CHAPTER 6

CAUSES OF INUNDATION

In this chapter, the author has critically discussed the two main categories to which the various causes of inundation could be assigned. His investigations have shown that the causes are sediment or geomorphic controlled.

ROLE OF SEDIMENTS

None of the previous workers have suggested the likely relationship that exists between the sediment properties and the inundation and water-logging. The author's investigations have very

clearly shown that sediments play an important part in the movement of water both above and below the ground surface, and this phenomenon has been a major factor in causing inundation of a very wide area.
In this part of the Chapter, an attempt has been made to clearly explain the various sediment properties in relation to the movement of water. A brief description of the experiments conducted has already been given, in Chapter 5. Here the author has discussed mainly the inter-relationship of the various sediment properties. Description of certain properties such as capillarity, efflorescence and horizontal permeability, is based primarily on the basis of field observations because laboratory experiments on these aspects could not be conducted. For arriving at definite conclusions, the author has taken into account such other properties, as grain-size, consistency and thixotropy of the sediments, and correlated them with his laboratory and field observations. An account of his broad conclusions relating to the role and behaviour of sediments is given in the following pages.

The various causes that control and influence the Rann inundation, related to the sediment properties, are as under:-

(i) Fineness of sediments
(ii) Field moisture capacity
(iii) Capillary rise in sediments
(iv) Hygroscopic absorption
(v) Infiltration capacity
(vi) Permeability
(vii) Compaction
(viii) Plasticity
(ix) Thixotropy
(x) Moisture absorbing capacity
(xi) Presence of salts.

Fineness of Sediments

Basic properties of any sediment are based primarily on grain size distribution. The results of laboratory experiments given in Table 6.1.

Fig. 6.1 shows that though the overall grain-size reveal some similarity, there are regions which show a distinct change in the percentages of sand, silt

TABLE 6.1

MECHANICAL ANALYSIS OF RANN SEDIMENTS

Depth (in cm)	Coarse sand	Fine sand	Silt	Clay
1. Location: North-east face of Dharamshala bet				
0-30	8.33	53.17	30.22	8.38
30-75	8.12	60.62	25.37	5.89
75-135	4.35	47.54	35.35	12.76
135-240	2.89	46.33	40.43	10.35
2. Location: Rann surface, west of Dharamshala bet				
0-1.25	Salt crust			
1.25-15	1.50	4.72	35.73	48.05
15-45	0.50	2.81	32.65	64.04
45-90	Nil	2.02	36.65	61.33
90-170	Nil	1.82	36.33	61.85
170	Nil	1.85	37.25	60.90
3. Location: 1.6 km south of Bedia bet in Rann				
0-2.6	1.50	22.33	41.65	34.52
2.6-75	Nil	15.73	47.33	36.94
75-195	Nil	15.33	48.22	36.45
195-260	Nil	12.22	51.39	36.39

TABLE 6.1 (contd.)

Depth (in cm)	Coarse sand	Fine sand	Silt	Clay
4. Location: Between Chota and Bada Sarbela				
0-5	2.20	24.65	55.92	17.23
5-45	0.15	13.33	59.33	27.19
45-90	Nil	9.22	58.22	32.56
90-170	Nil	3.22	50.29	46.49
5. Location: In the Great Rann on the road to Dharamshala				
0-15	1.22	5.61	32.81	60.34
15-45	1.05	5.33	33.21	60.41
45-76	Nil	3.12	29.63	67.25
76-105	Nil	2.25	29.51	68.24
105-135	Nil	2.71	29.35	67.94
6. Location: In the depressed area near Kuar bet in facet B_3				
0-5	Salt Crust			
5-15	0.25	3.22	26.50	70.03
15-60	Nil	5.10	21.32	73.58
60-107	Nil	1.12	19.12	79.76
7. Location: Region marked 'shallow-water depression' and 17 km west of Khavda near road leading to Dhorada Wandh				
0-5	Thick Salt Crust			
5-45	Nil	5.70	22.50	72.43
45-140	Nil	4.20	20.42	75.56

TABLE 6.1 (contd.)

Depth (in cm)	Coarse sand	Fine sand	Silt	Clay
8. Location: In facet B_3, shown as site No.8 on Fig. 4.1				
0-40	1.22	16.10	58.33	24.35
40-90	1.08	16.28	57.26	25.38
90-140	0.52	14.31	51.31	33.86
9. Location: South of Kuar bet and West of India Bridge in the region near the mainland				
0-25	22.62	38.33	28.22	10.83
25-30	1.25	5.66	20.00	73.09
30-45	Nil	2.33	20.22	77.45
45-55	Nil	2.65	12.33	85.12
55-80	Nil	0.35	21.33	78.32
80-85	Nil	1.25	5.65	93.10
85	Nil	2.12	15.28	82.60
10. Location: South of Kuar bet away from mainland				
0-2.5	Salt Crust			
2.5-20	Nil	2.25	15.31	82.44
20-45	Nil	1.05	23.61	75.34
11. Location: 2.4 km NNE of Lakhpat in the Rann				
0-15	2.25	7.35	47.36	43.04
15-105	1.22	8.62	49.77	30.39

TABLE 6.1 (contd.)

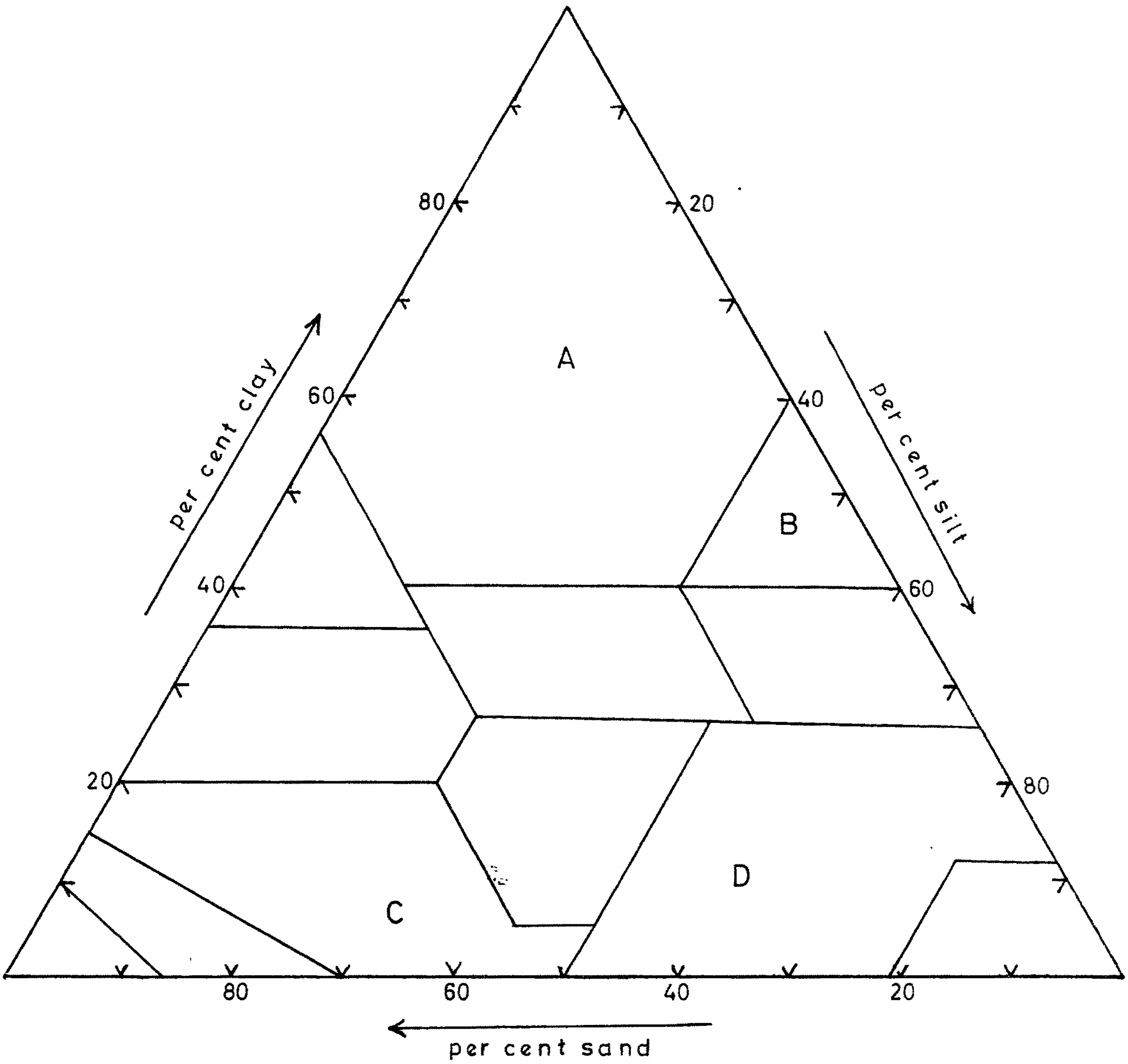
Depth (in cm)	Coarse sand	Fine sand	Silt	Clay
12. Location: In the facet B_3, about 13 km WSW of Pachham island in the Banni area				
0-20	2.25	34.62	45.33	17.90
20-65	1.00	30.33	47.38	21.39
65-155	0.50	31.42	42.22	25.86
13. Location: About 8 km north of Bela Island on the Bela-Nagar Parkar crossing of the Great Rann				
0-2.54	Salt crust			
2.54-10	4.30	11.22	20.60	63.88
10-75	Nil	10.28	24.50	65.22
75-90	Nil	10.33	50.41	39.26
90-145	Nil	8.65	42.63	48.72
14. Location: SSE of Kuar bet in the Great Rann				
0-2.5	3.85	8.32	53.44	34.39
2.5-105	3.05	6.42	56.31	34.22
105-230	Nil	4.21	51.61	44.18
15. Location: About 3.2 km north of Pachham Island				
0-2.5	Salt Crust			
2.5-10	1.55	2.33	22.62	73.50
10-60	1.22	5.63	35.42	57.73
60-90	Nil	2.33	15.33	82.34
90-155	Nil	2.22	29.65	68.13

TABLE 6.1 (contd.)

Depth (in cm)	Coarse sand	Fine sand	Silt	Clay
16. Location: Piprala silty clay (profile after Satyanarayana)				
0"-3"	6.0	22.8	23.1	48.1
3"-12"	1.3	7.3	39.6	51.8
12"-21"	3.6	11.0	43.7	42.5
21"-36"	5.5	4.0	39.1	51.4
36"-43"	8.1	30.1	16.6	44.7
43"-49"	3.0	23.2	23.1	50.7
49"-58"	2.8	35.7	16.8	44.7
58"-84"	0.0	25.7	22.4	51.9

Fig. 6.1.

TEXTURAL CLASSIFICATION OF RANN SEDIMENTS



A - Clays Organic clays from Kuar bet and various depressions north of hill massifs
Inorganic clays from inter-bet depressions.

B - Silty clays from region around Bedia bet, Biar bet etc.

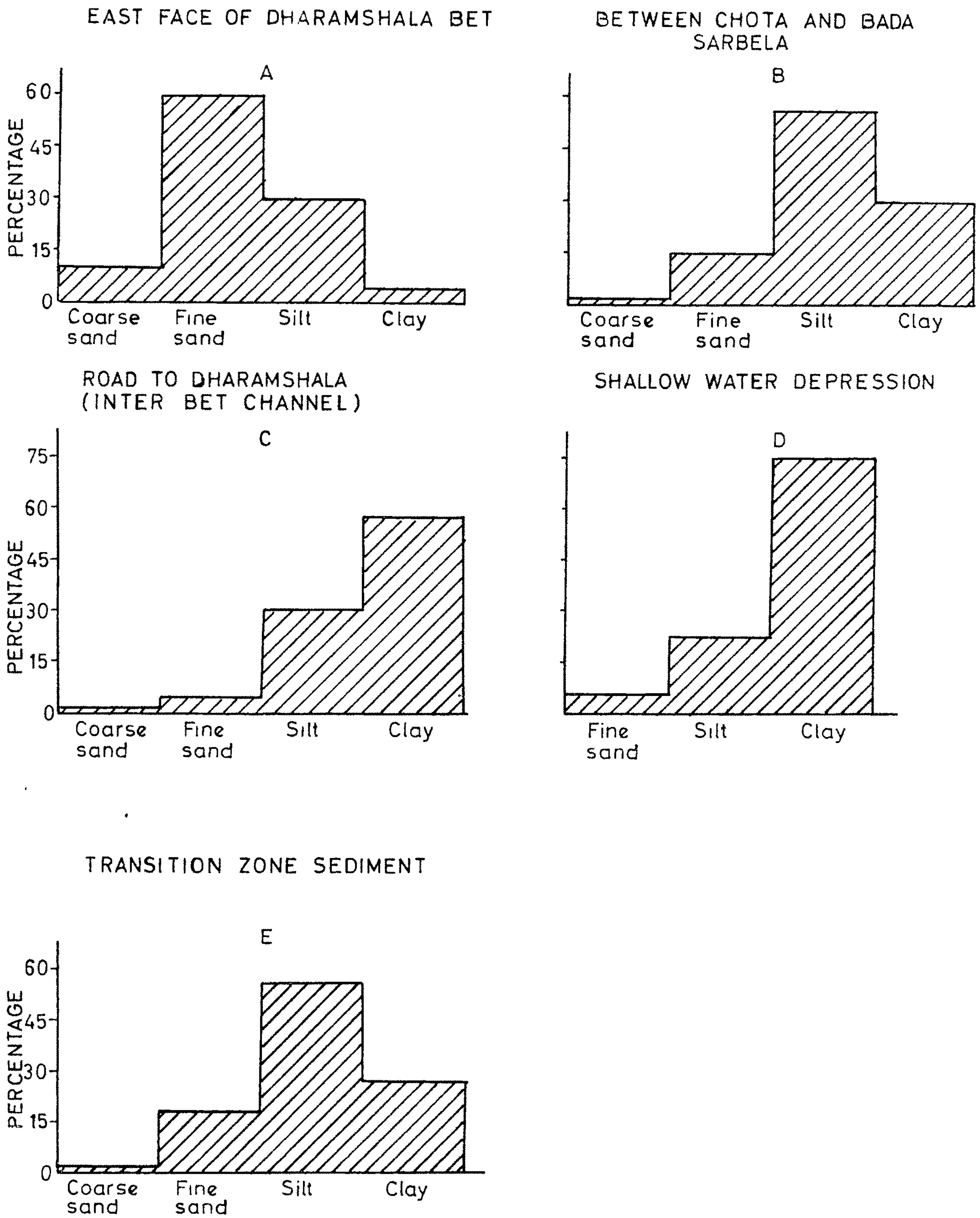
C - Sediments from bets.

