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Hydrogeo-Stratigraphic Model of Coastal Sediments in Kuttanad Area of Kerala, India

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ABSTRACT

The coastal sediments of Kuttanad mainly consist of recent alluvium and Tertiary sediments unconformably underlay the Precambrian crystallines. Hydrogeologic and stratigraphic characterization of a multi-aquifer system embedded in this coastal sedimentary sequence was conducted using mapping and analysis of lithological and geophysical logs from 125 boreholes. The lateral and vertical variations in the lithostratigraphy and a conceptual model of the hydrogeology of the area could be established from the study. The isopach maps and panel diagrams of stratigraphic formations indicate thick offshore extension of the aquifer systems. The hydraulic gradients in the Tertiary aquifers are indicative of an offshore freshwater interface. The depositional history of Tertiary sediments and the marine transgressions and regressions during Pleistocene glaciations played a major role in the evolution of aquifer systems in these sediments.

INTRODUCTION

‘Kuttanad’ is a low-lying area in the west coast of Indian peninsula bordering the State of Kerala (Fig. 1). The Kuttanad terrain is characterised by wetlands, below mean sea level areas and the Vembanad Lake, a Ramser site into which five rivers debouch before joining the Arabian Sea. The area comprises recent alluvium mainly consisting of sand, silt and clay, underlain by Tertiary sediments. The sediments of Kuttanad area are deposited on a sagging basin dipping towards west with a thick pile of sediments. Thus, the sediment thickness increases towards the coast which further extends offshore. The basement rocks, charnockite and migmatite complex are exposed in the east, bordering the peripheral areas of the coastal sedimentary formations. Residual laterite formations are encountered in the south-eastern parts of the study area. The area has complex hydrogeological environment evolved out of various geological and tectonic activities in the geological past. Based on the analysis of lithological and electrical logs of Tertiary sediments, four distinct stratigraphic units were deciphered in the area, viz; Alleppey, Vaikom, Quilon and Warkalai beds (CGWB 1992). Exploratory drillings in the area by Central Ground Water Board (CGWB) indicate more than 600 m thick pile of Tertiary sediments near the coast. Various litho-units in the stratigraphic sequence are given in Table 1.

Various studies on coastal Kerala sediments (GSI 1980, Nair 1987, CGWB 1992, 2002) have established an afluvio-marine depositional environment for the Tertiary sediments.

Geological history of the area: The history of sea level changes in the Pleistocene, are partly the geological history of the region. The formation of glaciers in the northern continents by the early Pleistocene had subtracted stupendous quantities of water from the world’s oceans, forcing the sea level to reach a level of about 130 m below the modern sea level. The sea level rise was not gradual; instead, it was episodic as the land rebounds due to offloading of ice (Thrivikramji et al. 2003). Curray (1961) published a sea level change curve based on ^{14}C dates of sediment particles depicting the procession of sea level during the last 40000 years before present (BP). Two events of sea level rise or transgressions are indicated here. Vaidyanathan (1981) suggested filling up a series of bays during the Holocene period with mud, which later on got covered by sand sheets moulded into sub-aerial dunes. Based on the investigations in western continental shelf (including Kerala offshore), Nair (1980) recognized four still stands demonstrated by submarine terraces at 92, 85, 75 and 55 m below the modern sea level and ranging in age from 9000 to 11000 years BP. Nair (2003) suggested that the rocks are of Holocene age and sea level was rising (transgressive phase). Kale & Raja Guru (1985) constructed a sea level rise curve and postulated a rate of 1.8 cm per year and the sea level reached the present-day position 6000 years BP. The lowest stand at 138 m below mean sea level occurred probably about 12000 years BP.

Table 1: Stratigraphy of the area.

