	134	145	24	18	106	6	<2	177	118	59	<1	13	0.6	0.5	-	
FCP32B	85902	2281	06.07.85	8.3	54	300	148	128	28	19	49	7	2	152	61	38	1	22	0.5	0.3	-	
FCP33A	85903	2282	10.06.85	8.3	87	490	227	169	40	31	85	7	3	200	127	66	2	32	0.2	0.4	-	
FCP34A	85904	2283	10.08.85	8.4	69	400	163	157	29	22	77	7	4	183	83	54	3	29	0.2	0.4	0.18	<0.02
MT SALT*	65694	2046	03.08.83	7.6	4170	27800	3300	135	680	389	9310	268	<2	165	17000	<2	31	17	-	0.2	-	
CORNER W	12427	0025	11.11.79	6.9	68	390	188	151	34	25	63	5	0	184	93	48	3	22	0.2	0.3	-	
WOOL SD	12428	0026	12.11.79	7.2	279	1510	531	265	74	84	356	14	0	323	604	167	6	40	0.9	-	-	
PILLING	12429	0027	13.11.79	6.9	134	770	405	200	85	47	112	8	0	244	243	111	9	33	0.2	0.4	-	
Guideline				6.5-8.5		1000	500				300				400	400	10				<0.3	<0.1

* samples from Yarraloola Conglomerate (all others are from alluvium)

YARRALOOLA CONGLOMERATE

The Yarraloola Conglomerate was intersected below the Trealla Limestone in FCP 2, FCP 14 and FCP 32, and appears to be present only in a narrow channel which coincides approximately with the present position of the Fortescue River (Fig. 14). It is a confined aquifer, and is confined by up to 30 m of Trealla Limestone in the exploratory bores.

The potentiometric head in the Yarraloola Conglomerate decreases northwards from 26 m in FCP 32 to 12 m in FCP 14 (August 1985). Recharge is presumed to be by downward leakage from the alluvium as the water table in FCP 2A and 14A is higher than the potentiometric head, and the water level changes are similar in both aquifers. At FCP 32 there is a slight upward head between the Yarraloola Conglomerate and the alluvium of 10–15 cm for most of the time which suggests that recharge takes place upstream of FCP 32, as well as downstream.

FCP 2A was test pumped at 1063 m^3/d for 26 m drawdown after 8 hours and a match of the time-drawdown data to a late-stage non-equilibrium type curve gives a transmissivity of 65 m^2/d (Commander, 1989). In FCP 14A a maximum yield of only 120 m^3/d could be obtained, giving a calculated transmissivity of 3 m^2/d.

The groundwater salinity in the Yarraloola Conglomerate ranges from 454 mg/L to 492 mg/L TDS. The ionic composition is similar to that of groundwater of similar salinity in the alluvium (Table 9).

A seepage of saline water (27 800 mg/L) occurs from below the summit of the mound of calcareous tufa at Mt Salt (Williams, 1965). This seepage is probably derived from the Mardie Greensand, as the Yarraloola

Conglomerate is not present in Coonga 1 and Mardie West 1 petroleum exploration wells. The high salinity of the Mt Salt spring is consistent with the groundwater salinity which is found elsewhere in the basal Cretaceous sands (Thomas, 1978), and contrasts with the fresh groundwater in the Yarraloola Conglomerate in the investigation area.

The groundwater temperature in FCP 2A during the pumping test was 32°C.

DEVELOPMENT

The area of the Fortescue River alluvium, including a small area of Yarraloola Conglomerate, which is most suitable for groundwater development is close to the present river bed, where rapid recharge can occur during streamflow. Bore yields of up to 900 m^3/d in the alluvium have been demonstrated by pumping tests.

The yield of the aquifer is limited ultimately by the amount and frequency of recharge from the Fortescue River. Based on the estimated recharge and throughflow, about 10×10^6 m^3 could be abstracted from the Fortescue River alluvium. The estimated groundwater in storage of 126×10^6 m^3 provides additional capacity in years of low streamflow.

The infiltration capacity of the aquifer could be increased by lowering the watertable close to the river and creating a larger immediately-available storage capacity to be filled when the river flowed. By artificially slowing river flow (or controlling release from a dam upstream), and by increasing the area available for direct infiltration, the storage capacity of the normally unsaturated gravel above the watertable away from the river could also be utilised.

CONCLUSIONS

Alluvial gravel extending over an area of 200 km^2, underlying and adjacent to the Fortescue River, contains a fresh unutilized groundwater resource in a region that is generally deficient in fresh water. The resources are sufficiently large to maintain a town water supply or irrigated agriculture.

Based on natural recharge rates the aquifer has the potential to yield about 10×10^6 m^3 per year of groundwater with a salinity ranging between 400-800 mg/L. The yield could be increased by conjunctive use with a dam on the Fortescue River.

