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THE EFFECT OF VERGE SLOPE AND COVER ON SOIL MOISTURE DISTRIBUTION UNDER A ROAD IN KENYA

by

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SUMMARY

A full scale experiment has been in progress since April, 1961 at Muguga, Kenya to investigate for the particular climatic conditions the effect of the slope and cover of the road verge on the moisture condition of the road subgrade. The experimental variations comprise verge slopes of 1 in 14 and 1 in 35 with verge treatments of Kikuyu grass, gravel and polythene membrane.

Analysis of the first two years' records shows that the slope of the verge had a considerable influence on the infiltration of water into the highly permeable soil, the effect of increasing the steepness of the slope being to reduce the quantity of water infiltrating.

Kikuyu grass dried the road verge to a depth of 10 ft but few roots, as yet, have spread laterally under the road.

The polythene membrane excluded light rain from the verge but was not effective against prolonged heavy rain. Once the verge was wet, however, the membrane prevented evapotranspiration losses and the moisture distribution changed little. The net result was the maintenance of fairly wet conditions under the verge and edge of the pavement.

The gravel verge permitted the maximum penetration of water into the soil and consequently under the road, while effectively reducing evapotranspiration losses. The verge and much of the subgrade were therefore maintained in a uniform relatively wet condition.

Cracks appeared in the pavement only alongside the Kikuyu grass covered verges. This is associated with the vigorous wetting and drying cycles followed by the soil under the grass.

Slow inward and upward movements of water beneath the road pavement at depths beyond 4 ft may be of importance in affecting the ultimate moisture condition reached under the centre part of the pavement.

It is intended to continue the measurements until only seasonal variations in moisture condition are apparent.

THE EFFECT OF VERGE SLOPE AND COVER ON SOIL MOISTURE DISTRIBUTION UNDER A ROAD IN KENYA

Introduction

The moisture condition of the soil beneath a road influences the bearing strength of the soil and hence the performance of the road under traffic. Pavement design research at the Road Research Laboratory has therefore necessitated studies of the distribution of moisture in subgrades beneath roads and airfields in many parts of the world.(1) Similarly, soil moisture distribution as it affects agriculture has been studied for many years at the East African Agriculture and Forestry Research Organization,(2) whilst the Materials Laboratory of the Ministry of Works and Communications, Kenya has used road pavement designs based on the probable ultimate moisture condition of the subgrade.(3) It is not known to what extent this condition will be affected by moisture exchange between the verge and the soil beneath the road.

In a co-operative investigation, the effect of variation in the slope and cover of the road verge on the moisture distribution is being studied on a length of experimental road constructed within the estate of the East African Agriculture and Forestry Research Organization by the Ministry of Works and Communications.

Details of the road construction and instrumentation phases have been given in a previous Laboratory Note(4) and this paper deals with the changes in moisture distribution which have taken place in the two years following the construction of the road. It is intended that the experiment will be continued until only seasonal variations in moisture distribution occur beneath the road structure.

The site

The climatic and soil conditions at Muguga, the East African Agriculture and Forestry Research Organization headquarters, are fairly typical of a large and important area of the Kenya Highlands. Muguga is situated at 1° 14'S, 36° 38'E at an altitude of 6,800 ft with an annual rainfall of 39 ins (12 years) and an annual evaporation from a U.S. Weather Bureau Class A pan of 77.6 ins (5 years). The bulk of the rain falls in two seasons, the "long" or main rains in March, April and May and the "short" or secondary rains in October, November and December. The monthly mean climatic data given in Table I were obtained from the Muguga meteorological site some 800 yds from the experimental road.

The soil is the so called Kikuyu Red Loam which, is an important agricultural soil in Kenya. Believed to have been formed from massive flows of lava and tuff by leaching in situ, it is characteristically deep and highly permeable with a large proportion of halloysite type clay in its composition. Some physical characteristics of the soil were included in the previous Laboratory Note and further properties, determined from core samples of undisturbed soil from a pit alongside the road, are given in Table II. Despite a slightly denser layer at a depth of 6 ft the soil is remarkably uniform and the very high permeabilities are noteworthy. From observations of the water level in a nearby borehole, the permanent water table is almost certainly more than 150 ft below the road surface.