	Age	Formation	Lithology
Quaternary	Recent	Alluvium	Sand and clays along the coast and flood plain deposits
	Sub-recent	Laterite	Laterite capping over crystalline and sedimentary formations
Tertiary	Lower Miocene	Warkalai beds	Sandstones and clays with thin bands of lignite
	Lower Miocene	Quilon beds	Limestone and clay
	Oligocene to Eocene	Vaikom beds	Sandstone, clay and thin bands of lignite
	Eocene	Alleppey beds	Carbonaceous clay with minor lenses of fine sand
		Unconformity	
	Archaean (crystalline formation)		Charnockites, Khondalites and granites

The sediment deposits along the Kerala coast during these marine transgressions and regressions and the palaeo-climate influenced the evolutionary history of groundwater in the tertiary aquifer systems.

Hydrogeology: The aquifer systems in the area are embedded in recent alluvium and Tertiary sediments. The top phreatic aquifer is spread over the entire area except in low-lying areas where the topsoil is clayey and water quality is poor or brackish. The recent alluvium is well developed near the coast where the phreatic and confined aquifer systems are very potent. Towards the east, the aquifer continuity is lost and the thickness of recent alluvium is also less. Brackish paleo-water is reported from tube wells in the low lying areas in the east (CGWB 1992, 2002).

The Tertiary sedimentary formation is classified into four beds viz; Alleppey, Vaikom, Quilon and Varkalai beds chronologically from older to younger, based on the geological, geophysical and fossil evidence (CGWB 1992). Of the four Tertiary beds, the Vaikom and Warkali beds bear potential freshwater aquifers. The Alleppey beds at the bottom contain brackish water as inferred from electrical logs, whereas, the Quilon beds are poor limestone aquifers. All the four beds are encountered in boreholes drilled in Kuttanad area.

The water table contour maps generated for Warkalai and Vaikom aquifers in previous studies (Vinayachandran 2015) suggest groundwater recharge to these aquifer systems from the southeastern part of the area (south of Alleppey) and further south from the eastern hard rock-sedimentary contact zone.

The aquifer geometry indicates a plausible hydraulic continuity of Tertiary aquifers with the deep fracture aquifer system in the east. The recharge from exposed beds of Warkalai and Vaikom formations are insignificant as the vertical flow of water is restricted by thick clay layers (Vinayachandran et al. 2013). The long-term hydrographs representing the Tertiary aquifers show a falling trend whereas, the hydrographs from the overlying phreatic aquifers are stable. This indicates a distant recharge area for the Tertiary aquifers.

Objective: The objective of the study is to develop a hydrogeo-stratigraphic model of coastal sediments in the Kuttanad area by defining the stratigraphic relation of the multi-aquifer systems, their interrelation, aquifer geometry and the hydro-chemical evolution of the aquifers.

MATERIALS AND METHODS

The lithological and electrical log data from 125 bore wells have been analysed for demarcation of various granular zones for defining the aquifer geometry, stratigraphic succession and formation thickness variations in the area. Panel diagram and cross-sections were prepared to decipher spatial and vertical changes in lithology. The study concentrates on the litho-stratigraphy and hydrology related to the three aquifer systems viz., the unconfined aquifer system in recent alluvium and the Warkalai and Vaikom aquifers in the Tertiary sediments.

The piezometric heads and water levels were collected from the monitoring wells maintained by Central Ground Water Board and State Ground Water Department for flow regime analysis. Pumping test data have been used to evaluate aquifer characteristics (transmissivity and storativity). The aquifer characteristics of deep confined aquifers in the Tertiary beds were collected from the unpublished reports of the Central Ground Water Board.

RESULTS AND DISCUSSION

The stratigraphic classification by CGWB is followed in defining the stratigraphic position of aquifer systems. The spatial variations in sediment thickness in Kuttanad area, based on 125 borehole litho-log, depicted in Fig. 2, indicate a steep gradient of basement with an increase in sediment thickness towards the coast, which further extends into the Arabian sea. The panel diagram depicting the lateral and vertical variations in litho-stratigraphy (Fig. 3) also indicates a similar pattern and here all the four stratigraphic units are well developed near the coast. Towards the east, recent alluvium unconformably rests either over the taper-