D - Transition zone sediments.

and clay. The author has prepared a map (Fig.3.1) based on the classification of the sediments according to the grain-size, which gives an areal distribution of sediment types over the Rann surface. It is seen that grain-size is dependent on many factors, the primary factors being (i) geomorphology of the area where the sediments have been deposited (Fig. 6.2), (ii) distance from the sediment source and (iii) nature of depositional agency i.e. marine, fluvial, aeolin or mixed environment such as deltaic.

Considering the values of mechanical analysis, and on a perusal of the sediment map, it is seen that the area could easily be divided into several sub-areas on the basis of sediment size distribution. The area that comes under marine influence, restricted or otherwise, consist mainly of fine-grained marine silts and clays. These fine-grained material appears to be typical of the deposits that collect in the tidal flats and bays in coastal regions. A similar deposition has been reported from Wadden Sea by Van Straaten and Kuenen (1957) and Postma (1959). Layers of black organic clays are also encountered. In the vicinity of mainland, there is much mixing of coarser fractions caused by sediments

RELATIONSHIP BETWEEN AVERAGE GRAIN SIZE AND GEOMORPHOLOGY



brought down by streams during rainy season. Transition zone is represented by sediments in the area grading from Banni to the Great Rann which are mostly silty. In the northern Bet-zone, the sediment is typically river silt, highly micaceous. However, in the 'inter-bet' depressions, where water collects during rains, the proportion of clay fraction is higher. In the former case, the main source of the micaceous silt was probably the various tributaries of the erstwhile Indus River which flowed through this area even during the historical past. The barren area north of the hill masses of Pachham, Khadir and Bela consists mainly of boggy, clayey sediments (Detailed soil profile description is given in Chapter 4).

Field Moisture Capacity

It was observed that most of the other properties that affect inundation, stem from the fine-grained nature of the sediments. Natural moisture content (field moisture) of the sediments was observed to be exceptionally high considering the present aridness of the area. In fact, four factors that control the moisture distribution in the sediments, are (a) inherent moisture content at the time of deposition (b) drainage

(c) capillarity and (d) hygroscopicity of sediments. The high field moisture values (Table 6.2) clearly reflect the fact that the Rann sediments were deposited through an aqueous medium (the river and sea water), and this much moisture is held in the lattices of the sediments even at present. In clays, such moisture holding capacity is very high and even heating cannot expel the water totally that is held in the pores. The moisture that exists in such fine-grained sediments belongs to the following categories: (a) The water in pores, on surfaces and around the edges of discrete particles of the minerals and (b) The water held in the inter-layer minerals grains. The latter form of water i.e. the "bound water" is in a different physical state from the "free" water. Boswell (1961, p.21) states that apparently dry fine-grained clay would hold about 30-50 gm of water per 100gm of dry clay. The value of held water is higher for fine-grained sediments. The high values of field moisture in the Rann sediments corroborate the above fact. The clays in the vicinity of Kuar bet in comparision, showed higher values of moisture content than the coarser sediments in the northern regions of the Rann (near

TABLE 6.2

FIELD MOISTURE CAPACITY FOR RANN SEDIMENTS

Depth (in cm)	Season	Field moisture capacity
1. Location: North-east face of Dharamshala bet		
0-30	After rains	12.50
30-75		10.20
75-135		10.10
135-240		8.65
2. Location: Rann surface, west of Dharamshala bet		
1.25-15	Dry	25.25
15-45		19.35
45-90		20.50
90-170		22.30
170		25.42
3. Location: 1.6 km south of Bedia bet in Rann		
0-2.6	After rains	22.50
2.6-75		19.60
75-195		20.52
195-260		20.21

TABLE 6.2 (contd.)

	Depth (in cm)	Season	Field moisture capacity
4. Location: Between Chota and Bada Sarbelo			
	0-5	Dry period	5.25
	5-45		16.35
	45-90		18.40
	90-170		18.51
5. Location: In the Great Rann on the road to Dharamshala			
	0-15		19.35
	15-45		22.50
	45-76		24.25
	76-105		25.50
	105-135		25.50
6. Location: In the depressed area near Kuar bet in Facet B_3			
	5-15	Dry	57.50
	15-60		48.50
	60-107		50.42
7. Location: Region marked 'Shallow-water' Depression' and 17 km west of Khavda			
	5-45		58.45
	45-140		60.35

TABLE 6.2 (contd.)

	Depth (in cm)	Season	Field moisture capacity
8. Location: In Facet B_3, shown as site No.8 on Fig.4.1			
	0-40	Dry	12.50
	40-90		11.25
	90-140		10.35
9. Location: South of Kuar bet and west of India Bridge in the region near the mainland			
	0-25	Dry	-
	25-30		50.00
	30-45		53.00
	45-55		59.00
	55-80		54.00
	80-85		62.00
	85		56.00
10. Location: South of Kuar bet away from mainland			
	2.5-20	Partly wet (Wet patch)	56.00
	20-45		43.00
11. Location: 2.4 km NNE of Lakhpat in the Rann			
	0-15	Remains wet most of the time	62.00
	15-105		42.00

TABLE 6.2 (contd.)

	Depth (in cm)	Season	Field moisture capacity
12. Location: In the Facet B_3, about 13 km WSW of Pachham Island in the Banni area			
	0-20	Dry	10.00
	20-65		10.00
	65-155		10.00
13. Location: About 8 km north of Bela Island on the Bela-Nagar Parkar crossing of the Great Rann			
	2.54-10	Dry	55.50
	10-75		52.30
	75-90		54.35
	90-145		58.42
14. Location: SSE of Kuar bet in the Great Rann			
	0-2.5	Dry	24.52
	2.5-105		25.62
	105-230		25.44
15. Location: About 3.2 km north of Pachham Island			
	2.5-10	Dry	55.60
	10-60		35.50
	60-90		59.35
	90-155		40.25

TABLE 6.2 (contd.)

	Depth (in cm)	Season	Field moisture capacity
16. **Location**: Piprala silty-clay (profile after Satyanarayana)			
	0"-3"		13.6
	3"-12"		19.3
	12"-21"		22.5
	21"-36"		27.5
	36"-43"		21.8
	43"-49"		22.1
	49"-58"		19.1
	58"-84"		20.5
17. **Location**: Rann surface, west of Dharamshala			
	1.25-15	Wet	32.50
	15-45		22.65
	45-90		21.05
	90-170		22.75
	170		25.50
18. **Location**: 1.6 km south of Bedia bet, in Rann			
	0-2.6	Dry	16.50
	2.6-75		17.45
	75-195		19.45
	195-260		19.30

TABLE 6.2 (contd.)

	Depth (in cm)	Season	Field moisture capacity
19. Location: Between Bada and Chota Sarbelo			
	0-5	Wet	12.60
	5-45		18.50
	45-90		18.55
	90-170		19.05
20. Location: In the Great Rann on the road to Dharamshala			
	0-15	Wet	26.50
	15-45		24.35
	45-76		25.35
	76-105		25.50
	105-135		25.55
21. Location: SSE of Kuar bet in the Great Rann			
	0-2.5	Wet	30.65
	2.5-105		27.50
	105-230		25.45

Bediya or Biar bets). Boswell (1961,p.26) has further stated that the grain-size of particles and the mineral character (layer-lattice structure) are connected with each other, and in turn contribute to the high void ratios by virtue of the relatively large surface areas provided, and the hydrophilic (water attracting) nature of these surfaces. (Fig.6.3a) illustrates the fact that sediments having higher percentages of clay show corresponding high values for field moisture capacity.

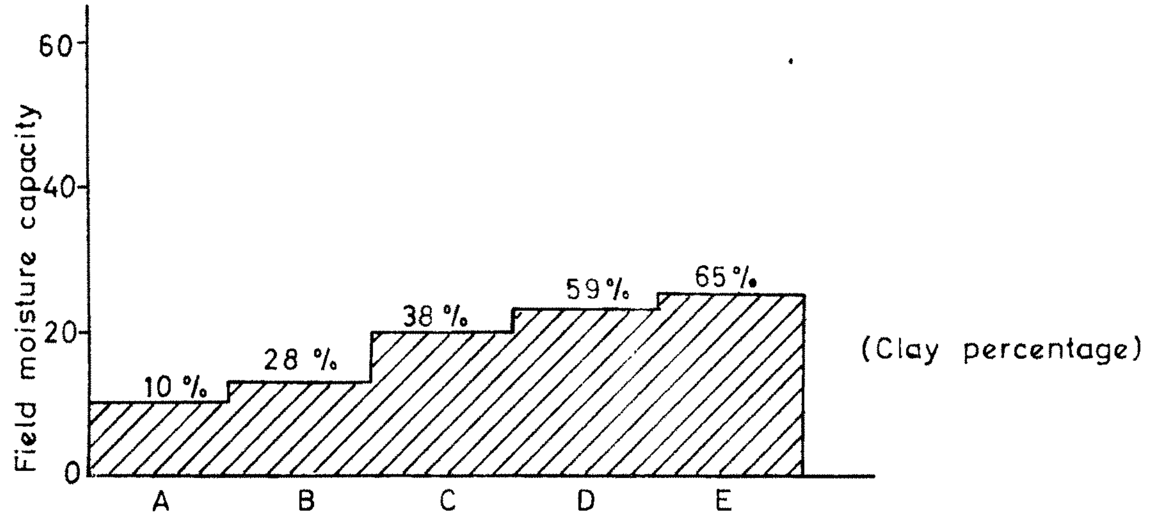
The study of the relation of field moisture with depth has also brought out some interesting facts. With increasing depth, the sediment size shows an overall decrease in size whereas the field moisture tends to increase (Table 6.2). The author conducted some experiments with sediment profiles from different locations to obtain a relationship between the moisture content and the depth. The general form of the curves obtained are hyperbolic (Fig.6.3b). The moisture content decreases rapidly with increasing distance above the ground-water level, after which the rate of decrease falls of rapidly. In case of organic horizons, there is a conspicuous rise in the moisture content values (Fig.6.4).

Capillary rise in sediments

The author observed that the field moisture values even during the driest periods are high. The

Fig. 6 .3a

RELATIONSHIP BETWEEN CLAY PERCENTAGE AND FIELD MOISTURE CAPACITY



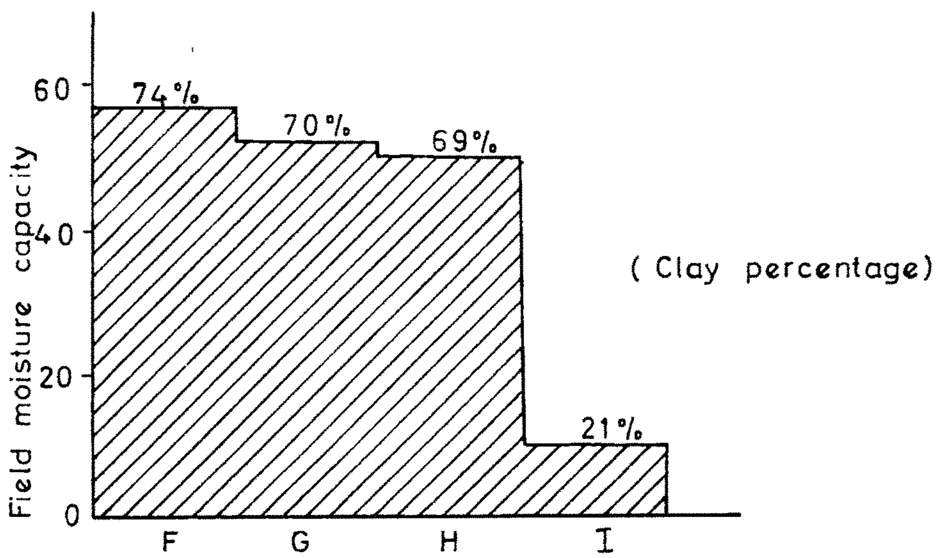
A - East face of Dharamshala bet.

B - Transition zone sediment.

C - 1·5 Km. South of Bedia bet in Rann.

D - East of Dharamshala bet in Rann.

E - In the great Rann on the road to Dharamshala bet



F - 10 Km West of Kavda in Rann.