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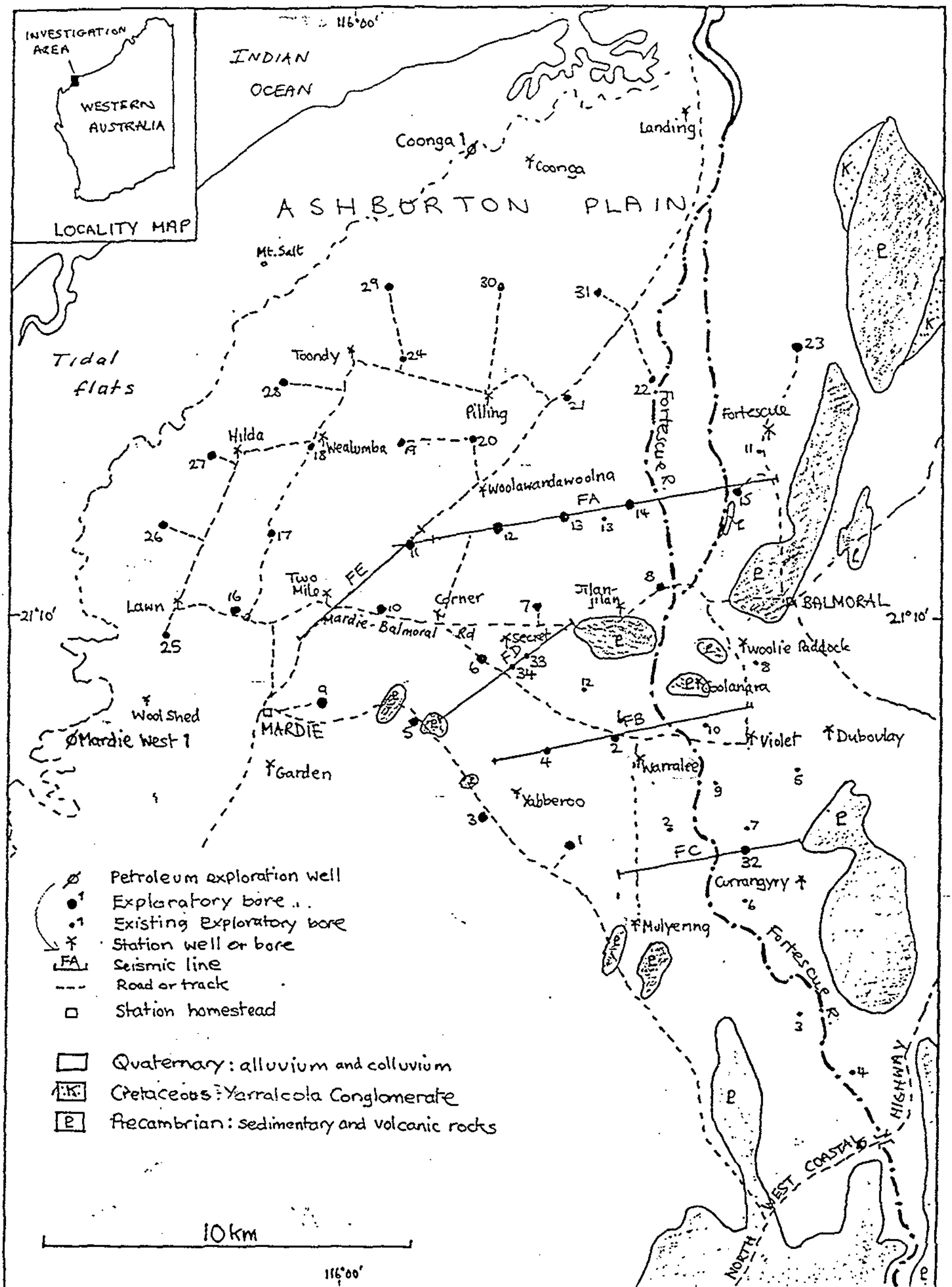
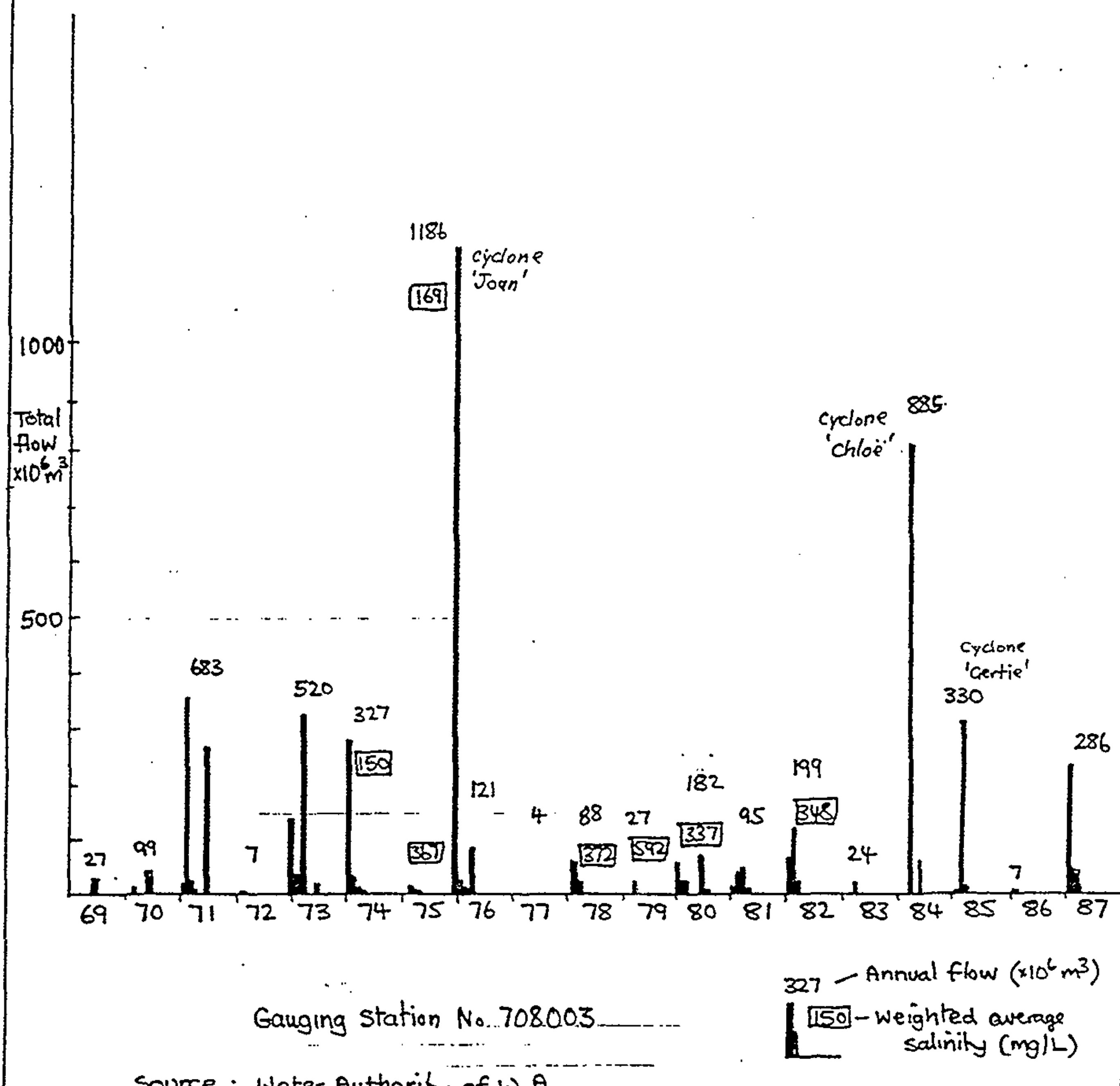


GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

	INITIAL	DATE		MAP INDEX
COMP	DPC	7/84	FIG.1: LOCATION AND GEOLOGY	
DRAWN				
CHKD				SF 50-6
APVD			TO ACCOMPANY Hydrogeology Report 1993/14 by D P Commander	

24780/3/83—2500—H/1995



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

	INITIAL	DATE	
COMP	DPC	10/92	FIG.2: FORTESCUE RIVER STREAMFLOW 1969-87 AND WEIGHTED AVERAGE SALINITY
DRAWN			
APVD			

MAP INDEX
SF 50-6

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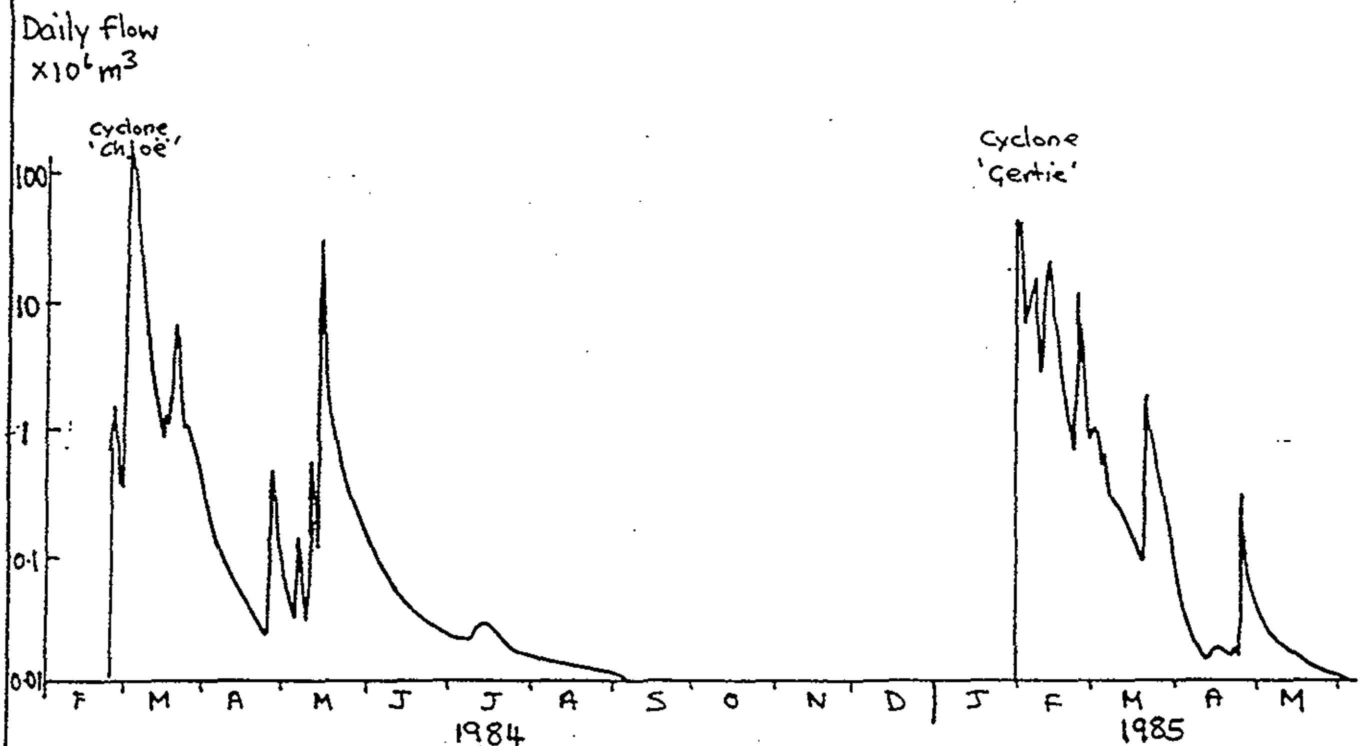