Layout and instrumentation of the experiment

The carriageway is 15 ft wide and the verges are each 7 ft wide. The method of construction is typical of pavements now being laid in East Africa. It consists of a base of nominal thickness 6 ins made of lime

/stabilised

stabilised gravel, with a surfacing in which priming of the base was followed by a double surface dressing. There was no sub-base. The soil subgrade, which in the natural state occurs at very low densities, was compacted to a density equivalent to 96 per cent of B.S. optimum density immediately under the base reducing to 90 per cent in the lower layers of the shallow embankment on which the road is constructed.

The road is divided into 3 sections each 60 ft in length, with a verge slope of 1 in 35 on one side of the road and of 1 in 14 on the other. Three verge treatments are being investigated:-

(1) Deep rooted Kikuyu grass. (Pennisetum clandestinum) Section B and E

(2) A two inch thick layer of gravel. Section C and F

(3) A polythene membrane laid across the verge at the level of the road base. Section A and D

The layout of the experimental section is shown in Fig. 1. Kikuyu grass is the normal vegetation on verges of roads in the area and its presenc assists drying of the verge by the process of transpiration. This grass has a very deep rooting habit and it was thought possible that roots penetrating under the road pavement would remove any water infiltrating into the road sub-grade during the rainy season. Excessive drying of the soil near and under the road is often accompanied by shrinkage with the consequent risk of cracks appearing in the pavement. The gravel treatment was designed to allow the maximum infiltration of water into the verge with a very low rate of extraction during the dry season. To this end vegetation was eliminated from the gravel by the use of a proprietary hormone herbicide. The polythene sheeting was installed in an attempt to reduce to a minimum the seasonal changes in moisture content of the verge. Teff grass (Eragrostis abysinica) was seeded heavily on the soil above the membrane as a protection against erosion.

On one side of the road (section A, C and E) the cover beyond the ditch consists of a 15 yd strip of blue gum trees (Eucalyptus saligna) planted in 1959. Beyond the trees is a field of planted star grass (Cynodon dactylon). The other side of the road was initially cleared to a distance of 10 yds during road construction but weed growth and black wattle trees (hybrid of Acacia decurrens and Acacia mollissima) rapidly covered the area.

Plaster of Paris electrical moisture gauges formed the main instrumentation installed to follow the moisture changes. Road tensiometers were also installed in case the wetting process was such that the soil water tension became less than pF 2.8 over comparatively long periods of time. This did not in fact occur, the soil moisture tension being outside the range of the tensiometers except for very short periods of time and at isolated positions near the edge of the pavement. Thermistors were installed under the road and under the grass covered verge, but the temperature measurements showed that the temperature variations under the road were comparatively small and were not likely to have any short term effects on the soil moisture distribution. The temperature data will be the subject of a later report. The layout of the instruments in the immediate vicinity of the road is shown in Fig. 2.

Characteristics of the electrical moisture gauge

The electrical moisture gauges installed under the road are composed of two concentric electrodes sealed in plaster of Paris. (Pereira 1951).(5)

/The

The principle of operation is that the resistance of the plaster is a measure of its moisture condition, and hence of the moisture condition of the surrounding soil. When the plaster is in close contact with the soil, the water films in both the plaster and soil can be considered to be at the same level of stress. The suction/moisture content relation for the plaster can be determined as well as the resistance/moisture content relation, and combination gives the resultant resistance/suction curves for the electrical moisture gauges as shown in Fig. 3.

Some difficulty arises in the interpretation of the resistance readings. The configuration of the water films in the plaster is dependent on its history of wetting and drying and this is reflected in the resistance/suction curves. Further difficulties arise because of random variations in gauge construction and, since it is impractical to calibrate large numbers of the gauges, the accuracy of readings is of the order $\pm$ 0.2 on the pF scale over the range pF 2.8 to pF 5.0.

Presentation of results

The large mass of data comprising approximately 500 readings per week carried out over a 2 year period, raises difficulties in presentation. Under a uniform vegetative cover, such as agricultural crop, the moisture distribution with depth and time can be shown on a single diagram. (2) The record is obtained by plotting the readings of the electrical moisture gauges with time for various depths in the soil profile. The range of response of the gauges approximately covers the soil moisture condition between field capacity and wilting point, hence, the resistance reading is a measure of the amount of water available to plants at that depth. The amount of available water can be shown by shading and the change in moisture condition of a soil profile conveniently represented on a composite diagram showing the change in the amount of available water at several depths. This method has been used in Fig. 4 to show the seasonal distribution of moisture beneath typical types of vegetation at Muguga.