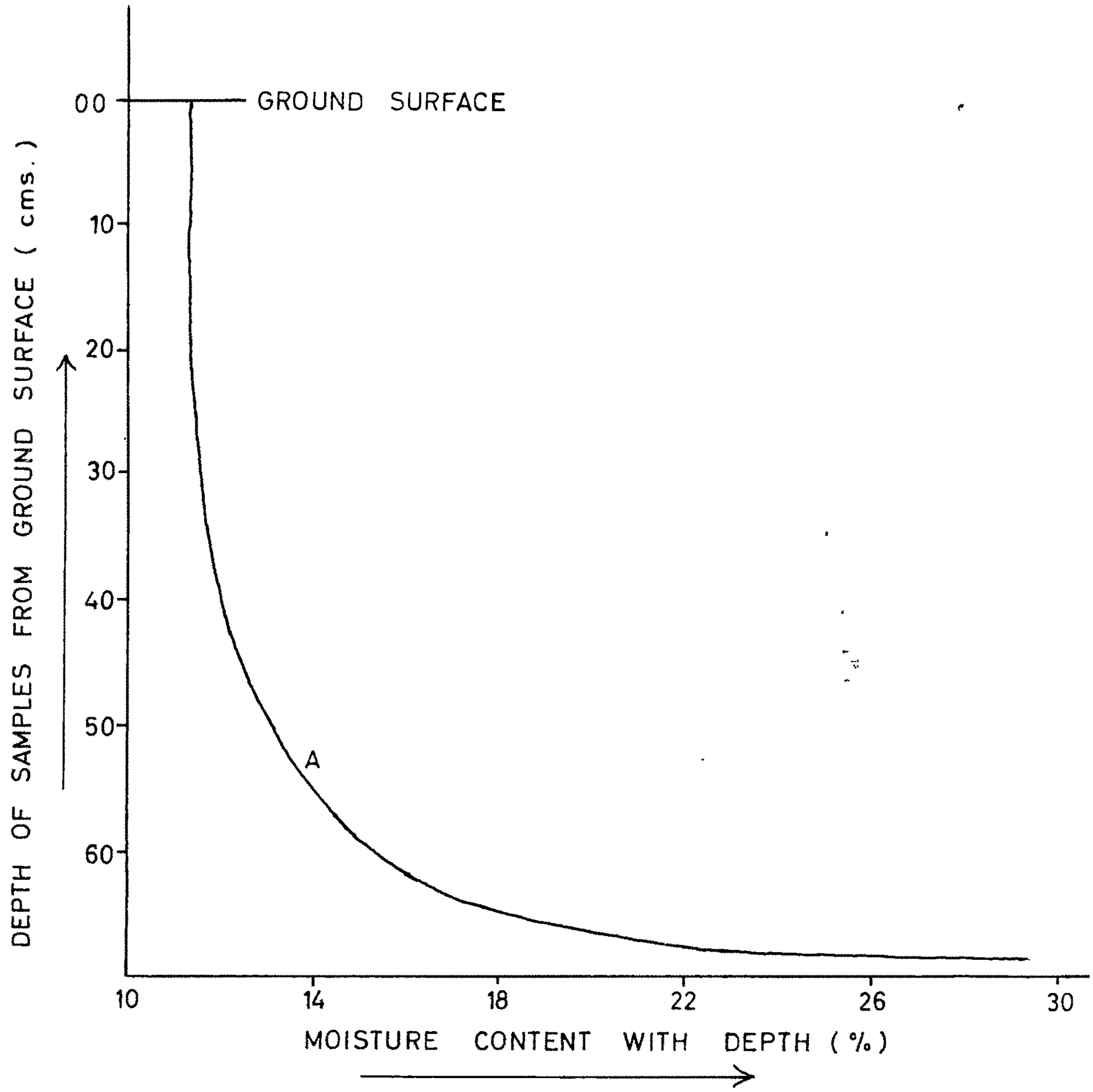
G - Region marked shallow water depression.

H - South of Kuar bet.

I - Khavda barren - area.

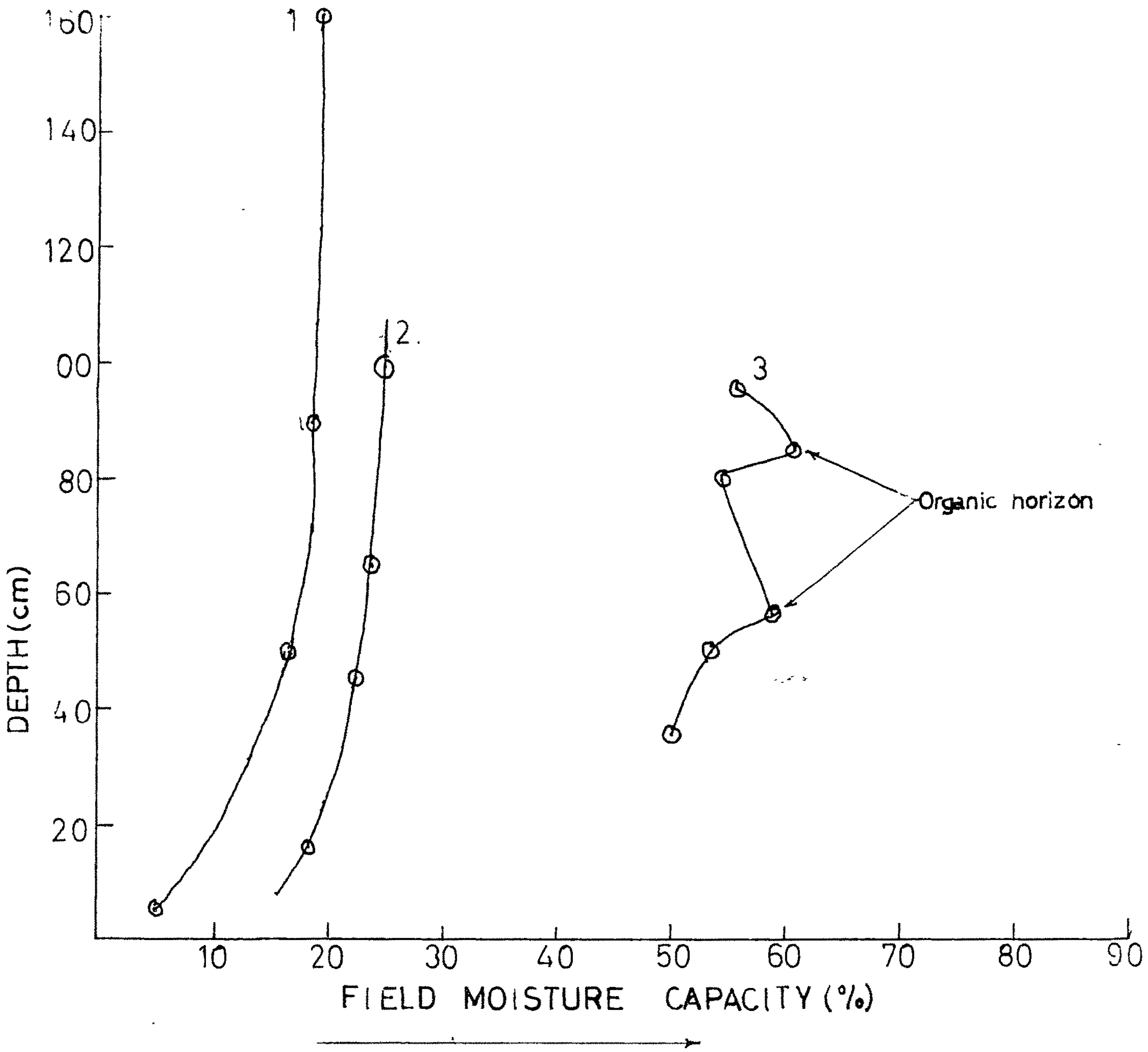
Fig. 6.3 b.

VARIATION OF MOISTURE WITH DEPTH FOR NORMAL CONDITIONS



CURVE A :- TYPICAL HYPERBOLIC CURVE SHOWING INCREASE OF MOISTURE CONTENT WITH DEPTH.

VARIATION OF MOISTURE



2. In the Great Rann on the road to Dharamshala.
1 Between Chota and Bada Sarbela
3 Region near mainland

inherent or held moisture percentage is augmented by the capillary rise, thus causing an increase in the overall moisture values of the sediment profiles. Though the extent of capillary rise has not been calculated in the laboratory, field observations have adequately corroborated the fact that capillarity is an important phenomena in the Rann, such that the capillary fringe at places is upto the ground surface. Whereas the capillary potential decreases slowly upward with decrease in moisture content, this decrease is seen only below the saturation value.

Puri (1949, p.349) has compared the sediments, with a bundle of capillary tubes to which the laws of surface tension and capillarity could be applied. He has stated (Ibid, p.347) that "the capillary pull exerted by a sediment column to raise water, or the negative pressure required to pull water from a saturated column, is approximately equal to the reciprocal of the diameter." This concept is ideally applicable to the sediments of the Rann which show fineness of grain-size and high capillarity. Calculated values of Millar and Turk (1949, p.165) shown in Table 6.3

TABLE 6.3

Capillary rise in Sediments

Time	Height of rise in inches		
	Sand	Silt loam	Clay
½ hour	13.5	7.3	5.4
1 hour	14.3	11.2	8.0
6 hour	16.6	26.6	15.5
12 hour	17.2	35.3	18.5
1 day	18.4	46.4	21.0
3 days	20.3	65.4	24.7
6 days	21.8	78.5	27.3
9 days	23.0	86.3	28.8
18 days	25.3	99.2	33.2

give an idea of the relationship that exists between the capillary rise and the size of sediments. It has been observed that maximum height of capillary column both calculated and observed, for a sediment containing 50% clay is of the order of 3 to 4 metres, and in some cases even more. Hogentogler (1937, p.122) has stated that below water-table, in the case of sand the moisture content is 20.4 per cent by weight of the dry sand and above the water table the capillary fringe has a moisture content of 0.6 per cent. In comparision, in silts the moisture content below water-table is 40 per cent and the capillary fringe extends upward from the water table to a distance of 4 metres with a moisture content of 36 per cent." This serves us the idea of the extent of capillary rise in fine-grained sediments and its influence on the overall field moisture values. In the Rann, excellent and convincing evidences of capillary rise are furnished by the salt encrustations observed at the base of freshly dug pits. These salt deposits, generally known as efflorescence deposits, result directly from the evaporation of subsurface water brought to the surface by capillary rise (Plate 6.1).

PLATE 6.1

Photograph showing salt crusts at the base of pit due to efflorescence.
Location: 3 km north of village Dhorada Wandh in the Great Rann(Sub-Facet B_3)

Thus, taking into consideration the various factors listed and discussed above, to explain the wetness of Rann sediments, it is obvious that on account of the fineness of sediments, the natural field moisture content is very high, even during the driest period. Capillary rise which is very extensive in the Rann sediments, augments the already high soil moisture value. As a result, even under normal dry conditions, the whole profile from the surface downwards is relatively moist.

Hygroscopic absorption

One more factor that augements considerably to the already high moisture content, is hygroscopic absorption.

In the Rann, the moist periods with higher humidity considerably increase the sediment moisture values due to hygroscopic absorption. 'Hygroscopicity' has been defined as the ability to suck in, or sorb, moisture from the vapour in the air, the moisture thus absorbed being called 'hygroscopic moisture'. Apart from laboratory experiments to compute the hygroscopic coefficient (Table 6.4) field observations have fully corroborated this phenomenon.

TABLE 6.4

HYGROSCOPIC ABSORPTION FOR UNLEACHED SEDIMENTS

Humidity	Absorbing capacity (%)	Sediment	Location
	8.00	Inorganic clay	East of Dharamshala
	1.50	Bet sediment	Dharamshala bet
	8.65	Organic clay	South of Kuar bet
30%	5.00	Silty clay	Between Bada and Chota Sarbelo
	10.00	Partly organic clay	In Facet B_3
	7.50	Clay	North of Biar bet
	9.50	Inorganic clay	East of Dharamshala
	2.50	Bet sediment	Dharamshala bet
	10.50	Organic clay	South of Kuar bet
60%	6.50	Silty clay	Between Bada and Chota Sarbelo
	12.50	Partly organic clay	In Facet B_3
	8.75	Clay	North of Biar bet
	10.50	Inorganic clay	East of Dharamshala
	3.60	Bet sediment	Dharamshala bet
85%	12.50	Organic clay	South of Kuar bet
	7.50	Silty clay	Between Bada and Chota Sarbelo
	14.00	Partly organic clay	In Facet B_3
	9.25	Clay	North of Biar bet

It has been noticed during field reconnaissance that during cloudy weather of pre-monsoon months, a sudden and conspicuous sogginess develops on the ground and the accessibility becomes difficult. Previous workers often mistook this phenomenon of sudden and pronounced increase of wetness of Rann surface as a rise of water-table. The author found no truth in these statements, and his studies have fully established that it is not the rise of ground water but the phenomenon of hygroscopic absorption that causes the sudden sogginess.

The values of hygroscopic coefficients for the various sediment types were calculated in the laboratory, sampling of the soil having been done during the driest period to ensure complete absorption. Values were also obtained for different seasons considering (i) different values of relative humidity and (ii) different grain size. It was observed that the absorbing capacity increased with the humidity (Table 6.4). In fact, during wet seasons, the sediment mass turned absolutely wet.

Puri (1949, p.387 & 388) has established a very interesting relationship between the vapour pressure relation of sediments and the fineness of grain-size.

The finer fractions of the conventional mechanical analysis were separated by repeated sedimentation in distilled water. He subjected samples of each fraction of original sediments to exposures of varying humidity.The curves he obtained showed an increasing absorbing capacity with humidity and grain size.