Water Authority of W.A. data Station No. 708 003

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

	INITIAL	DATE	
COMP	DPC	10/92	FIG.3: FORTESCUE RIVER - DAILY FLOW 1984-5
DRAWN			
APVD			

MAP INDEX SF 50-6

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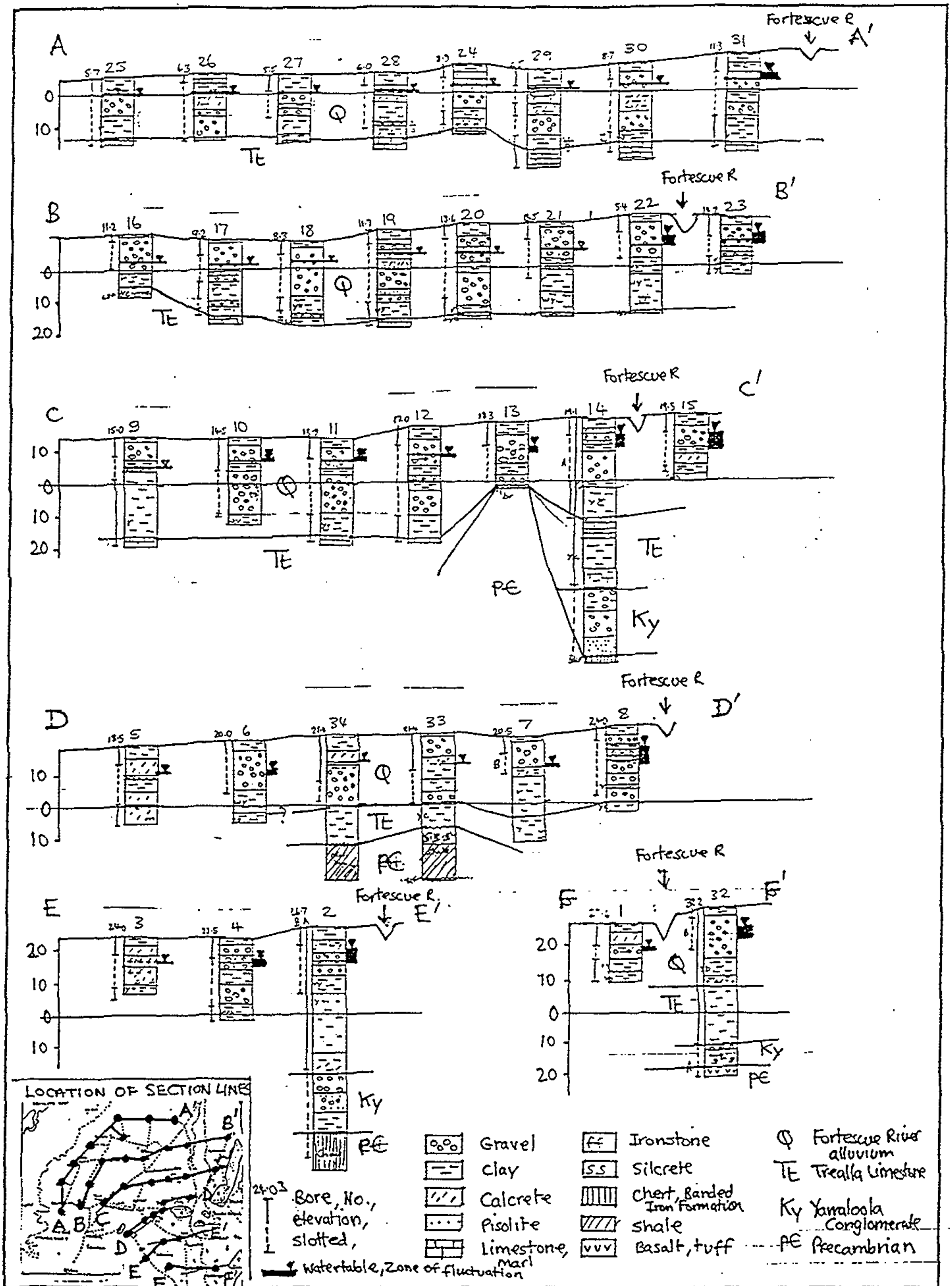

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

	INITIAL	DATE		
COMP	DPC	10/92	FIG.4: GEOLOGICAL SECTIONS	MAP INDEX
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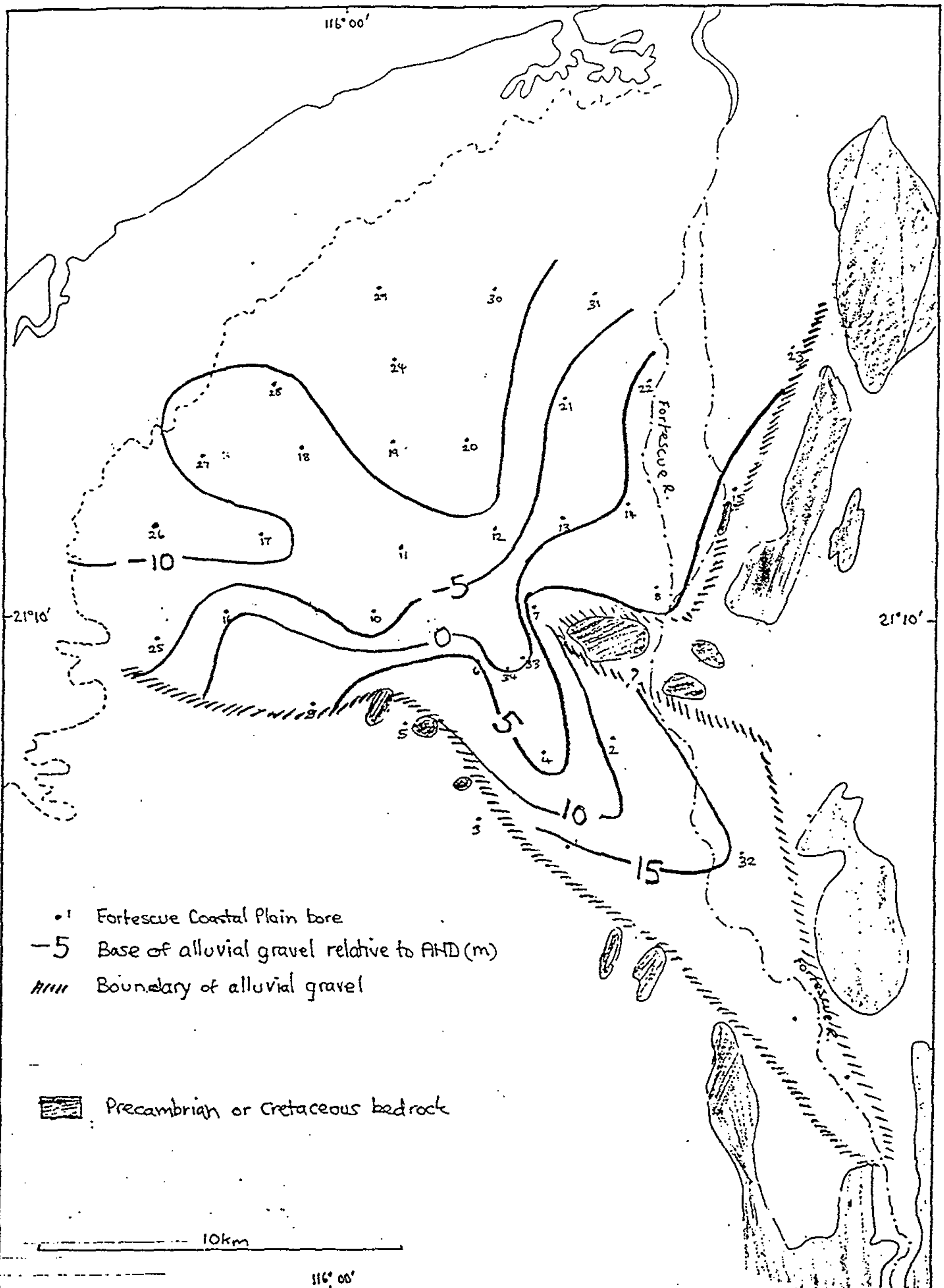
APVD				SF50-6
TO ACCOMPANY	Hydrogeology Report 1993/14 by D P Commander			