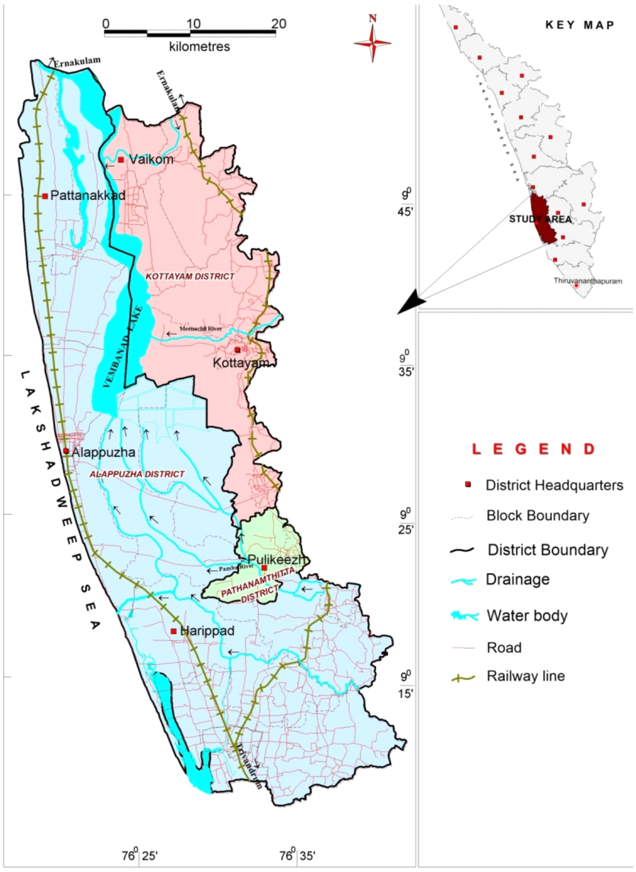

Fig.1: Location map of the area.

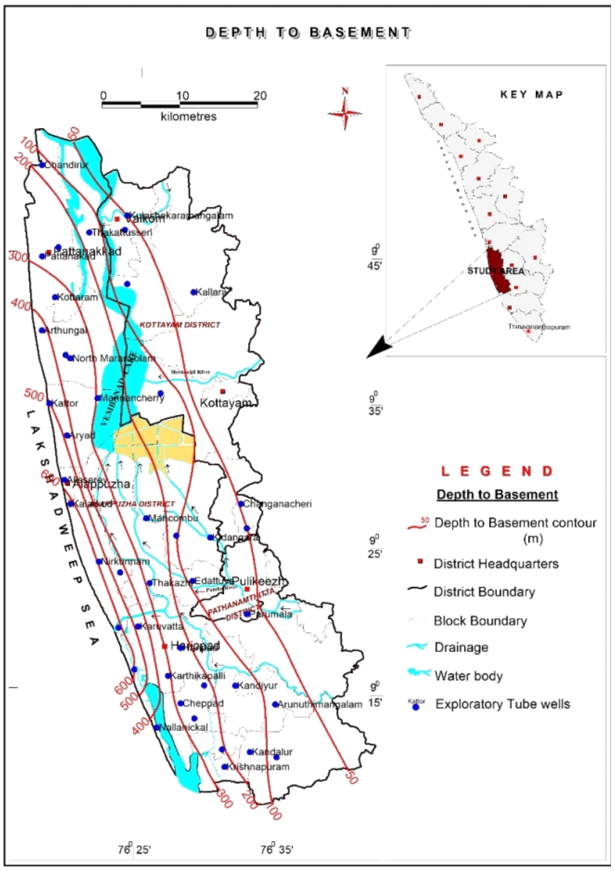

Fig. 2: Isopach of coastal sediments in Kuttanad area.