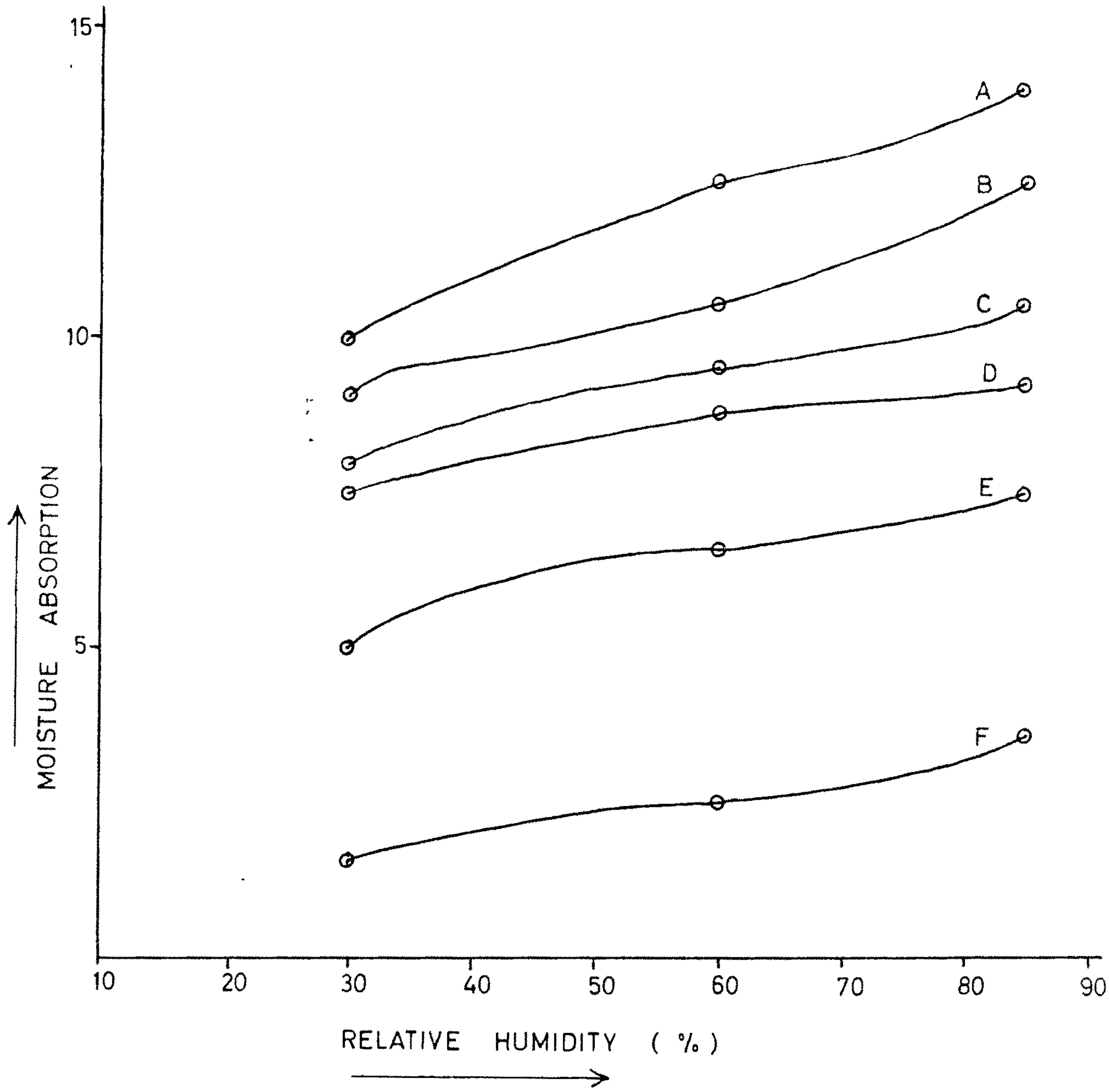
Author's curves (Fig. 6.5) also testifies Puri's claim, and proves that water content for any relative humidity increases with the increase in the amount of clay.

Thus, it has been concluded, that the field moisture capacity of the Rann sediments is augmented by the 'hygroscopic water' absorbed from the atmosphere as the wet season approaches.

Infiltration Capacity

As already stated, the phenomenon of inundation in the Rann comprises a complex combination of the wetness of the Rann sediments and the surface movement of water over them. Whatever the source of surface water - sea, river or rain, its behaviour over the Rann sediment is very interesting. The author has investigated

HYGROSCOPIC ABSORPTION FOR UNLEACHED SEDIMENTS



A - Partly organic clay.

B - Organic clay.

C - Plastic clay from inter bet depression.

D - Plastic clay near Biar bet.

E - Silty clay near Bedia bet

F - Dharamshala bet sediment.

this aspect also and has come to some revealing conclusions. The role of transfer of surface water moving and standing, in augmenting the wetness of the Rann, is in turn controlled by two important properties of the sediments, viz. infiltration capacity and permeability.

Infiltration capacity has been defined by Horton (1933) as the maximum rate at which a given sediment can absorb precipitation in a given condition. He suggested that infiltration capacity would decrease exponentially in time from a maximum initial value to a constant rate. This movement, or hydraulic conductivity has been defined by Buckman and Brady (1967) as the difference in moisture tension between two points a unit distance apart, the water adjusting towards greater tension with comparative rapidity. The hydraulic conductivity or the ability to transmit water through sediments was found to be highly variable. In case of well sorted gravels and sand, the conductivity is very high, whereas it will be low in case of fine-grained compact sediments like those of the Rann. Other factors that appear to control the infiltration capacity of Rann sediments include (i) amount of water applied, (ii) infiltration capacity of the surface sediments, (iii) total moisture conductivity of the lower horizons and (iv) the amount of water which the profile retains at field moisture capacity. Side by side, the texture and structure of the various sediment horizons also influence the factor of percolation. Sediments having fine texture, as of the Rann, have low percolation rates where the colloidal material tends to clog the connecting channels. Thus fine textured sediments that crack during dry weather (Fig. 6.6a) at first allow rapid percolation down the cracks initially, but later on, as these cracks get sealed due to swelling, the percolation is reduced to a minimum. These cracks could explain why, in most cases the field moisture values were observed to increase only in the top 15 cm. The author has observed that heavier the clay in the sediments, deeper were the mud cracks (Plate 6.2 and Plate 6.3). The rate of infiltration was observed to be faster in the top 20 cm or so of the dry Rann sediments after which infiltration rate decreased rapidly owing to the greater moisture content of the sediments below. The decline in infiltration rate with

Fig.6.6 A

ROLE OF MUD CRACKS IN INFILTRATION

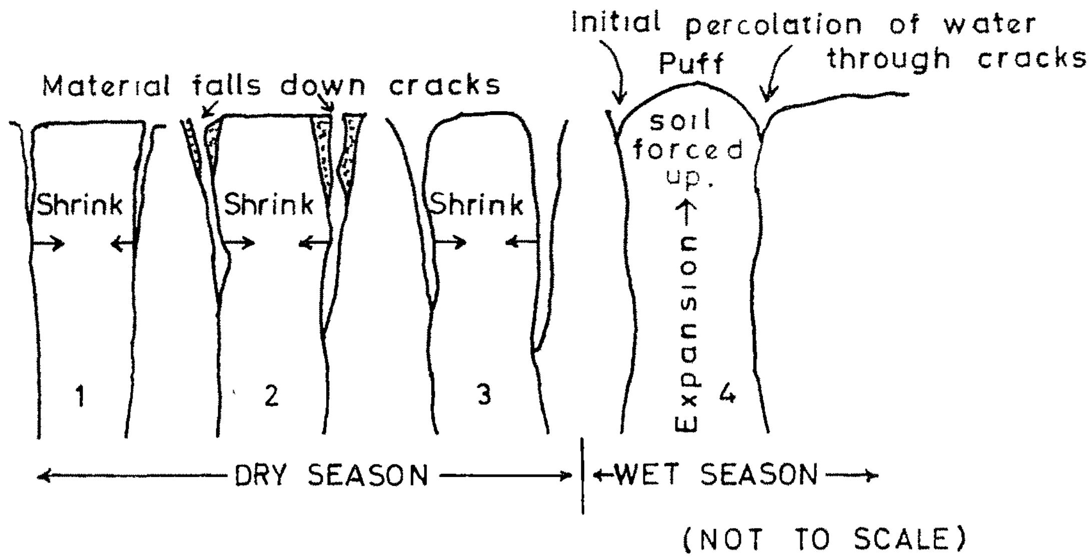


Fig.6.6 B

PROCESS OF SALINIZATION

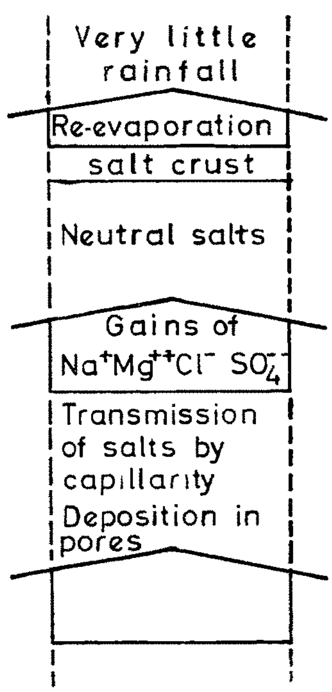


PLATE 6.2

Mud cracks in heavy clays during dry seasons (Depth of cracks around 50 cm; width around 10 cm)
Location: 50 metres south of Bediya bet

PLATE 6.3

Mud cracks in silty clays.
Location: 50 metres south of
Bediya bet.

time occurred regardless of how water was applied and appeared to be mainly dependent on the moisture content of the sediments at the beginning of the rain. Hence, in wet sediments, where the field storage capacity is high, the infiltration is very much lowered. The conclusions arrived at by the author in respect of the infiltration phenomena are fully supported by the work done by Frere, Browning and Musgrave (cf. Dudal, R. and Bramas, Luis D., 1965, p.39). The enclosed Table 6.5 highlights the relation of the moisture capacity of sediments with the infiltration rate. For the same sediment type, the infiltration rate depends on the moisture content of the sediment. It was observed that clay sediments showing 38.50% of water showed an infiltration rate of 15 mm in 15 minutes whereas with an increased moisture content of 54.60% the infiltration rate went down as low as 0.5 mm for 15 minutes.

Another factor observed was that on account of the lack of plant cover, there was a great deal of 'puddling'. The rain fall in the Rann, strikes on exposed ground and as a result of churning, 'puddling'

TABLE 6.5

Infiltration rates for clays

SOIL	% of water in surface	Cumulative infiltration in mm				
		15 mm	30 mm	60 mm	120 mm	180 mm
HOUSTON CLAY	a) 32.4	26	27	28	29	30
(Moderately eroded)	b) 54.9	1	1	1	2	2
HEAVY BLACK CLAY	a) 38.5	15	18	20	22	23
(Slightly eroded)	b) 54.5	0.5	0.8	1	2	3
HEAVY BLACK CLAY	a) 28.0	22	24	26	28	29
(Moderately eroded)	b) 40.7	0.5	0.5	1	2	2

TABLE 6.6

Permeability Values

Location	Sediment type	Value for K (Coefficient permeability)
1. SSW of Kuar bet	Organic clay	10-3 (impervious)
2. North of Biar bet (depressions)	Inorganic,plastic	10-2 (impervious)
3. South of Bediya bet	Laminated silty clay	10-2
4. NNE of Lakhpat	Marine silts	10.10
5. Dharamshala bet	Sandy silt (Bet sediment)	1

occurs. Consequently the rain water becomes muddy. Bennet (1955, p.109) has stated that clear water penetrates a sediment much more rapidly than muddy water because of the fine, suspended material which tends to choke the openings and impedes downward movement. This phenomenon is ideally seen in the Rann where there is no surface vegetation. Thus a major portion of the surface water does not enter the Rann sediments, especially at lower horizons, as the various factors described above hinders its entry.

Permeability

Permeability depends on the grain size of sediments, and it calculated values (Table 6.6) have revealed certain interesting results. In spite of local variation in permeability values, the overall picture is that the Rann sediments, owing to their fine and compact nature, have very low permeability. Saline sediments like those of the Rann, possess a high proportion of sodium salts which goes into suspension immediately on coming in contact with water. The fine clay particles thus produced, fill up all the interstices and the sediment is rendered impervious to water.

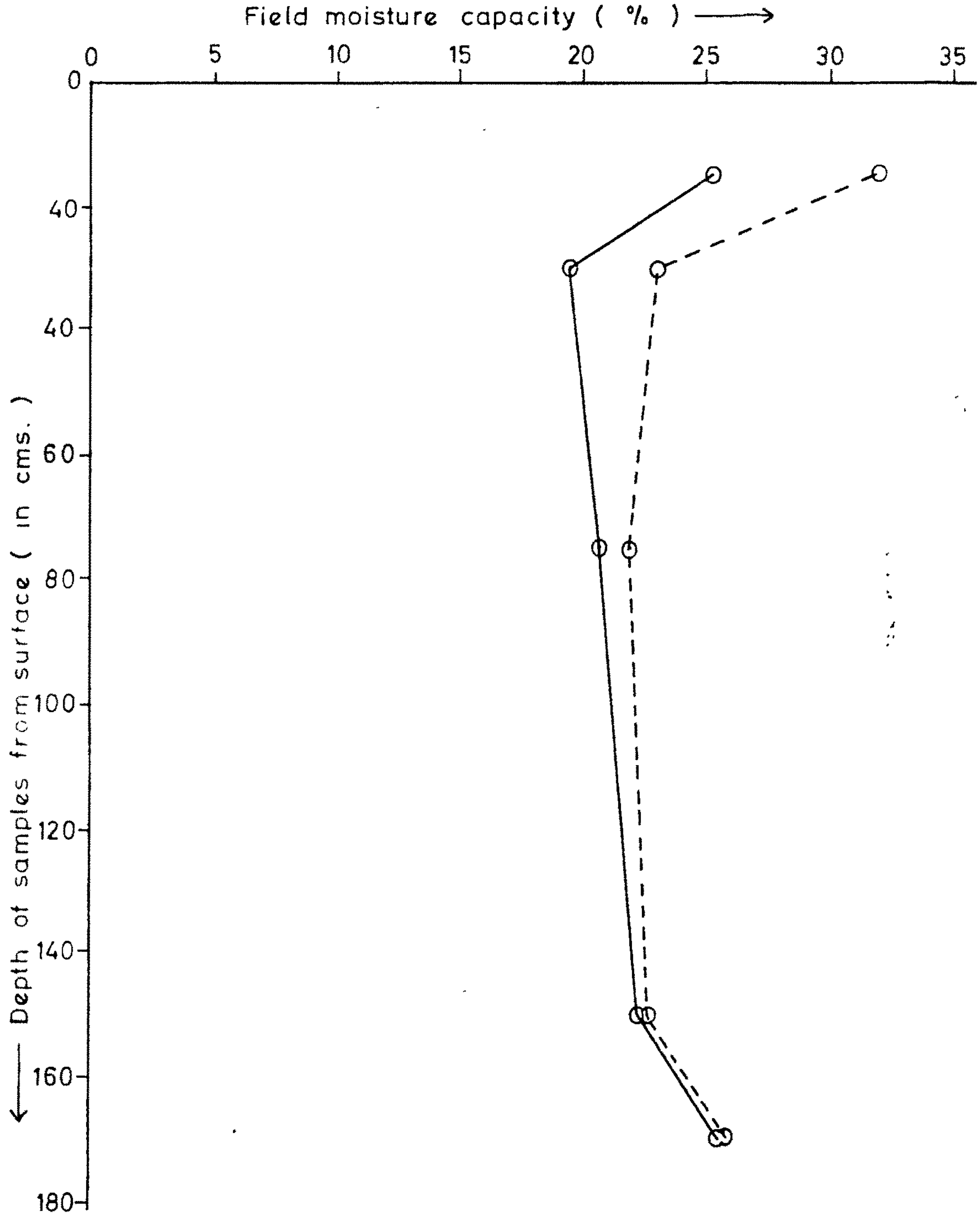
Davis and De Wiest (1967, p. 380) speaking on the permeability of clayey sediments has observed that the clays and the colloids tend to form coatings on larger particles. Clay coatings are best developed at depth where permeabilities may be reduced to only a small fraction of their original values. In as much as clays will expand on hydration, the permeability of clay-cemented material will be strongly influenced by the amount of moisture present, which as has been mentioned already is quite high in the Rann. The Rann sediments thus are rendered more impervious.