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

	INITIAL	DATE	
COMP	DPC	10/92	FIG.5: STRUCTURE CONTOURS ON BASE OF ALLUVIAL GRAVEL
DRAWN			
CHKD			
APVD			TO ACCOMPANY : Hydrogeology Report 1993/14 by D P Commander

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SF 50-6

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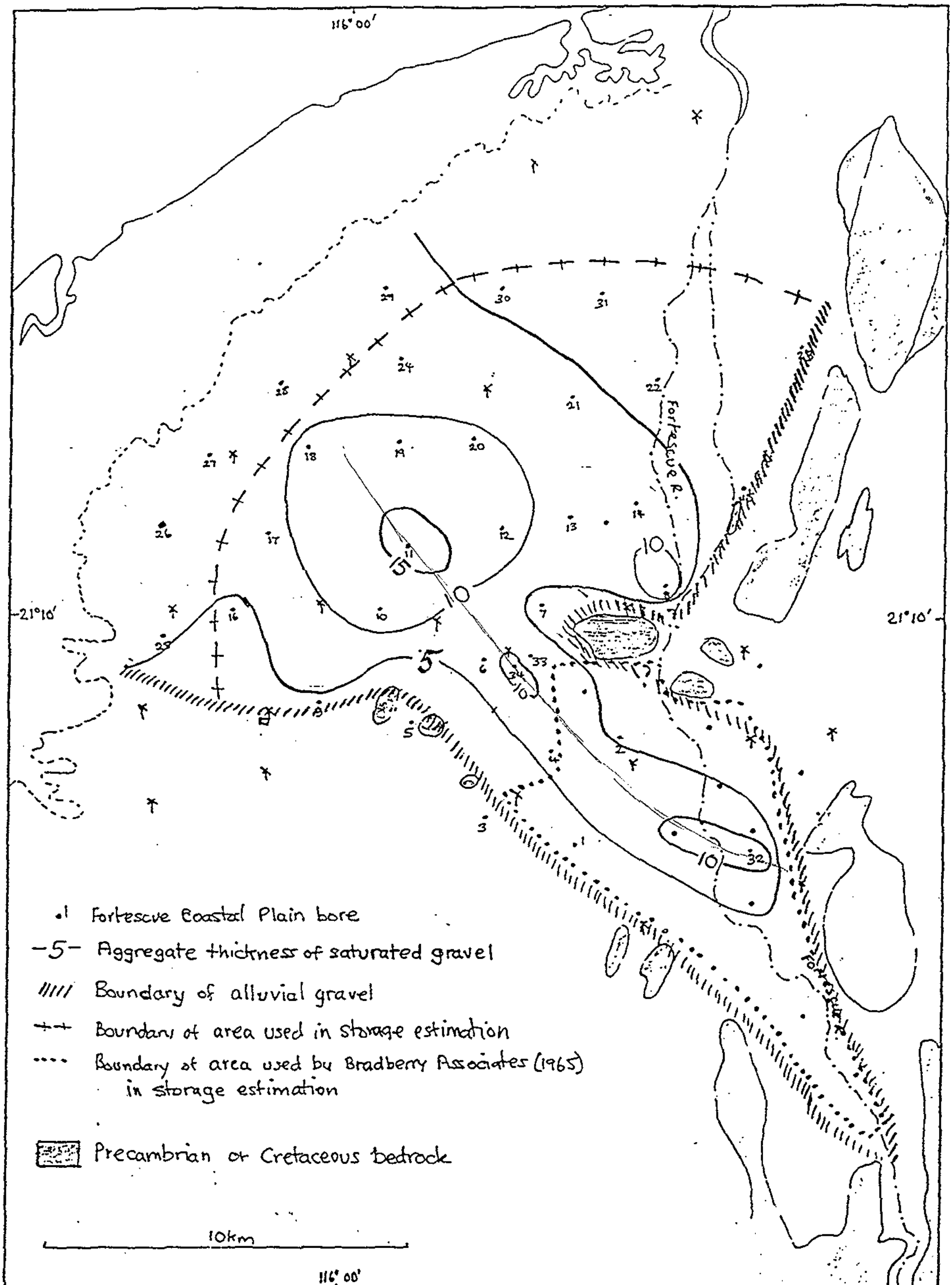

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

	INITIAL	DATE		
COMP	DPC	10/92	FIG.6: EXTENT AND THICKNESS OF SATURATED ALLUVIAL AQUIFER	MAP INDEX SF 50-6
DRAWN				
CHKD				
APVD			TO ACCOMPANY Hydrogeology Report 1993/14 by D P Commander	