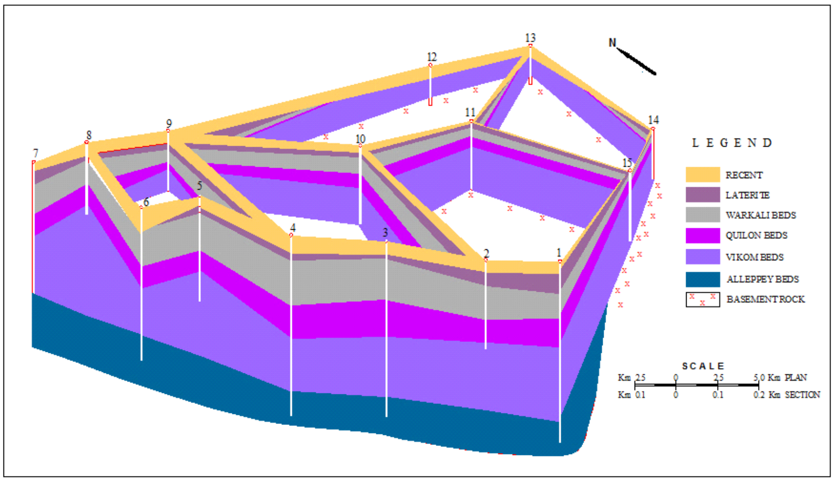

Fig. 3: Panel diagram showing lateral and vertical variations in lithology.

ing Warkali beds or directly over the Vaikom beds. Presumably, the recent alluvium was deposited over an eroded and faulted Tertiary bed. This is elaborated in the findings of the studies by ONGC in the Kerala coast.

According to seismic measurements carried out by ONGC in the sea outside Kerala, a series of mainly NNW-SSE trending faults affect the offshore sediments and basement (Fig. 4). This is completely in accordance with what

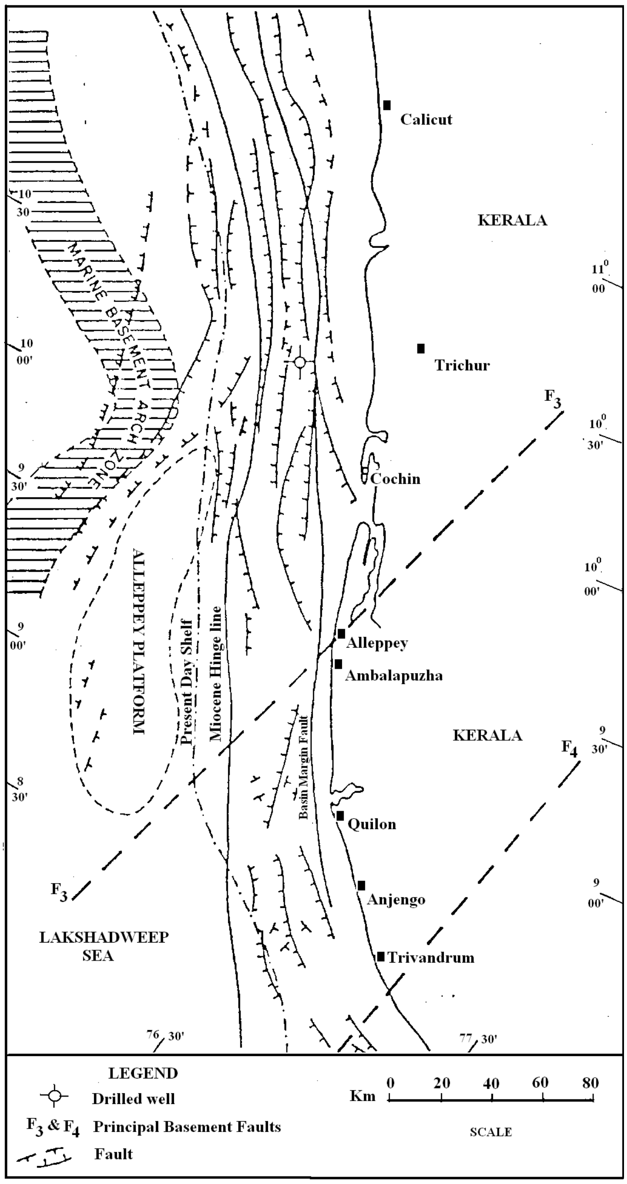

Fig 4: Tectonic map of Kerala coast and offshore (Prasada Rao 1984).

can be expected in areas with a geological history of the kind the Indian west coast has experienced in connection to rifting, separation from the African continent and following the plate tectonic events.