From the values obtained (Table 6.6) it is observed that the most impermeable sediments are the black boggy clays in the vicinity of Kuar bet and the similar sediments north of the hill massifs of Pachham and Khadir. These clays occur in regions of depressions where the impermeable sediments lead to water stagnation for long periods. The laminated sediments around Bediya bet, Chota Sarbelo etc. also show low values of permeability though they can be regarded as a shade more pervious than the black, organic clays. The bet sediments, in comparision, show higher permeability values (Table 6.6).

The author calculated the field moisture values of sediments before and after the rains, and observed only a little difference in the values. This slight difference even, decreased with depth (Fig. 6.7). It clearly shows that surface water does not infiltrate to any appreciable depth even after heavy rains and thus it stagnates in depressions. If the rainfall is especially very heavy the entire Rann surface gets under water, at times 4.50 metres deep. At times, standing water is swept over the wet Rann from one part to the other by strong winds.

This stagnation further enhances the water-logging problem, as clayey minerals are developed leading to the formation of specially impermeable clayey horizons in these depressions. The absence of eddies or currents further favours the accumulation of the organic clay sediments at times of colloidal nature which possess a very high absorptive capacity

SEASONAL VARIATION OF MOISTURE WITH DEPTH



LOCATION:- 1·6 Km South of Bedia bet, in Rann.

——— Values for dry season.

- - - - Values after rains.

for water. As a result, in these regions of the Rann, such clay layers act as a sponge which have the ability its hold several times its weight of water.

Another factor observed was that of the absence of seepage. A pit dug as much as 4.50 metres showed a dry base (water having receded from the location just about a fortnight ago) even though standing water was observed less than 200 metres away. This lack of horizontal permeability was also observed around Kuar bet. During one season (1971), tidal water reached the western face of India Bridge withstanding water of 15 cm. To the east of the bridge and barely 100 metres away, pits dug and kept for the duration of over a week showed no seepage of water from the western side.

The results, when summarized and correlated, reveal following important properties regarding the Rann sediments that control inundation.

(1) High field moisture capacity which increases with depth and during monsoon.
(2) Low infiltration rate.
(3) Impermeable sediments.

Sea, river or rain water remains on the Rann surface, as very little of it percolates below the surface. These factors, coupled with a total lack of gradient, poor drainage and runoff enables the water to stagnate over the Rann surface, especially in the depressed regions.

Compaction

Compaction of the fine-grained sediments of the Rann have also special significance in the present context, as this property controls the infiltration rate and permeability. It is observed that in the Rann the compaction is found to increase downward and with increasing depth the rate of seepage also decreases.

Field tests, for compaction, were carried out, using a portable cone penetrometer. To observe the effect of water on sediment compaction, tests were carried out during the rainy periods as well as during the receding phase of inundation. Most extensive testing was carried out in the monsoon of 1971 in the month of July when a large part of the Rann comprises an inundated treacherous, sticky and almost inaccessible terrain. Readings obtained during drier periods served as useful mode of comparision (Table 6.7). The following conclusions were arrived at :-

(a) The Rann sediment was observed to be very compact under normal conditions, i.e. during dry period (Plate 6.4). The surface during this period was hard and smooth such that penetration below 15 cm was not possible. Accessibility during such dry periods was easy though several perennial wet patches were encountered. Such patches were observed around Kuar bet, north of Pachham and Khadir and in some of the prominent depressions of the Great Barren zone. The Plate 6.5 illustrates the nature of such a patch during dry period. In these wet patches, the Cone Index Values were comparatively lower. Average cone Index Values of other areas was found to be around 250.

(b) With the onset of monsoon, the sediments upto a maximum depth of 25 cm were observed to be affected. Cone Index Values at depths greater than 25 cm showed no change (Table 6.7). In fact, in most of the region, penetration below 25 cm was not possible even at the

PLATE 6.4

Compact Rann sediments during dry season.
Location: 2 km north of Gainda bet.

PLATE 6.5

Soft, slushy clay in wet season.
Location: Near Gainda bet.

TABLE 6.7

CONE INDEX VALUES

Location	Season	3"	6"	9"	12"	15"	18"
South of Kuar bet	Dry	8	25	65	75	85	125
	Wet	2	15	45	50	54	60
SSE of Kuar bet	Dry	10	35	65	115	175	260
	Wet	10	28	57	85	115	260
South of Dharamshala	Dry	35	150	260	-	-	-
	Wet	10	85	165	260	-	-
East of Mori bet	Dry	35	135	265	-	-	-
	Wet	10	65	135	260	-	-
Between Mori and Bedia bets	Dry	30	125	260	-	-	-
	Wet	15	75	225	260	-	-
South of Bedia bet	Dry	65	270	-	-	-	-
	Wet	40	200	270	-	-	-
Between Mori bet and Gainda bets	Wet	15	65	200	270	-	-
North of Mori bet	Wet	20	65	270	-	-	-
4 km west of Kuar bet	Wet	0	10	25	36	40	45
4 km south of Kuar bet	Wet	10	25	65	175	270	-

TABLE 6.7 (contd.)

Location	Season	3"	6"	9"	12"	15"	18"
About 6 km west of Khavda in Facet B_3	Dry	50	200	270	-	-	-
	Wet	35	165	270	-	-	-
About 16 km west of Khavda in Facet B_3	Dry	45	85	270	-	-	-
	Wet	20	45	185	270	-	-
About 22 km west of Khavda in Facet B_3 fringing Banni	Dry	45	205	270	-	-	-
	Wet	20	180	270	-	-	-
About 8 km east of Lakhpat in Face B_1	Dry	25	145	210	270	-	-
About 12 km east of Lakhpat in Facet B_1	Dry	20	150	220	270	-	-
In the Allah Band region	Dry	25	165	270	-	-	-
South of Karimshahi	Wet	25	105	270	-	-	-
Between Bada and Chota Sarbelos	Wet	25	105	270	-	-	-
Just west of Biar bet	Wet	10	45	165	270	-	-
Inter bet depression between Biar bet and Bawarla bet	Wet	12	145	170	270	-	-
NNE of Biar bet	Wet	5	40	163	270	-	-

maximum pressures exerted. Similar conditions appeared to prevail over in general, though the perennially wet patches showed further deterioration in conditions. Even human pressure was able to bring compaction upto 10 cm (Plate 6.5) in such regions.

(c) The low permeability and infiltration rate of the Rann sediments explain the phenomenon of high Cone Index Values even during wet seasons. The top 15 cm (at the most 25 cm) can be regarded as the maximum depth to which water infiltrates; as a result, the sediment mass to this depth was seen to disperse and lose its compactness. Sediments below the influence of percolating water remained unaffected and retained their natural compactness.

(d) The author found that the high Cone Index Values were often misleading. Certain clayey patches showing high values were often not negotiable during wet seasons. In such cases plasticity of sediments definitely played an important role, where after the rains, the hard clay was observed to be converted into a sticky, gluey mass which further inhibited percolation of water.

It is a popular misconception that men and vehicles often get bogged and sink to a considerable depth on the Rann terrain, especially during rains. The author's traverses through the Rann even during rains clearly showed that the obvious stickiness of the plastic clayey sediments hindered the movement. At no times, the quick-sand like effect was encountered, as the Rann sediments with increasing depth are definitely more compact. Even in the boggy patches compression of more than 30 cm under normal human pressure, was never observed.

Theoretically speaking, this compaction in the Rann sediments could be attributed to their grain size. In the non-indurated sediments, factors like porosity and packing depend on the size of the constituent particles. Pore reduction and consequently compaction is therefore more important in clays and to a lesser extent in sands and gravels. In most cases, as inferred by the work of many investigators, such as Boswell (1961, p.81-82) who stated that in 'confined gravitational compaction' the reduction in volume is taken up wholly in the vertical direction i.e. in the thickness of the beds. However, the relation between void ratio and depth has still to be established with precision and so far. Boswell (1961, p.81) have stated that there is a rapid reduction of void space to begin with, especially in the clayey sediments, so that greater portion of the moisture in clayey sediments appears to have been expelled shortly after burial. Based on his own observations, the author would suggest certain modifications. There is no doubt that compaction of Rann sediments increases with depth. On the other hand, the moisture still retained by the Rann sediments is appreciably high and increases with depth which points to the fact that most of the moisture is still being held in clay pores and especially so at depth. This could be due to the fact that in sediment thicknesses of appreciable dimension like those of Rann, the lower horizons were unable to expel the water owing to the quick compaction of the overlying horizons. This would explain the presence of the wet, sticky clays even at depths of 4 metres in spite of the impermeable nature of the Rann sediments and their inability to transmit water to the lower sediment horizons. This phenomenon appears to be more pronounced in case of fine-grained sediments.

Plasticity

An important feature of sediments, on which their behaviour depends, is their consistency. Of special interest is the tendency shown by the plastic materials such as clay and fine silt, to display coarse fracture systems in well-marked patterns (Plate 6.2 and 6.3). The consistency of those fine-grained sediments also plays an important role in controlling moisture and this property has thus been recorded by determining their water contents. It was therefore important that values for Plastic and Liquid Limits be obtained. Sediments taken from various locations and depths were analysed for their Atterberg's limits.

On the basis of the Plastic and Liquid Limit values the author could sub-divide the Rann sediments as under:-

(1) Organic silts

(2) Inorganic silts

(3) Micaceous silty clays

(4) Inorganic clays

(5) Organic clays

(6) Bet Sediments; sandy-silts

(7) Mixed sediments near mainland-Rann junction.

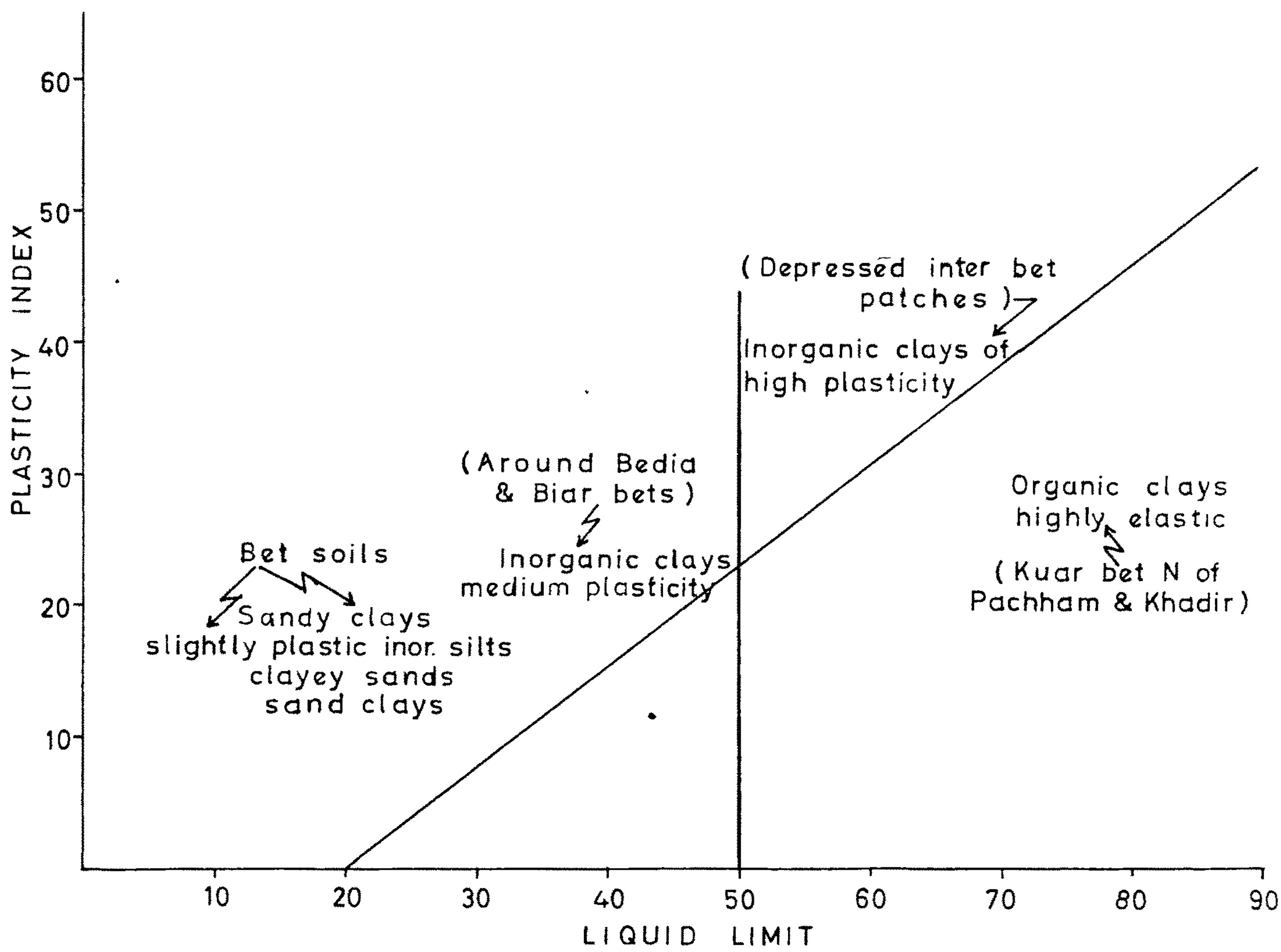
Various zones were recognized (Fig. 6.8). Their main sediment types along with their Plastic Limit and Liquid Limit values are given in Table 6.8.