In order to show the variation in soil moisture in both space and time in the vicinity of the road structure, however, a change in the method of presentation is necessitated. Over periods of duration of one month, the variation of the twice-weekly resistance readings was usually small, particularly under the road pavement. The monthly average resistance measurement for each electrical moisture gauge was therefore calculated and plotted at the appropriate point on a diagram showing the cross section of the road. Lines of constant gauge resistance were then drawn over the whole of the cross section as shown in Fig. 5. The series of diagrams of average monthly conditions prepared in this way are given in Fig. 6. and represent the changing moisture distribution of the 6 experimental sections over the period April 1961 to March 1963.

Experimental environment

The measurements considered here were made over the period April 1961 to March 1963: the monthly mean rainfall totals are given in Table III. The initial conditions were influenced by the failure of the short rains in 1960: only 6.08 ins were recorded at the Muguga Meteorological Site in the months October, 1960 to January, 1961 compared with the 12 year average of 13.76 ins (See Tables I and III). The soil at depths beyond 2 ft was therefore uniformly dry. This state was modified by the water applied in the soil stabilisation process which wetted the upper layers of the road subgrade. The long rains of April, May and June 1961 were lighter than usual and penetrated no more than 2 ft under natural vegetation. Severe drought conditions were apparent under natural vegetation as soon as July. This state continued until the exceptionally heavy short rains of 1961 began in October. Some 48 ins of rain fell in the period October, 1961 to January, 1962 to give easily the wettest conditions ever recorded at Muguga (See

/Table III).

Table III). Based on the Muguga records over 12 years, the rainfall over this 4 month period exceeded the 50 year expectation for rainfall in any 4 month rainy period. After a very brief dry spell in February, the long rains of 1962 were slightly heavier than average with more rain in May than would normally be expected. The short rains of 1962 were distinctive only in that the rain continued late into January and as the long rains in 1963 began late they do not enter into the 2 year period under consideration.

Whilst the main purpose of the experiment is to determine the effect of verge treatment on the subgrade moisture condition in the environment of the Highlands of Kenya, the soil moisture regime under normal vegetative cover is also being studied. The results, Fig. 4, provide a general assessment of the environment and will be useful when comparing road experiments in other environments such as the tropical monsoon climate of Malaysia.

The replicate profiles under 2 to 4 year old blue gums are similar and show that water was removed steadily down to 10 ft following the cessation of the rain both in March, April and in September1962. The star grass was almost equally efficient in using the stored water except that no water loss from the 10 ft depths was shown in the brief dry period of March and April, 1962. The profile under weeds and regenerating wattle trees showed that the incomplete cover used less water in March and April 1962. Faulty resistance units confused the picture later in the year but the soil at a depth of 2 ft remained wet about 6 weeks longer than that under grass suggesting that the transpiration rate was still lagging behind that of the complete vegetation cover.

A comparison of the water regimes under the grass covered ditch and in the field, shows that the light rains in April and May 1961 were insufficient to wet the soil beyond 2 ft under the level surface, but the run-off into the ditch filled all the available storage to 10 ft. The subsequent moisture patterns until November were therefore markedly different. However, the extremely heavy rains of late 1961 were sufficient to fill both profiles to 10 ft, any excess run-off into the ditch merely draining beyond this depth. The soil moisture patterns in the following dry spell were therefore very similar. Differences arose again in late 1962 when run-off again caused a concentration of water into the ditch while no penetration even to 2 ft was observed under grass or the trees. These observations demonstrate that in freely draining soils the effect of run-off from the road causes significantly wetter conditions at the edge of the road relative to the surrounding soil only in times of light rain. Under the normal long rains at Muguga, soil moisture conditions could be expected to be similar over a depth of 6 ft in the verge, ditch, and surroundings.

The effect of the road construction on the local soil moisture environment will now be discussed in relation to the imposed verge treatments.

Discussion of results given in Fig. 6.

Slope of shoulder In view of the permeable nature of the soil, it was thought that the effect of the slope of the verge on the rate of ingress of water into the verge would be small; however, such an effect was evident, particularly in the early part of each rainy period, when water penetrated more deeply under the gently sloping shoulder than under the other. This can be seen readily on all 3 treatments, A, C and E, with a shoulder slope of 1 in 35, compared with the corresponding cover treatments D, F and B with a verge slope of 1 in 14, especially in the months of October and November, 1961.

As a corollary, it would be expected that more water would reach the ditch beyond the steeper verge in each treatment. However, the longitudinal flow of water along the ditch, disposing of excess water from each section, confuses the picture. The lowest part of the

/experimental

experimental section might be expected to show some cumulative effect and, in fact, the ditch below treatment E is consistently much drier than that below treatment F which is in accord with the higher rate of infiltration of water on the gentler slope. It should be stressed that the vegetation (Kikuyu grass) in the ditches is uniform throughout the experimental section.