It can be taken as a fact that the faulting also has affected the overlying sediments that were present at the time of faulting. In this connection, it should be kept in mind that the Vaikom, Quilon and Warkali sediments today are not very consolidated. This is reflected in the caving and sometimes even total collapse of boreholes that are not cased for a few days or even a few hours after the drilling has stopped. It is obvious that these sediments were even less consolidated at the time of faulting. The faulting probably took place over a period of time, so it is not likely that all the faults have affected all the sediments. It can also be expected that the faulting and the sedimentation to a large extent were synchronous.

With this background, it is rather unlikely that the sediments have reacted to faulting by developing clear-cut fractures, as is in the case in brittle rocks. It is more likely that they have reacted by developing monoclinal folds or flexures, especially if each fault step is not too much displaced.

The isopach maps of Warkali and Vaikom beds (Fig. 5 and 6) show an increase in the thickness of sediments towards west (sea coast) where the Vaikom beds are thicker and spatially cover the entire area. A gradual increase in sediment thickness of Vaikom beds compared to that of Warkali is evident from these maps. The top elevation maps of Warkali and Vaikom beds (Fig. 7 and 8) show gradient towards the coast, and near the coast it is steeper. Compared to Vaikom the bed gradient near the coast is steeper in Warkali. Thus, the seaward extension of Vaikom beds should be much higher than the Warkali beds.

The borehole made by ONGC about 30 km off shore, just north of Cochin shows the sequence as given in Table 2, according to ONGC. The electrical log of this borehole indicates the presence of freshwater sediments between 701 and 1814 m. However, it is quite possible that the log merely indicates that the sediments originally were deposited under freshwater environment. This matter has to be checked in detail. Anyhow, the log shows that freshwater is present in these sediments and it is quite possible that parts of it have been entrapped between clayey layers at considerable depths. It is quite possible that the lower layers (701-1814 m) seem to be containing freshwater, has a hydraulic connection with the Vaikom layers that we are encountering on land.

Table 2: Sequence shown by the borehole made by ONGC about 30 km off shore, just north of Cochin.

Depth range(m)	Lithology
0-295	Shallow marginal marine sediments. Dominantly sandstone.
295-694	Shallow marine sediments. Clays with sand stone and carbonate.A layer of basalt of unspecified thickness.
674-701	Clay, sand, and carbonate. Another layer of basalt of unspecified thickness
701-1814	Continental sediments. Sandstone with clay and trap derivatives (dominantly fresh water)
The borehole ends in Basalt.	

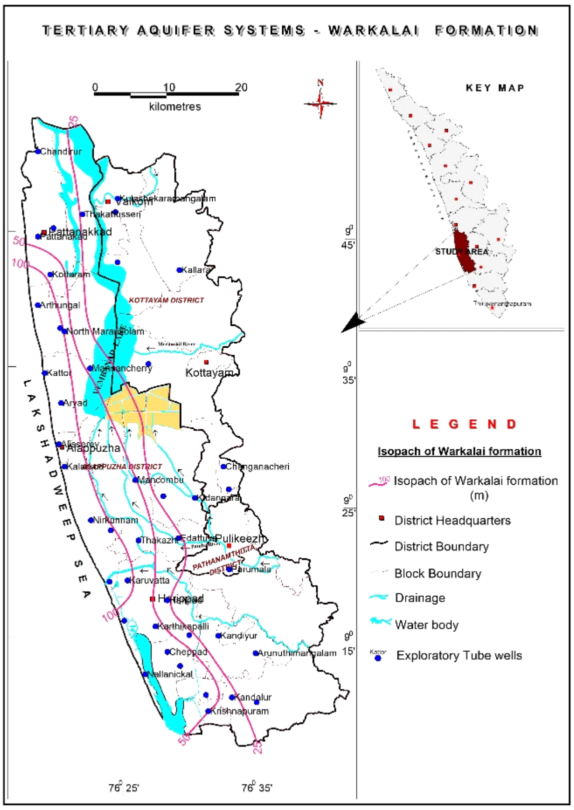

Fig. 5: Isopach of Warkali beds.