Organic Silts: These are mainly inorganic but contain certain amount of fine, decomposed organic material (about 5%) which render the sediment dark in colour. They are highly compressible, relatively impervious and somewhat plastic (LL = 54, PL = 19). Their colour is generally light-grey to dark grey or black. They always possess an odour resulting from decomposition. When moulded by fingers, these organic silts have a soft feel, a property by which they are distinguished from inorganic silts.

Inorganic silts: These contain mostly mineral grains (micas, hornblende etc.) and are always free from organic matter. Inorganic silts contain an appreciable amount of 'platy' grains and are highly compressible. In the north-western portion of the Rann, especially in the Vigukot-Bediya-bet section, the proportion of the micaceous minerals in these silts was found to be conspicuously high. The author has termed these silts

Fig. 6.8.

PLASTICITY CHART



rich in platy minerals as micaceous silts. They show little cohesion when dried, and on drying, dust off easily. Their Plasticity Index Values vary between 60 and 65. Basically, these inorganic silts are the dominant Rann sediments and their proportion is observed to increase northwards in the Bet zone.

Inorganic clays: These materials are generally referred to as clays. Following categories are recognised:

(i) Lean clays containing about 35% of silt and often termed clayey-silts. Plastic Limit values are around 29 and Liquid Limit values average 74. These occur in the eastern part of the Kuar bet area.
(ii) Fat clays containing a high proportion of clays and with Plastic Limit values around 23 and Liquid Limit values around 82. These can be termed as 'heavy' clays also. These are found in some of the prominent inter-bet channels of the Bet-zone.

Organic clays: Blue-black and black organic clays are always encountered in the various depressions of the Rann where water (rain or sea water) stagnates for long periods. These clays are always highly plastic, soft and oozy to touch, and totally impervious. They usually occur as distinct dark-coloured horizons of varying thickness. Around Kuar bet they occur as alternate bands (5 cm thick) in association with coarser layers. North of the hill massifs of Pachham, Khadir and Bela and the region marked as Facet B_3, all being sites of larger depressions, the organic clay bands attain thicknesses around 30-45 cm. They have a considerable proportion of organic matter (about 4%) and show high values for Liquid Limit (85) and Plasticity Index (35).

Bet sediments: The author has given a separate name to this group of sediments which is confined to the bets and is quite different from typical Rann sediments, possessing low plasticity. The sediments of this group are generally light coloured, and more pervious than the Rann sediments. Details of these sediments are given in Chapter 4.

Mixed sediments: The author has designated the term 'mixed sediments' to those that are encountered along the junction of the Rann and the rocky mainland.

TABLE 6.8

PLASTICITY VALUES

Type of soil	Locality	Upper limit (LL)	Plastic-PL	Lower PI
Silty clays	Biar Bet	54	19	35
Moderately Plastic clay	Dharamshala	74	29	45
Clay	Shallow water depression	82	23	59
Organic clay	Kuar Bet Bridge	85	50	35
Mixed soil	Near mainland	40	20	20
Laminated deposit	Bedia Bet			
(i) Silty fraction		47	17	30
(ii) Clayey fraction		73	31	42
Clay	Inter-bet depressions	60	25	35
Bet Soil	Dharamshala	39	24	15
Loess (Surficial deposit)	Vigukot side	27	20	07

TABLE 6.9

THIXOTROPIC VALUES

Type	M	Nst	Nsh	UTV
Laminated clay	140	148	245	255
Plastic clay	282	307	501	504
Silty clay	60	72	84	102
Normal clay	185	205	460	460

M = Thixotropic value after momentary rest
Nst = After stirring
Nsh = After shaking
UTV = Upper thixotropic limit

Such sediments are always heterogeneous in origin, being mixtures of the assorted weathered material brought down by streams from the flanking mainland rocks, and the silts and clays of the Rann. Near the mainland, a layer of this material, often as much as 30 cm thick, is often observed.

Thixotropy

Thixotropy is basically a flow phenomenon in which change from a rigid to a fluid condition is produced by mechanical action only, and not as in melting by the application of heat.

This phenomena assumes importance in case of fine-grained sediments. Pioneer work on thixotropy has been done by Freundlich (1935,1934), Von Kuhne (1863) and Shalek and Szegvary (1923), even though, initially, they were unable to explain the phenomenon completely. Peterfi (1927) fully explained this phenomenon, while investigating the peculiar mechanical properties displayed by the suspensions of finely powdered particles in liquid.

As the Rann sediments mainly comprise silts and clays their thixotropic values were found of considerable significance. These values ideally explain some aspects of the behaviour of the Rann sediments. The author has calculated the thixotropic values of the representative sediment types, and has arrived at interesting conclusions.

He observed this phenomena, during his various traverses through the Rann in the wet season. Any vehicle that moved over the surface churned up the clays to a viscous and almost liquid mass and settled down to rock hard mass on drying.

Fine-grained particles, as it appears, promote thixotropy (Table 6.9). Freundlich (1934) observed that addition of suitable electrolyte in appropriate concentration increases the thixotropy. Sediment samples, especially marine and organic clays within reach of present sea water influx, showed higher thixotropic values than the clays collected from the areas away from the present day sea water influx. Experiments by Boswell (1949, 1951, 1955) on various sediments have shown that effect of electrolytes in changing thixotropic values is greatest in case of fat clays, less in lean clays and least in clayey or ferruginous sands.

The author has observed that there exists great difference in thixotropic values for organic and inorganic clays of the Rann (Table 6.9), and the values increase considerably in organic clays. He is inclined to suggest that in addition to presence of electrolytes, the action of decomposing organic matter also plays an important role in flocculating the clays, and in making them more plastic. On the whole, the inorganic Rann clays, have the tendency to be converted into a thick, partly-flowing, mud-water system. Artificial peptiser like sodium hexametaphosphate when added rendered them more mobile. In comparision, in the darker organic clays, the organic matter itself acts as a peptiser such that in these sediments, the sediment/water system flows comparatively easily without the addition of any artificial peptiser.

Thixotropy explains two distinct phenomena in the Rann. Firstly, it explains the anomalous behaviour caused by mechanical disturbance in suspension which causes slushiness. This is more so in areas that are more clayey and rich in organic content. This causes inaccessibility and water-logging in clayey areas around Kuar bet, north of Pachham, Khadir and Bela even during dry seasons.

Secondly, thixotropy also explains the increase in shear strength of the inorganic sediments in particular, when allowed to rest after application of stress. Clays when dried and allowed to rest, turn to a rock-hard mass. In contrast, organic clays remain in a flocculated state throughout the year.

Moisture absorbing capacity

The thixotropic values indirectly reveal the moisture absorbing capacities of the Rann sediments. The air dried samples showed an appreciable capacity for the Rann sediments to absorb 'free water' (Table 6.10). The tendency of the finer-grained sediments to absorb more moisture was very clear (Fig. 6.9). This can also explain the Rann sediments with such absorbing capacity still retaining the high quantity of moisture they had absorbed during deposition under water. On account of the clay sized particles

TABLE 6.10

MOISTURE ABSORBING CAPACITY OF RANN SEDIMENTS

Depth (in cm)	Moisture absorbing capacity (%)
1. **Location**: North-east face of Dharamshala bet	
0-30	15
30-75	13
75-135	13
135-240	-
2. **Location**: Rann surface, west of Dharamshala	
1.25-15	41
15-45	44
45-90	-
90-170	-
170	42
3. **Location**: 1.6 km south of Bedia bet in Rann	
0-2.6	36
2.6-75	-
75-195	37
195-260	37

TABLE 6.10 (contd.)

	Depth (in cm)	Moisture absorbing capacity (%)
4. Location: Between Chota and Bada Sarbelos		
	0-5	34
	5-45	-
	45-90	36
	90-170	36
5. Location: In the Great Rann on the road to Dharamshala		
	0-15	41
	15-45	-
	45-76	45
	76-105	-
	105-135	45
6. Location: In the depressed area near Kuar bet in Facet B_3		
	5-15	52
	15-60	53
	60-107	56
7. Location: Region marked 'shallow water' depression and 17 km west of Khavda		
	5-45	54
	45-140	55

TABLE 6.10 (contd.)

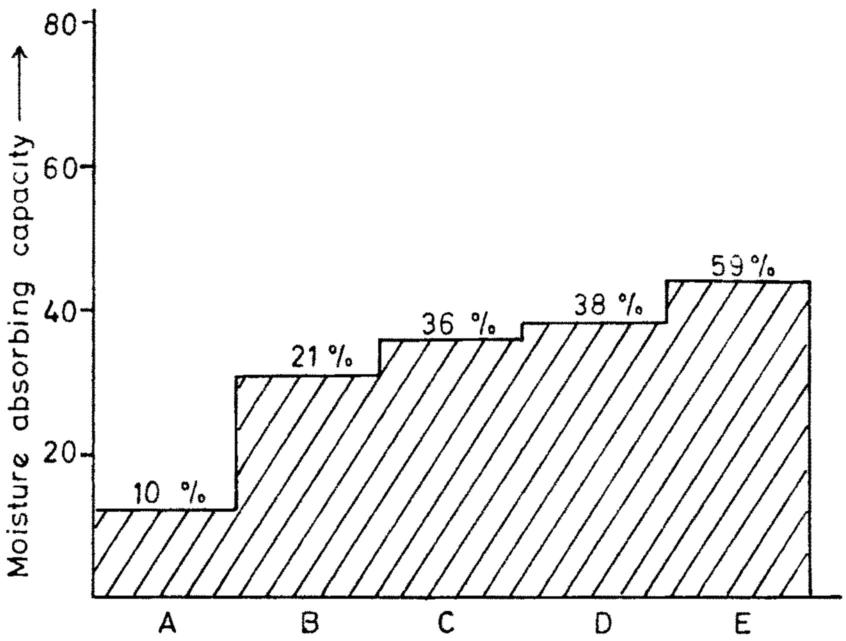
	Depth (in cm)	Moisture absorbing capacity (%)
8. Location:	In Facet B_3, shown as site No. 8 on Fig. 4.1	
	0-40	39
	40-90	36
	90-140	38
9. Location:	South of Kuar bet and west of India bridge in the region near the mainland	
	0-25	2
	25-30	59
	30-45	51
	45-55	-
	55-80	-
	80-85	-
	85	61
10. Location:	South of Kuar bet, away from mainland	
	2.5-20	61
	20-45	63
11. Location:	2.4 km NNE of Lakhpat in the Rann	
	0-15	40
	15-105	33

TABLE 6.10 (contd.)

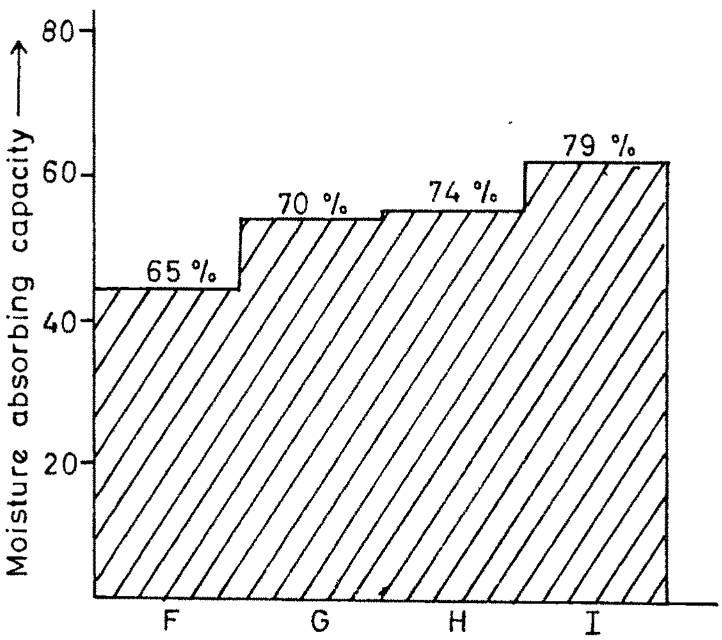
	Depth (in cm)	Moisture absorbing capacity (%)
12. Location: In the Facet B_3, about 13 km WSW of Pachham Island in the Banni area		
	0-20	33
	20-65	30
	65-155	32
13. Location: About 8 km north of Bela Island on the Bela-Nagar Parkar crossing in the Great Rann		
	2.5-10	47
	10-75	-
	75-90	-
	90-145	40
14. Location: SSE of Kuar bet in the Great Rann		
	0-2.5	35
	2.5-105	39
	105-230	34
15. Location: About 3.2 km north of Pachham Island		
	2.5-10	57
	10-60	63
	60-90	-
	90-155	42

Fig.6.9.