Kikuyu grass verge

Sections B and E Initially under section B the top two feet of the subgrade was wet from water applied in the construction of the road, together with the water which entered the unsealed trench from a shower during the installation of the instruments. Below this depth the soil was very dry from thd preceding drought. This relatively small amount of water probably diffused downward into the large mass of dry soil, and by July the whole of the subgrade was very dry.

The rain in April and May wetted the verge only to a depth of 2 ft, but the concentrated run-off wetted the profile under the ditch to a depth of more than 10 ft. High transpiration with no additional rain brought about a rapid drying of the verge by August, although the ditch remained moist at depths beyond 3 ft.

The heavy rain of October, November and December filled all profiles outside the road and the wetting front advanced laterally into the subgrade, resulting in wet conditions as much as 3 ft from the edge of the pavement near the surface. Penetration was only between $1\frac{1}{2}$ and 3 ft at depths below 1 ft. Rapid drying of the verge and ditch to a depth of 3 ft occurred in February, March and early April 1962 but a ridge of moist soil remained just inside the edge of the road pavement beyond a depth of 1 ft.

The rains in late April and May wetted the verge again to about 4 ft but the lateral penetration under the road was not as great as in the previous rainy period. Thereafter, the verge and ditch dried out steadily except for the small contribution of rain during November, December and January but the soil just under the pavement remained moist throughout the drying period. The ditch did not dry out as thoroughly as might have been expected and may have received run-off from areas uphill of the test section of the road. The moisture status of the centre of the road changed little after July, 1962, except for some evidence of infiltration of a small amount of water from the opposite side of the road at depths of 4 to 6 ft, beginning in June, 1962.

The soil moisture pattern under the road section with the corresponding treatment on the other side of the road (Section E), was similar to that under B except for the difference imposed by the gentler slope on the verge. As a result of this, the accumulation of water at the edge of the road is more marked in E than in B, and the penetration of the water front under the road in December, 1961, was more extensive, spreading more than 3 ft under the pavement from the surface to depths of more than 4 ft. These wetter conditions under the pavement persisted throughout the remaining 15 months, and the ridge of moist soil just inside the pavement was therefore more marked. One significant difference between treatments B and E perhaps arose from this. A lateral advance of a wetting front under the road at depths beyond 6 ft was observed in treatment E which was absent from treatment B. This was particularly apparent after June, 1962.

The effects of cracks in the road surface in Section B were evident as early as August 1961, when the surface resistance gauge 3 ft inside the pavement edge was wetted. Evidence of cracks in Section E did not appear until February 1962, although any effect would have been masked from December. It is of interest to note that cracks in the road pavement occurred only on those sections with Kikuyu grass planted on the verges. The visible cracks were sealed in April, 1963.

/Visqueen

TABLE II

Physical properties of soil determined from 3" x 4" diameter undisturbed cores

Depth in ft	% M.C. by Wt. at tension of 20 cm. (pF.1.3)	% M.C. by Wt. at tension of 330 cm. (pF.2.5)	Bulk density in gm/cc	Total pore space % of total volume	Pore space drained at 20 cm. tension % total volume	Pore space drained at 330 cm. tension % total volume	Permeability in cm/sec x 10^{-2}	Permeability in cm/hr
Surface	47.28	39.82	1.09	56.08	4.29	12.46	2.37	85.34
1	52.07	39.32	0.93	62.06	13.76	25.58	9.65	347.28
2	47.42	36.07	1.06	58.71	8.64	20.62	5.31	191.26
3	47.47	38.35	1.11	57.52	5.01	15.10	2.46	88.39
4	42.49	36.54	1.17	55.79	6.09	13.05	4.17	150.11
5	42.31	36.01	1.16	56.55	7.52	14.82	6.21	223.65
6	38.09	33.19	1.21	54.40	8.46	14.37	0.90	32.39
7	42.32	37.31	1.15	57.34	8.81	14.55	2.37	85.34
8	41.76	36.68	1.16	56.23	7.61	13.53	2.86	103.06
9	42.00	36.93	1.17	56.18	7.23	13.14	3.68	132.40
10	38.94	35.24	1.18	56.05	10.29	14,64	0.66	23.62

TABLE III

Rainfall at E.A.A.F.R.O. during experimental period monthly totals in inches

		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Muguga Met. Stn. monthly values	1961	0.26	0.28	2.74	6.62	3.85	0.62	1.05	1.00	1.29	6.46	21.93	13.57	59.67
	1962	6.35	0.68	1.29	5.67	14.80	1.30	0.05	1.29	0.32	2.76	4.44	3.53	42.48
	1963	3.47	2.12	1.83										

Acknowledgements

The construction and maintenance of the experimental road was carried out by the Ministry of Works and Communications, Kenya. The authors would like to thank them and particularly Mr. F.S. Strongman, Chief Materials Engineer, for their help and co-operation on the planning and execution of the experiment.