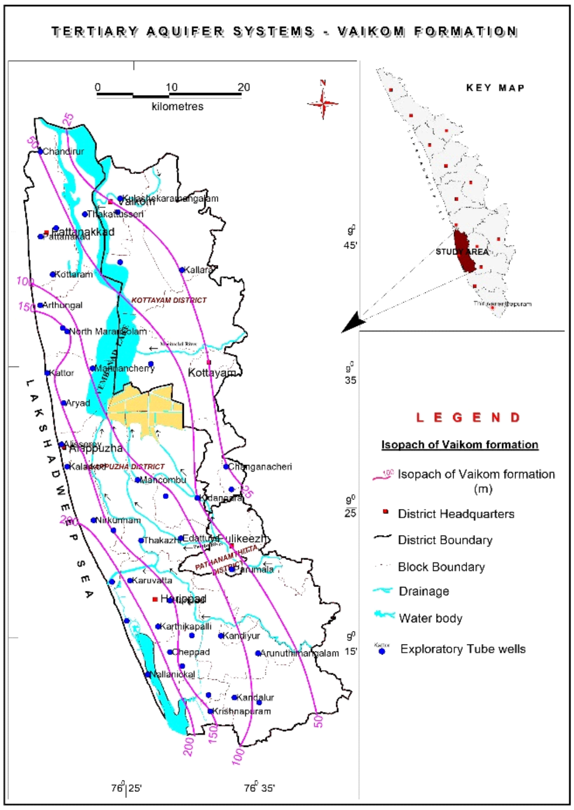

Fig. 6: Isopach of Vaikom beds.

Certainly, the presence of freshwater in a position like this is not normal. However, it is known to occur in similar positions at several different places around the world. The freshwater with lower specific density than saltwater will strive to reach higher elevations, and the easiest way under the confining clay layers and the general dip of the sedimentary formations will be to the east.

A theoretically possible, although a quite fictive picture can be drawn from the coast to the shelf slope. If the Vaikom layers are extended up to this slope, keeping their general dip as we know it on land, they will intersect the shelf slope at a depth of about 1600 m below msl. The column of 1600 m of salt sea water will hydrostatically correspond to a column of 1640 m of freshwater. This means that hypothetically and also possibly there can be a hydrostatic pressure of salt water corresponding to a piezometric freshwater head of +40 m acting on the aquifer at a distance of 130 km from the coast. This could be the force driving the (very slow) flow of fresh groundwater from the west to the east in the Vaikom aquifer, as we record it in terms of a piezometric gradient in this direction on land in the coastal area. The piezometric head observed at the time of construction of piezometers in Vaikom aquifer at Karthikapally about 5 km from the beach was 6 m above msl and at Muttom and Kandiyur located 9 km and 13 km further inland were 5 m and 4 m above msl respectively. That is, in this area the conditions were artesian, and the gradient suggests a flow mainly from west to east in this aquifer. Also, the flow across the hard rock contact zone may be negligible as the existing pressure head in the Tertiary aquifer system is high.

Large-scale pumping from this aquifer system created a trough around the area of extraction of water with flow from all the sides. The piezometric gradient observed at present show groundwater flow towards west (towards the sea) or towards the trough with heads below msl. The flow from offshore towards the trough could not be evidenced as there is no provision to measure the piezometric heads offshore.

The conclusion of this is that the fresh/saltwater interface, very likely is situated farther out under the sea, possibly more than 25 to 30 km. Hence, the pumping wells taping this aquifer very close to the sea may not be affected by salt water intrusion as the seawater-freshwater interface is further off than it normally is.