RELATIONSHIP BETWEEN AVERAGE CLAY PERCENTAGE AND MOISTURE ABSORBING CAPACITY



A - East face of Dharamshala bet.
B - Khavda Barren area.
C - 1·6 Km. South of Bedia bet in Rann.
D - In Facet B_3, shown as site No. 8.
E - East of Dharamshala bet in the Rann.



F - In the great Rann near road to Dharamshala bet.
G - Region marked as shallow-water depression.
H - 17 Km. west of Khavda in Rann.
I - South of Kuar bet.

the moisture is held between the layers of such particles. The top 10 cm or in very extreme cases 25 cm is comparatively drier (usually in the mud-cracked regions). During rains this zone absorbs water very considerably and quickly closes all available cracks and impeding moisture transfer to the lower and wetter horizons.

Presence of salts

Rann is a salt impregnated area where gypsum and anhydrite crystals occur in the form of surficial deposits or disseminations in the profile. The author has investigated the salt content of the sediments, all over the Rann and calculated the total soluble salts (Table 6.11).

It is observed that high salt content plays an important role in controlling the physical properties of the Rann sediments. Maximum salt content was found in the clay-dominant sediments in the depressed locations which are also the sites of surface salt encrustations. Such regions are around Kuar bet and regions west of it, and north of the individual hill massifs. In this area,

TABLE 6.11

TOTAL SOLUBLE SALTS

Depth (in cm)	T.S.S. (%)
1. Location: North-east face of Dharamshala bet	
0-30	6.55
30-75	8.65
75-135	7.79
135-240	7.82
2. Location: Rann surface, west of Dharamshala bet	
1.25-15	15.65
15-45	16.33
45-90	13.39
90-170	13.32
170	12.81
3. Location: 1.6 km south of Bedia bet in Rann	
0-2.6	6.65
2.6-75	8.22
75-195	5.42
195-260	5.68
4. Location: Between Chota and Bada Sarbelos	
0-5	8.62
5-45	9.02
45-90	7.52
90-170	7.41

TABLE 6.11 (contd.)

Depth (in cm)	T.S.S. (%)
5. Location: In the Great Rannon the road to Dharamshala	
0-15	10.33
15-45	12.61
45-76	9.22
76-105	8.33
105-135	8.39
6. Location: In the depressed area near Kuar bet in Facet B_3	
5-15	19.92
15-60	20.85
60-107	17.65
7. Location: Region marked 'shallow-water' depression and 17 km west of Khavda	
5-45	20.62
45-140	22.68
8. Location: In Facet B_3, shown as site No.8 on fig. 4.1	
0-40	10.33
40-90	11.81
90-140	9.93

TABLE 6.11 (contd.)

	Depth (in cm)	T.S.S. (%)
9. Location: South of Kuar bet and west of India Bridge in the region near the mainland		
	0-25	2.23
	25-30	25.62
	30-45	21.33
	45-55	23.44
	55-80	19.33
	80-85	26.81
	85	20.15
10. Location: South of Kuar bet away from mainland		
	2.5-20	22.33
	20-45	26.81
11. Location: 2.4 km NNE of Lakhpat in the Rann		
	0-15	16.39
	15-105	18.22
12. Location: In the Facet B_3, about 13 km WSW of Pachham Island in the Banni area		
	0-20	23.35
	20-65	15.68
	65-155	18.23

TABLE 6.11 (contd.)

	Depth (in cm)	T.S.S. (%)
13. Location: About 8 km north of Bela Island on the Bela-Nagar Parkar crossing of the Great Rann		
	2.5-10	20.52
	10-75	22.66
	75-90	18.33
	90-145	15.87
14. Location: SSE of Kuar bet in the Great Rann		
	0-2.5	13.33
	2.5-105	14.01
	105-230	12.31
15. Location: About 3.2 km north of Pachham Island		
	2.5-10	20.22
	10-60	23.12
	60-90	19.61
	90-155	20.42

TABLE 6.11 (contd.)

Depth (in cm)	T.S.S. (%)
16. Location: Piprala silty-clay (Profile after Satyanarayana)	
0-3"	10.1
3"-12"	13.1
12"-21"	6.1
21"-36"	11.8
36"-43"	7.1
43"-49"	9.4
49"-58"	12.3
58"-84"	10.8

the average Total Soluble Salt values are around 20%. In the northern reaches of the Rann, in the Bet-Zone the T.S.S. values are comparatively less (9%). However, in the shallower inter-bet regions in Bet-zone containing greater clayey proportions, salt content is seen to increase (12%). Bet sediments show strikingly low values of salt content, indicating a mode of origin different from that of the Rann sediments. The author has observed an interesting relationship between grain-size and salt content, and it is seen that the Total Soluble Salt values are invariably higher for fine-grained sediments (clays) than for coarser sizes (silts and fine sand). This could be attributed to the fact that fine-grained particles have the tendency to attract the various ions in the salts. The top 15 cm of any profile showed a higher proportion of salt which is definitely a result of evaporation of the moisture that reaches the surface by capillary action. This efflorescence phenomenon is very common in the Rann.

Values of physical properties of the Rann sediments showing changes after leaching are shown in Table 6.12 and Table 6.13.

The author has also observed the variation in index properties of sediments with varying (Table 6.12) salinity. His findings are amply supported by the recent work in W. Europe where the work on post-glacial clays which have been raised above sea-level and brought under the influence of percolating ground-water, has shown that the leaching out of sodium chloride has had the effect of considerably modifying, the index properties of sediments, such as reducing their plasticity values.

The hygroscopic coefficient (Fig. 6.10) for leached Rann sediments shows a considerable decrease. This points out that apart from the fact that the fine-grained Rann sediments absorb moisture from the air, the absorbing capacity is further augmented by the presence of an appreciable quantity of hygroscopic salts. The difference in the values of the absorbing capacity for leached and unleached sediments are given in Table 6.13.

TABLE 6.12

EFFECT OF LEACHING ON INDEX PROPERTIES

	Unleached	Leached
1. Location: After Boswell		
Natural moisture	41.0	40.4
Salt concentration	39.0	1.0 gm/litre
Liquid limit	43.5	27.5
Plastic limit	20.0	18.0
Plasticity Index	24.0	9.5
2. Location: Shallow-Water Depression (Organic Clays)		
Natural moisture	38.0	36.5
Salt concentration	20.85	1.5 gm/litre
Liquid limit	82.0	54.0
Plastic limit	23.0	19.0
Plasticity Index	59.0	35.0
3. Location: Around Dharamshala (Clay)		
Natural moisture	25.0	24.3
Salt concentration	12.61	1.5 gm/litre
Liquid limit	74.0	50.0
Plastic limit	29.0	20.0
Plasticity Index	45.0	30.0

TABLE 6.12 (contd.)

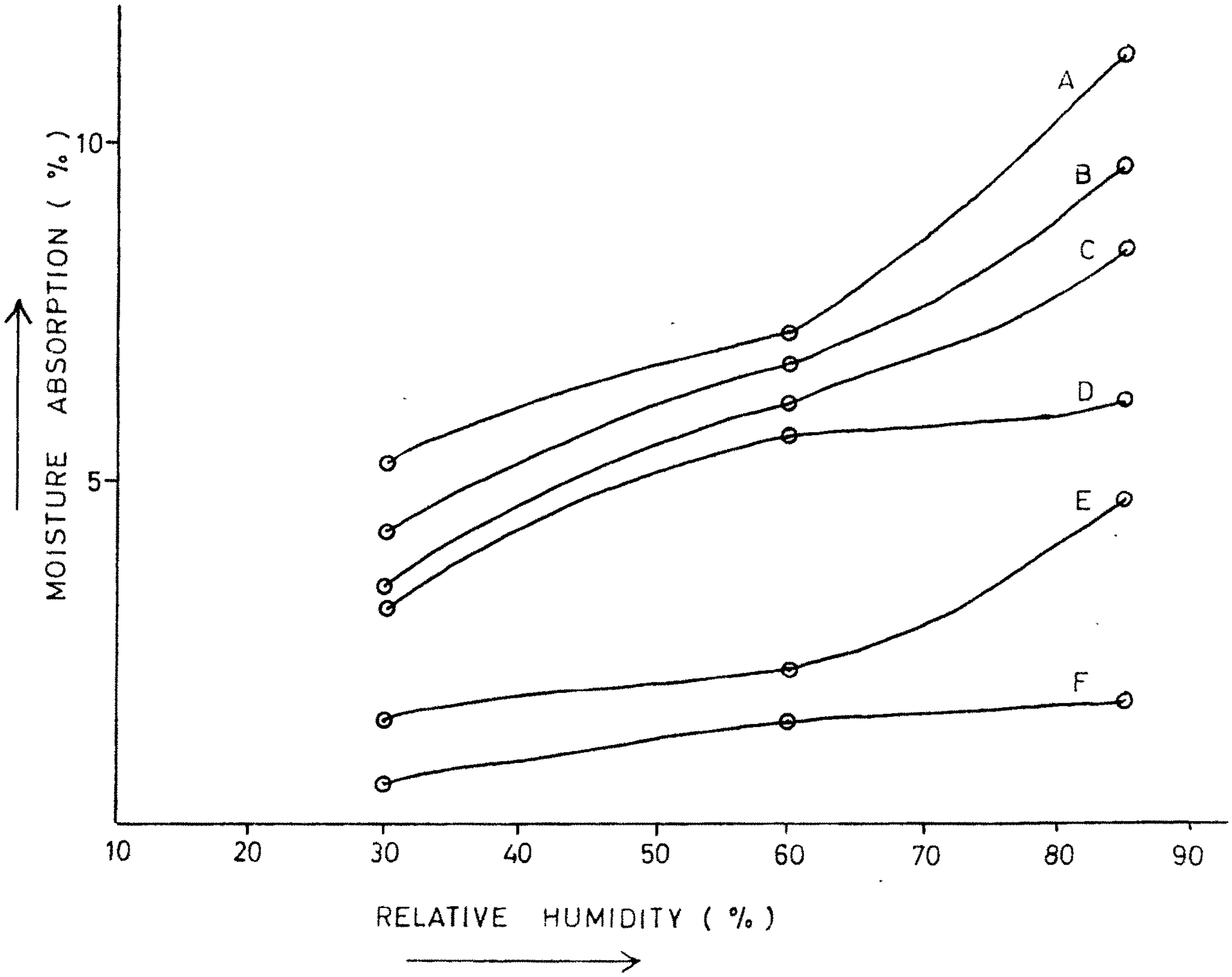
	Unleached	Leached
4. Location: East of India Bridge (Organic Clay)		
Natural moisture	65.0	63.4
Salt concentration	26.81	2.0 gm/litre
Liquid limit	85.0	62.0
Plastic limit	50.0	41.0
Plasticity Index	35.0	21.0
5. Location: South of Bediya Bet (Silty Clay)		
Natural moisture	20.0	19.5
Salt concentration	8.22	0.5 gm/litre
Liquid limit	73.0	50.0
Plastic limit	31.0	22.0
Plasticity Index	42.0	28.0
6. Location: Near Lakhpat (Marine Silty Clay)		
Natural moisture	45.0	43.0
Salt concentration	18.22	0.5 gm/litre
Liquid limit	54.0	27.0
Plastic limit	19.0	11.0
Plasticity Index	35.0	16.0

TABLE 6.13

HYGROSCOPIC ABSORPTION FOR LEACHED SEDIMENTS

Humidity	Absorbing capacity (%)	Sediment	Location
30%	3.51	Inorganic clay	East of Dharamshala
	0.52	Bet sediment	Dharamshala bet
	4.25	Organic clay	South of Kuar bet
	1.50	Silty clay	Between Bada and Chota Sarbelo
	5.10	Partly organic clay	In Facet B_3
	3.13	Clay	North of Biar bet
60%	6.15	Inorganic clay	East of Dharamshala
	1.45	Bet sediment	Dharamshala bet
	6.82	Organic clay	South of Kuar bet
	2.12	Silty clay	Between Bada and Chota Sarbelo
	7.13	Partly organic clay	In Facet B_3
	5.81	Clay	North of Biar bet
85%	7.52	Inorganic clay	East of Dharamshala
	1.77	Bet sediment	Dharamshala bet
	9.74	Organic clay	South of Kuar bet
	4.68	Silty clay	Between Bada and Chota Sarbelo
	11.33	Partly organic clay	In Facet B_3
	6.05	Clay	North of Biar bet

HYGROSCOPIC ABSORPTION FOR LEACHED SEDIMENTS



A - Partly organic clay
B - Organic clay
C - Clay from inter bet depression
D - Inorganic clay near Biar bet
E - Silty clay near Bedia bet
F - Sediments from Dharamshala bet

Saline sediments show low values of permeability as chemical precipitates occupy the interstices of the sediment. As a result of this low permeability and compaction due to increasing depth of burial, flushing is impossible even during rainy seasons. Whatever rain falls there, it remains so and subjected to fierce evaporation (Table 3.1) augments to the salinity.

DISCUSSION

From the preceding account of the various sediment properties and their theoretical explanations, it is observed that the individual properties are mostly inter-related and typically show how one aspect after another has proceeded to build-up a terrain where the sediments are now unfit for any water transfer. Thus in short, the Rann sediments can be described as being fine-grained, plastic, impermeable with a high field moisture capacity and capable of absorbing a considerable proportion of moisture.

The high proportion of salts tend to augment to the problem. The sediments have been rendered more impervious, their absorbing capacity increased twofold and values of other physical parameters as plasticity and thixotropy increased. Thus a flat and gradient-less terrain with sediments of such types, provides an ideal site for the inundation of the sort witnessed year after year in the Rann.