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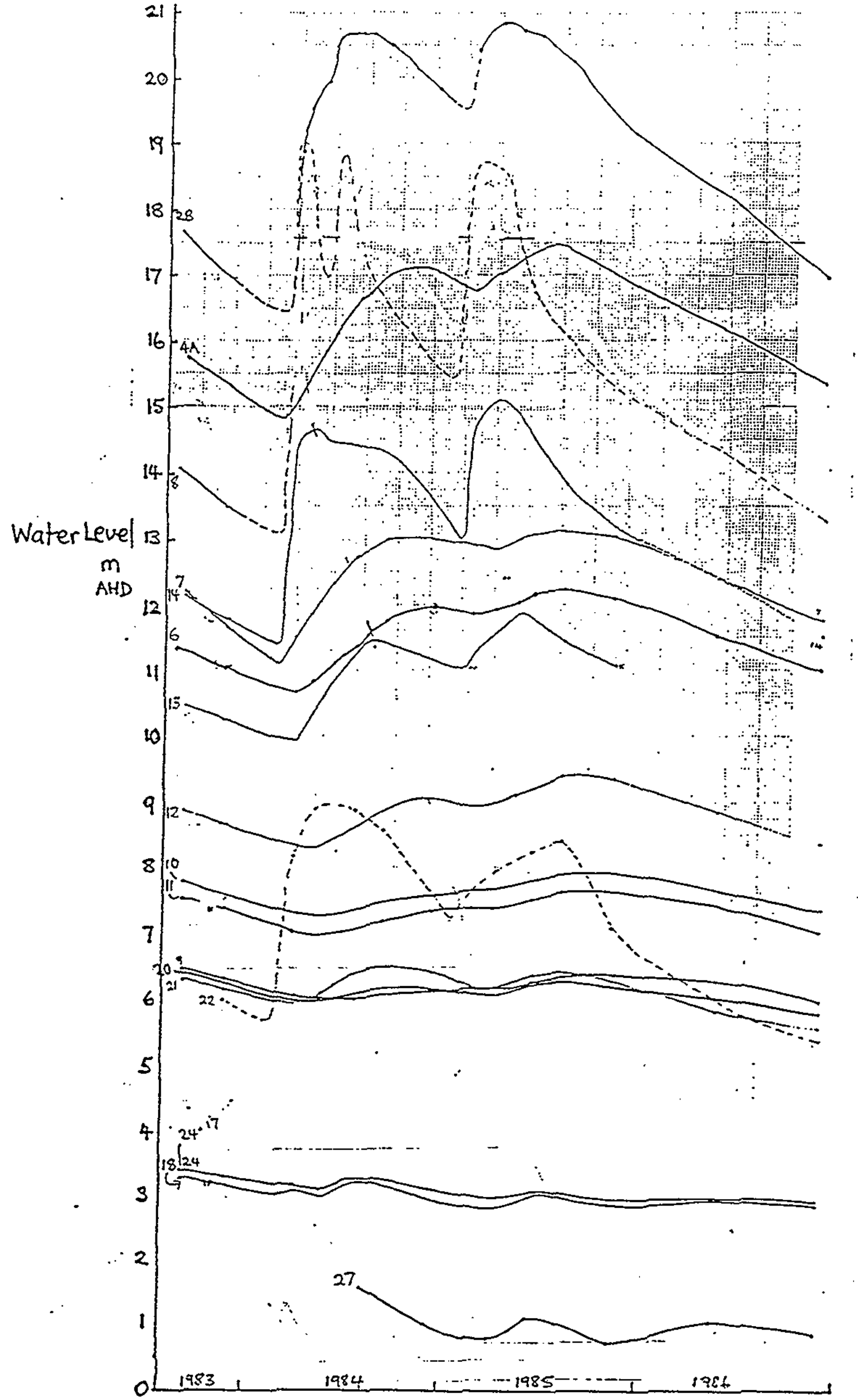

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

	INITIAL	DATE
COMP	DPC	10/92
DRAWN		
APVD		

FIG.7: HYDROGRAPHS OF FORTESCUE COASTAL PLAIN BORES

MAP INDEX

SF50-6

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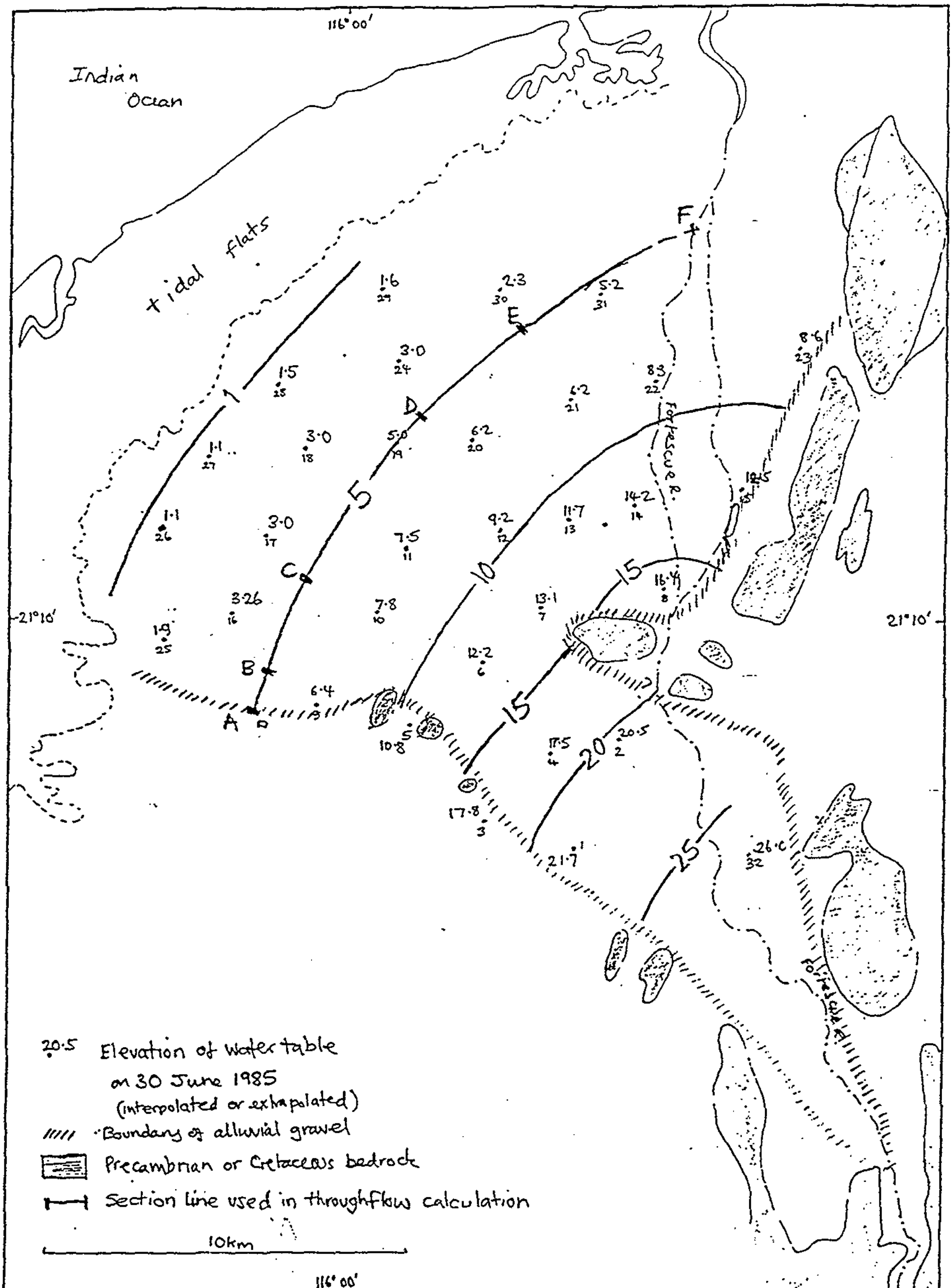

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

	INITIAL	DATE	FIG.8: WATER TABLE ELEVATION	MAP INDEX SF 50-6
COMP	DPC	10/92		
DRAWN				
CHKD				
APVD			TO ACCOMPANY Hydrogeology Report 1993/14 by D P Commander	