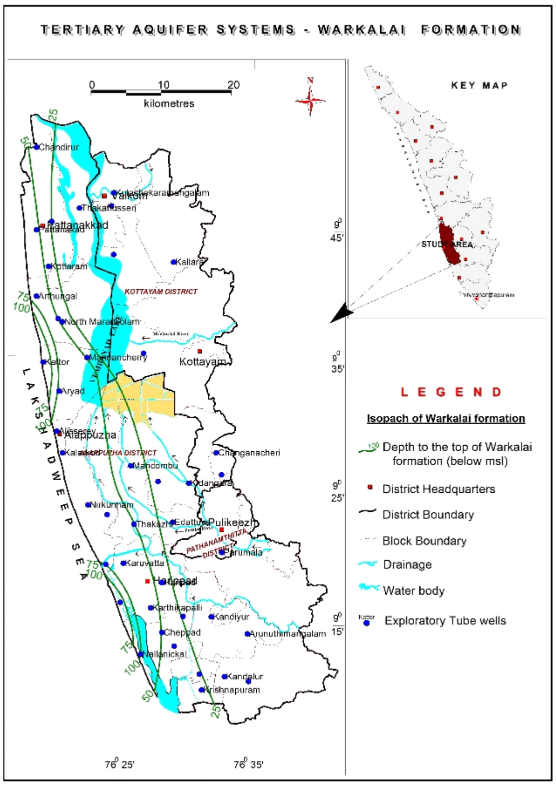

Fig. 7: Top elevation of Warkali beds.

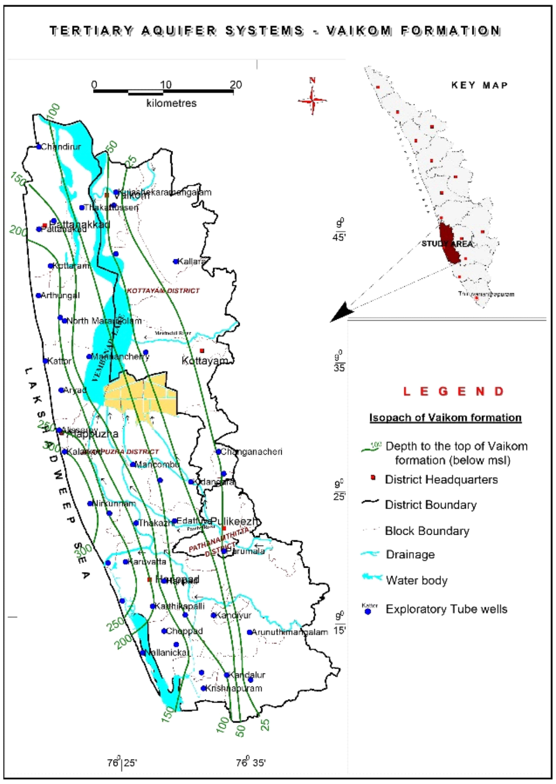

Fig. 8: Top elevation of Vaikom beds.

CONCLUSION

The hydrogeology of the area is evolved out of various sedimentation and hydraulic cycles underwent during the marine transgressions and regressions in the geological past.

During the Quaternary period, the latest 3 million years, the time span of the glaciations has been in the order of ten times longer of the inter-glaciations and the sea levels were in the order of 100 to 200 m lower during the glaciations than it is now (because large volumes of water were confined in the huge ice masses). The shoreline at the peak of this glaciation would be the shelf edge, which in this area is situated 60 to 70 km west of the present coast.

This means that the sediments that were deposited during the inter-glaciations, on the present shelf, in seawater or brackish water, during glaciations came in a position above the sea level. During such periods, the original interstitial salty water was flushed out and replaced by freshwater and under certain conditions, with overlying confining clay layers, this freshwater was trapped in the sediments when they were transgressed during the subsequent inter-glaciation. Thus, it is possible that the fresh/salt water interface in the Vaikom aquifer is situated rather far out in the shelf. Further detailed study is required to confirm this conclusion.

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