Thus sheets of water of any form (rain, river or sea) inundate the Rann surface for large distances because of lack of gradient and low permeability. In the clayey depressions, stagnation results and if the rainfall is heavy and the volume of water sufficient, water mass inundates one portion and then the next in turn, depending on the wind velocity and direction. In fact, the author would regard the sediments as the fundamental cause for Rann inundation. It is evident that even with the existing flatness, geomorphology and meteorological conditions, had the Rann contained better, well-drained, non-plastic, permeable sediments, the problem of inundation would not have been of this intensity.

ROLE OF GEOMORPHOLOGY

The author has already discussed the role of sediments in controlling the surface and sub-surface movement of water in the Rann. Apart from the role of sediments in controlling inundation, another very important factor that controls water movement on the Rann surface, is that of geomorphology. The author, in an earlier Chapter 3 , has already discussed the various geomorphic Facets and Sub-Facets into which the Rann has been divided. In this part of the chapter, the author has attempted to elucidate how the individual Facets and their associated landforms have controlled the inundation.

Role of Kori Creek

The Creek has an interesting configuration in being almost nozzle-shaped, tapering to a point towards the Great Rann (Fig. 3.3). The sea-water, during high tides rushes with great velocity and is 'ejected' from the narrow mouth of the Creek to be carried many kilometres inland. As already mentioned earlier, the sea water emerging from tidal channels of the Kori Creek's configuration, are capable of generating high velocity currents. The configuration of the Kori Creek is such that tidal velocity as high as 12-15 knots can be expected. The effect of strong wind augments the velocity of onrushing water so that sea-water during stormy conditions can travel as much as 90 km inland, obviously a very high tidal range.

Role of trough-like channel

The ejected water enters from the narrow mouth of Kori Creek, into the trough-like channel - a geomorphic feature which is definitely at a very shallow elevation (RL at various locations given in Chapter 3). The configuration of this east-west channel is ideal for carrying sea water over greater distance. It is:-

(i) linear in form

(ii) aligned along the direction of the strong southwesterly winds

(iii) has a very imperceptible gradient towards east and

(iv) is bounded on either sides by land-forms of higher elevation.

As a result, sea water on entering the trough, travels quite far eastward. It is observed that under normal tide conditions, the sea water reaches a distance of about 30 km from the edge of the creek. During monsoons aided by strong winds it travels upto Kuar bet, a distance of 90 km, to the east. Field reconnaissance have revealed the existence of an elevation at a distance of about 45 km from the creek beyond which eastwards, the ground is somewhat depressed (Fig. 3.4). This 'geomorphic high' controls the extent of inundation eastwards, as this point marks the limit of monsoon high tides (Fig. 7.6), and only during stormy conditions tidal water 'spills' over this depression and travels towards Kuar bet. The region between the 'geomorphic high' and Kuar bet has therefore been marked as a 'shallow water depression' (Fig.6.11). It is in this depression that the receeding sea water is retained as an 'inland lake' to be evaporated subsequently, leaving behind thick crusts of salt resting over black, oozy mud.

This trough-like geomorphic feature is bounded to its south and north by geomorphically high areas. The elevation of Allah Band is to its north. The western part of the southern flank is marked by the mainland rocks that rise vertically, while the eastern part comprises the elevated plains of Banni. The entire feature tapers off towards the Kuar bet channel. The sea water is thus kept restricted within this channel, with Allah Band and the mainland rocks and Banni, preventing the sea water spreading to regions north and south respectively. The mainland drainage to the south contributes only some water during the rare periods of rain. No major stream of perennial nature flows into this trough.

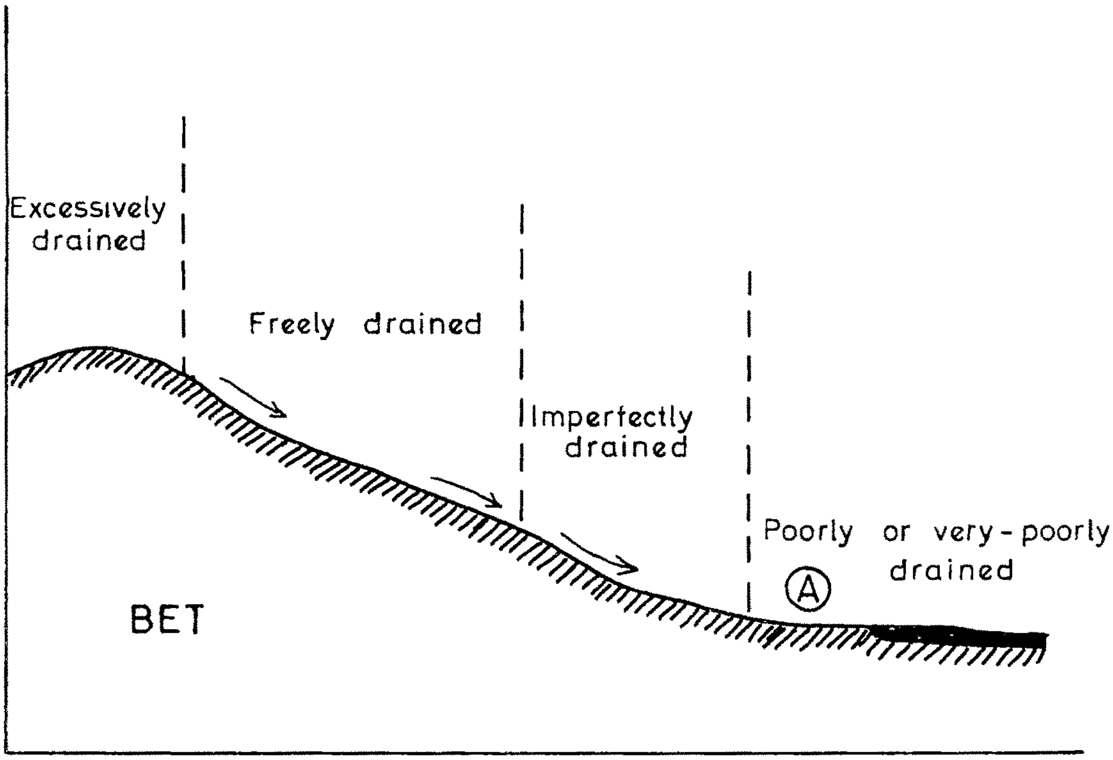
It is thus obvious that the nozzle-like Kori Creek configuration enables sea water to inundate a considerable part of the Rann. Furthermore, the trough-like feature, bounded by geomorphic highs to the north and south, guide the sea water movement east-ward to an abnormal distance.

Role of abandoned channels and inter-bet channels in the Bet-zone

The inundation of Bet-zone is somewhat peculiar. Here during monsoon months, a sudden increase in the depth of water is recorded overnight around certain bets, in spite of the absence of any rainfall in that particular area. Sea water definitely does not reach this part of the Rann and, some workers in the past thought that there was a rise of ground water level corresponding to a rise of sea-level. But this view is untenable. The author after several traverses across the Rann surface, especially during rainy seasons, and the subsequent correlation of field data with air photo studies, ruled out ground water rise. Instead, he found that the inundation of the Bet-zone is brought about by rain water only and even though a particular area may not receive rain, water is transferred to that region via the abandoned channels, broken drainage and other similar geomorphic features (discussed in detail in Chapter 3). Air photos show good examples of 'inter-bet' regions acting as channels for water transfer. One such conspicuous inter-bet channel is that situated between Dharamshala bet and Mori bet (Plate 6.6). The various inter-bet areas are shown in Fig. 3.2. Most of the bets being at higher elevations are free from submergence though the water has been observed during very heavy rains to submirge low-lying bets like Karimshahi and partially submerge other bets.

Another inference based on day to day observations from the B.S.F. border outposts located on the various bets point to the fact that the inter-bet regions around the bets are always the first to be inundated and badly affected. During heavy rains, the rain water debouches from the bet surfaces, on account of their sloping faces and higher elevations, to augment to the water collected by direct precipitation (Fig. 6.12). Apart from water, fine clay-size particles also are washed down the bets and get accumulated in these channels. As a result, these inter-bet low areas are seen to be made up of fine clays, and when wet become in-accessible. In fact, it is the net-work of such areas that have rendered this part of the Rann somewhat treacherous and inhospitable.

FORMATION OF CLAY BEDS AROUND 'BETS' AND PROCESS OF WATER-LOGGING



(Not to scale)

Clayey horizons at the base of bets and inter-bet region region.

Ⓐ Region that are always water-logged.

⟶ Direction of water movement.

PLATE 6.6

Typical inter-bet region of Sub-Facet A_2.
Location: Between Dharamshala bet and
Mori bet.

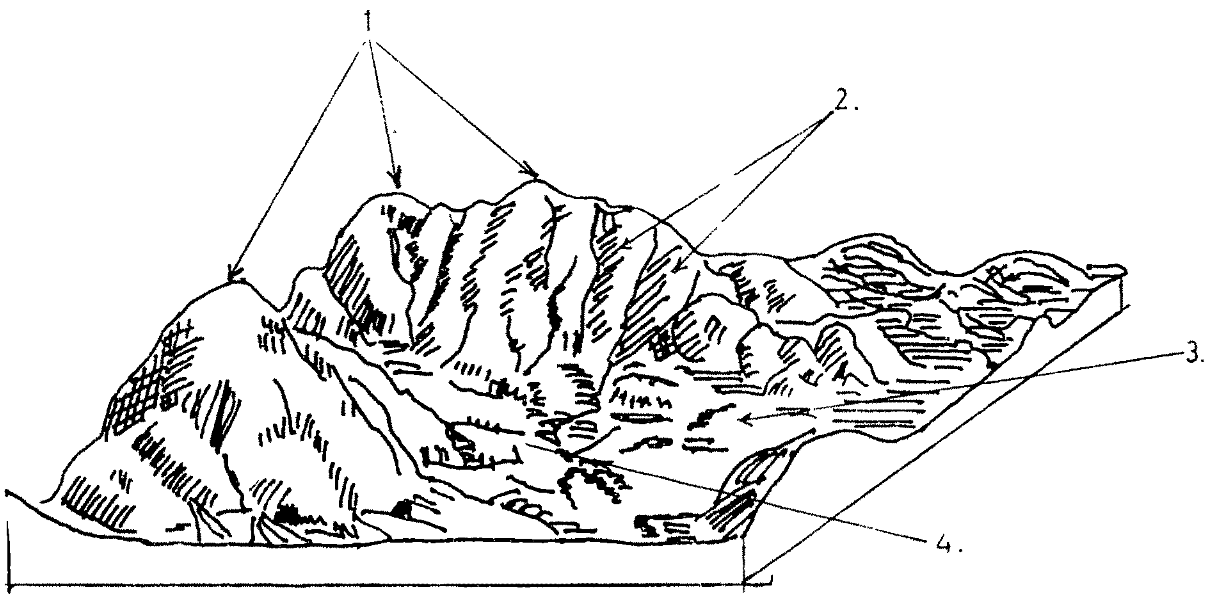
On air-photos (Stereo Plate 7) the erosional gullies on the surface of the bets debouching into the channels and characteristically recognised by the pattern of these gullies and the darker hue tone of the channels, reveal moist and fine-grained sediments. The above feature is diagrammatically represented in Fig. 6.13, where the higher ground represents a bet. It is observed that bigger a bet, the more is the depth of surrounding channels and greater is the inundation.

Of the entire Bet-zone, it has been found that the worst affected areas are (i) region north of Biar bet (ii) bet A (iii) around Karimshahi (iv) region fringing the south of Chad bet (v) north of Vigukot high and (vi) area between Gainda bet and Mori bet (Fig. 7.2). All these areas are obviously inter-bet areas, characterising a net-work of early channels of a major abandoned river.

The important conclusions in respect of the Bet-zone inundation are as follows:-

(i) The Bet-zone (including the bets and the inter-bet channels) is at a slightly higher elevation than the surrounding zones).

BETS AND INTER BET REGIONS



1. Bets
2. Erosional gullies at the bet faces
3. Channels on Rann surface.
4. Clayey inter bet patches.

NOT TO SCALE

STEREO-PLATE 7

Stereo-plate showing a bet and its associated features.

E.G.: Erosional gullies   E.C.: Erosional channels

W.R.: Wet Rann. (Inter-bet region). Note its dark tone, indicating a wet and clayey patch.


E.G.
E.C.
E.C.

(ii) As a result, sea water influx is absent and the source of inundating water is precipitation only.

(iii) The water movement, takes place within the geomorphic lows, represented by the abandoned channels which act as conduits. The bets, in comparision being at a higher level, are never completely submerged.

Inundation of the Great Barren Zone

The geomorphic map shows that the Bet-zone abruptly ends with the disappearance of bets eastwards (Fig. 3.2) with Bediya bet occupying the easternmost extremity. From there further east, the high land slopes into a vast depressed zone - the Great Barren zone, very clearly seen during monsoon, by its standing water body.

But for a single elevated feature of Sindal bet, an outcrop of Archaens of Nagar Parkar uplift, the entire tract is featureless and barren. This region as has been described is an extensive depression within which exist several smaller depressions, which are situated to the north of Pachham, Khadir and Bela and around them and are sites of boggy clay formation, overlain by thick salt crust. These areas are often inaccessible. Some of these patches remain perennially wet throughout the year. This depressed region does not receive any sea water at all from the Kuar bet side. Nor its inundation is in any manner connected with the water transfer from the Bet-zone area. The entire water body that inundates the feature comprises rain water derived by direct precipitation. Its inundation is mainly a phenomenon of surface accumulation of rain water in the depressions. During heavy rains, this depressed region gets filled up with water upto a depth of even 3 to 4 metres. Some augmentation in this water content is by the flowing of the streams down the slopes of the islands during monsoons. However, as in the case of mainland streams, these are of minor importance, and carry only an insignificant fraction of the total accumulated water. The geomorphic map of the Rann reveals that in comparision to the Bet-zone facet, this facet comprises a typical geomorphic low.