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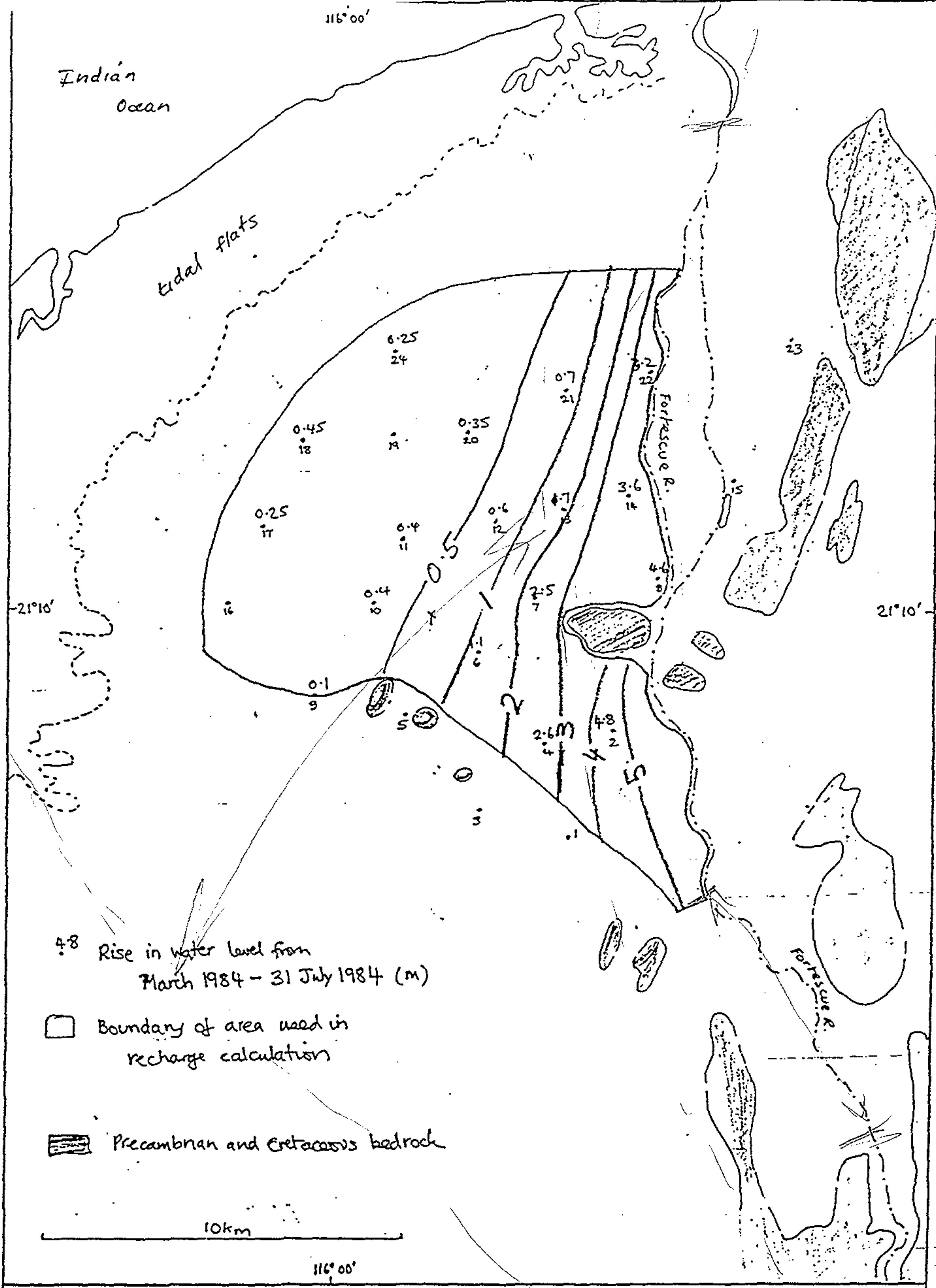

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FIG.9: RISE IN WATER LEVELS FROM 3.84 - 31.7.84

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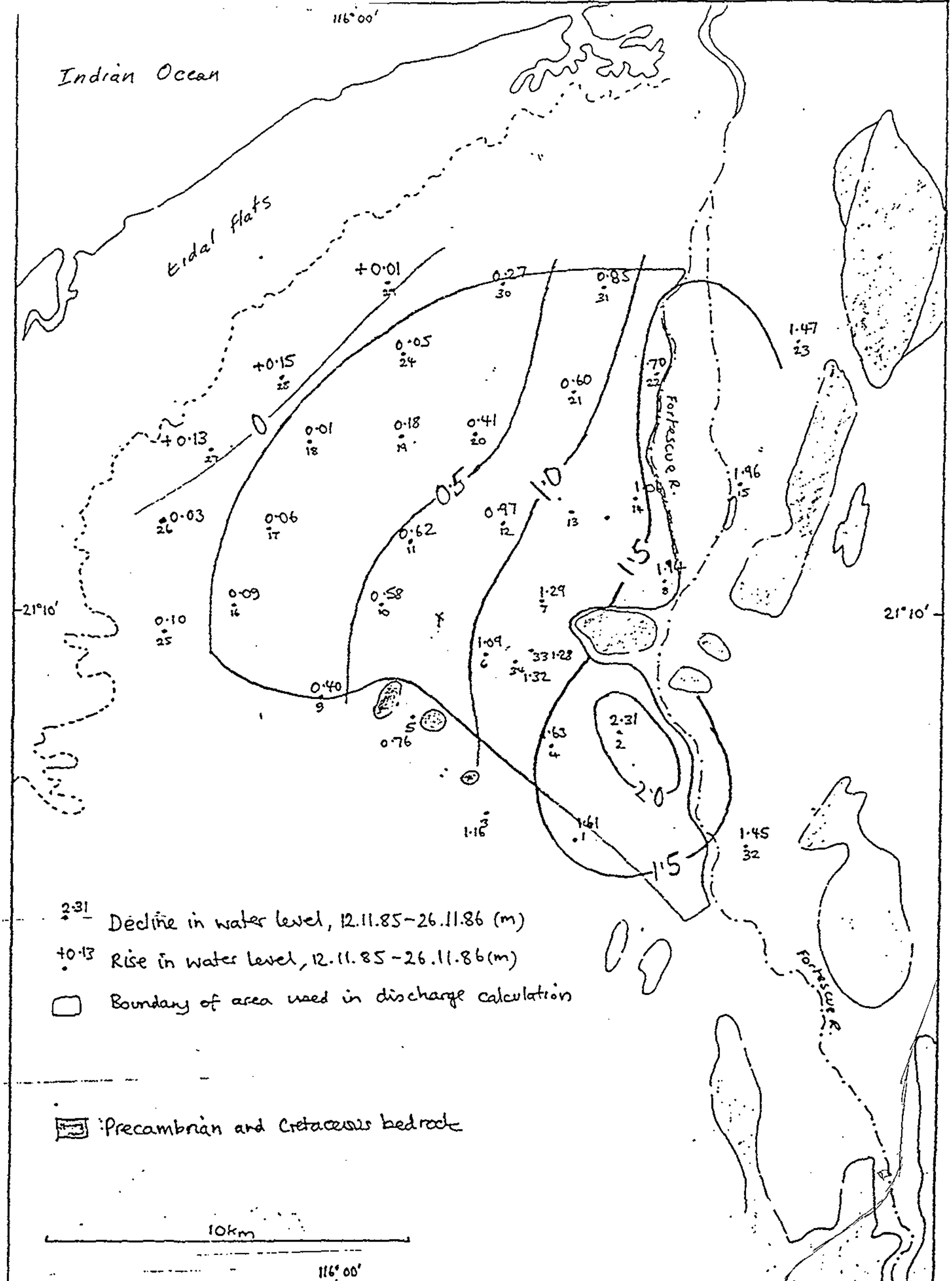

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FIG.10: DECLINE IN WATER LEVELS

12.11.85 - 26.11.86

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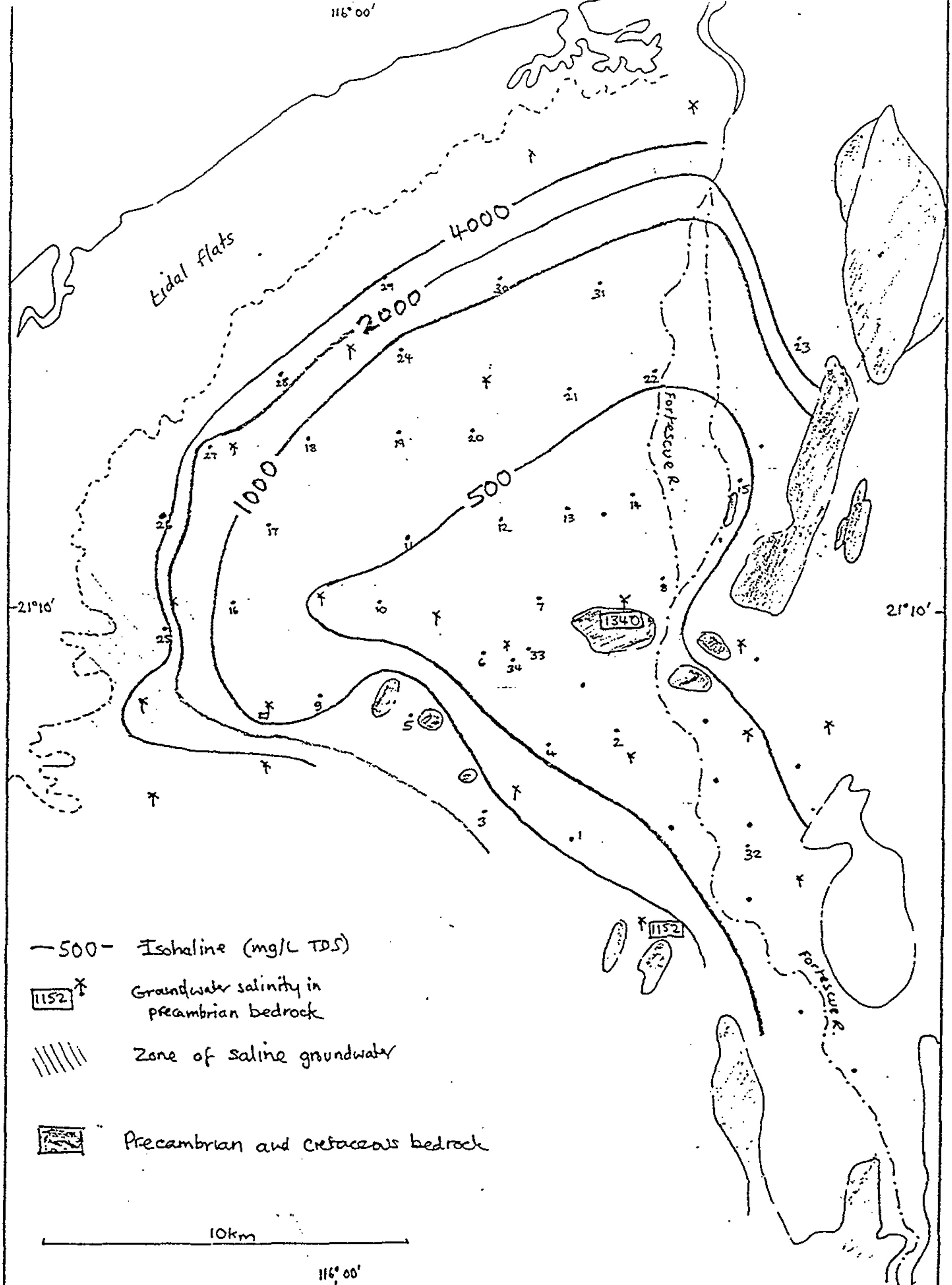

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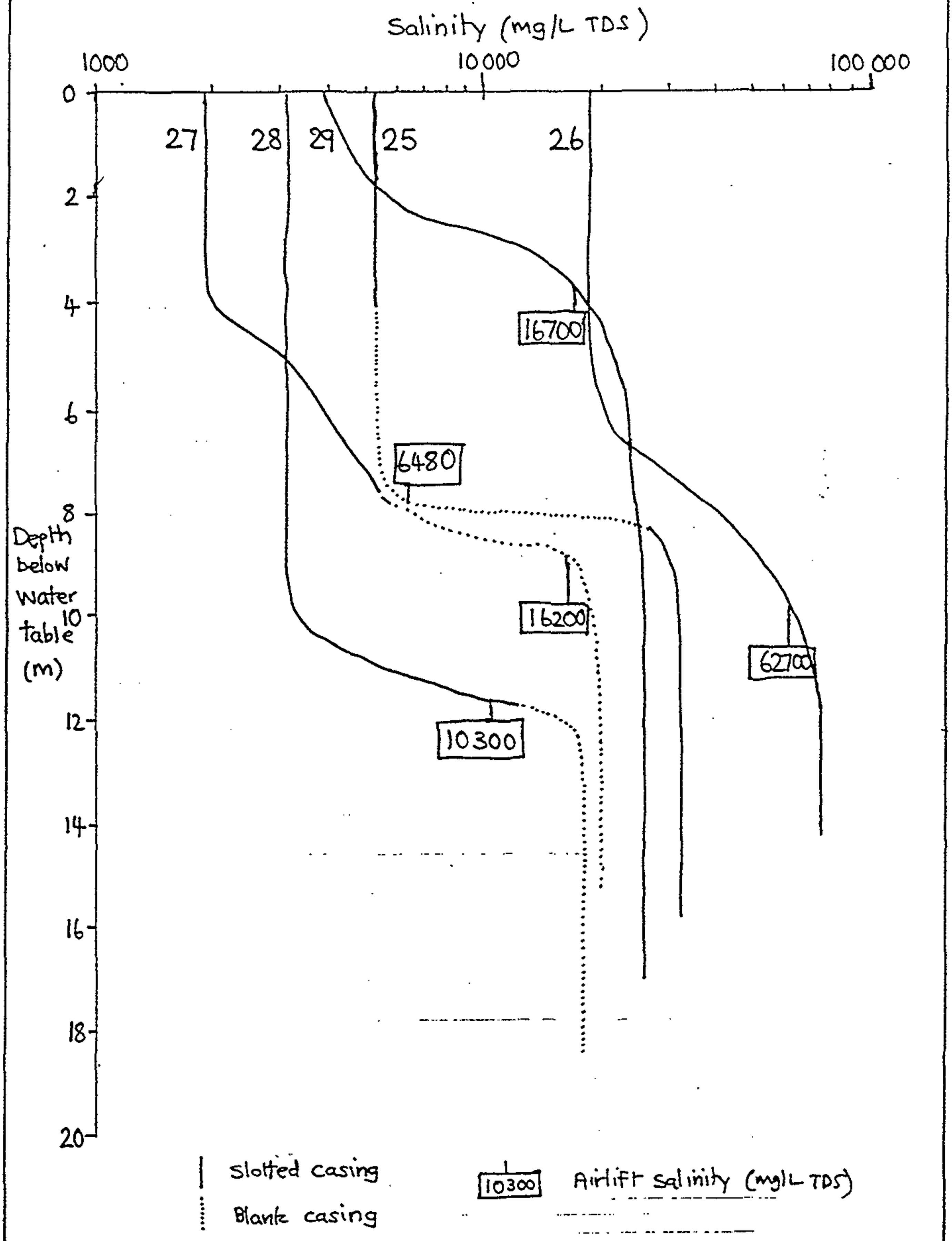

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FIG.12: SALINITY-DEPTH PROFILES IN FCP 25-29

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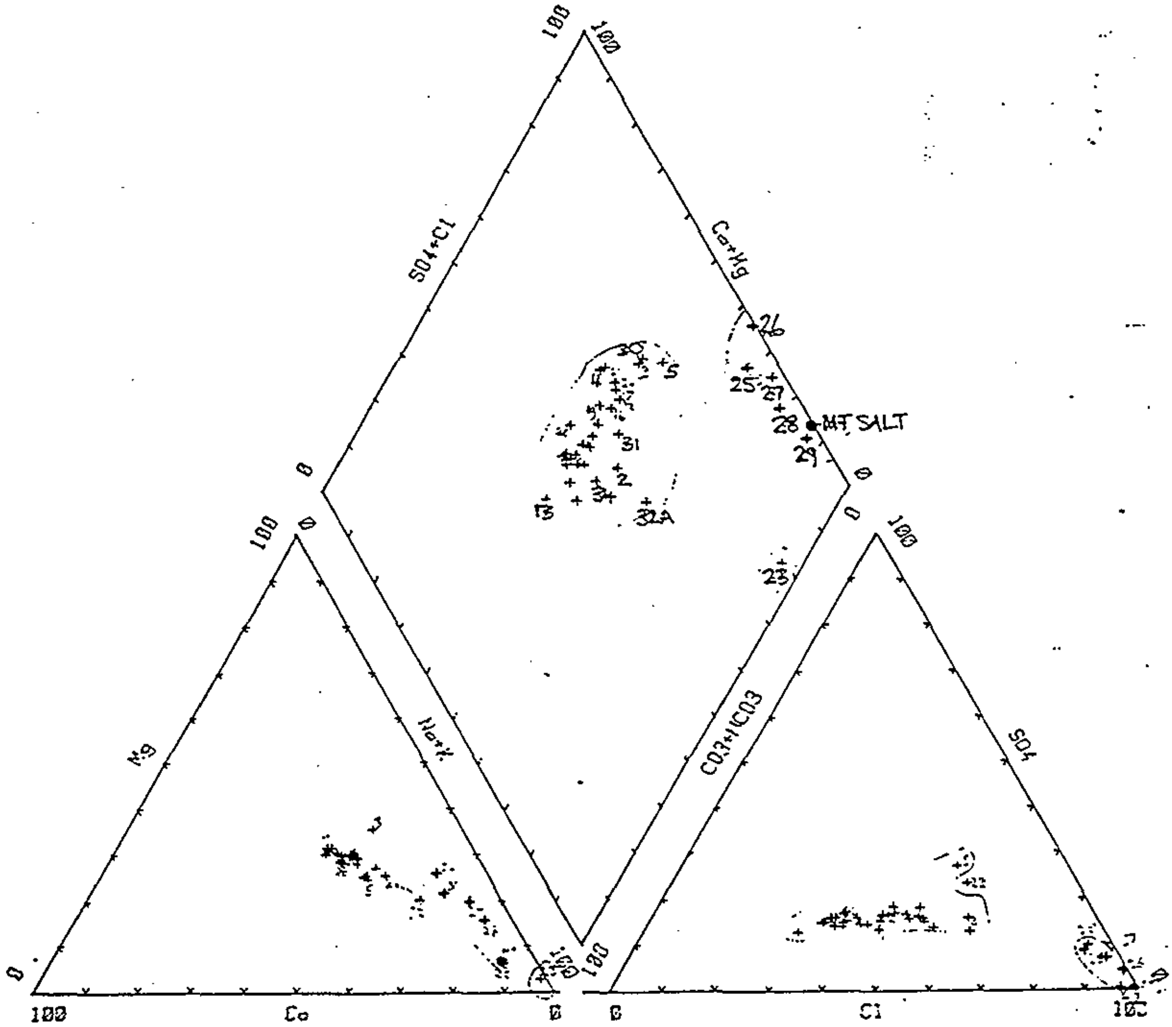

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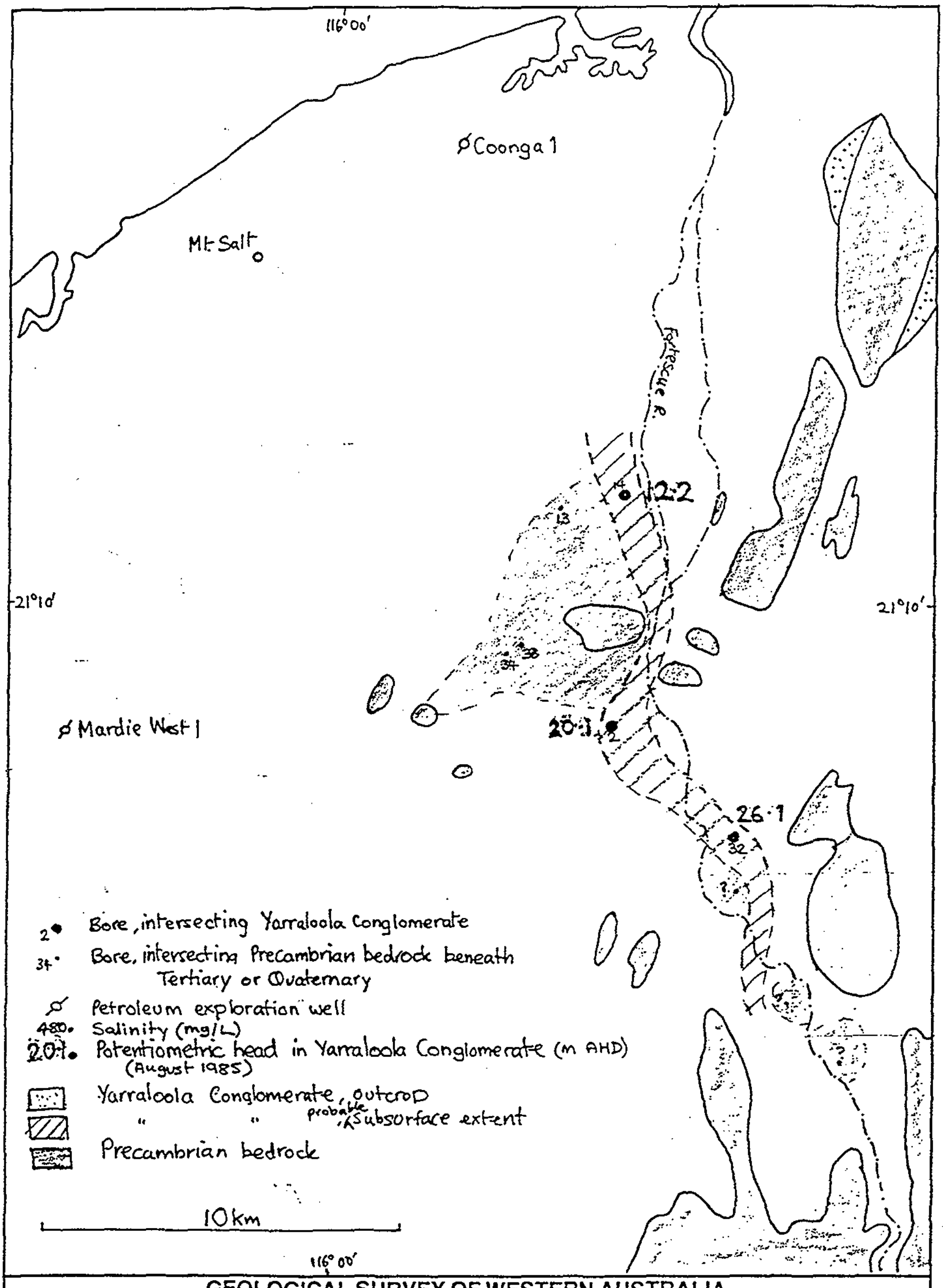

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FIG.14: YARRALOOLA CONGLOMERATE DISTRIBUTION AND HYDROGEOLOGY

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