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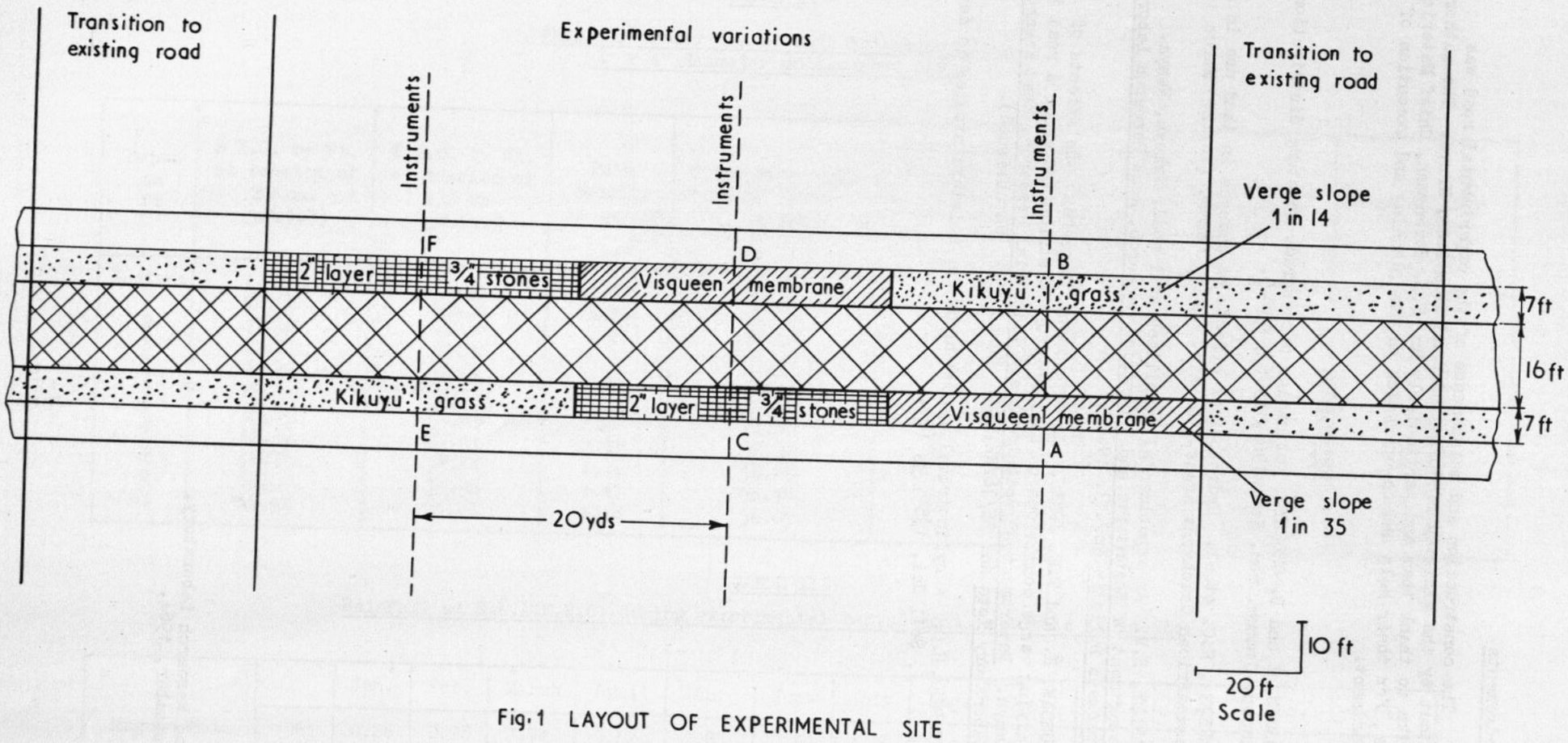

Fig. 1 LAYOUT OF EXPERIMENTAL SITE

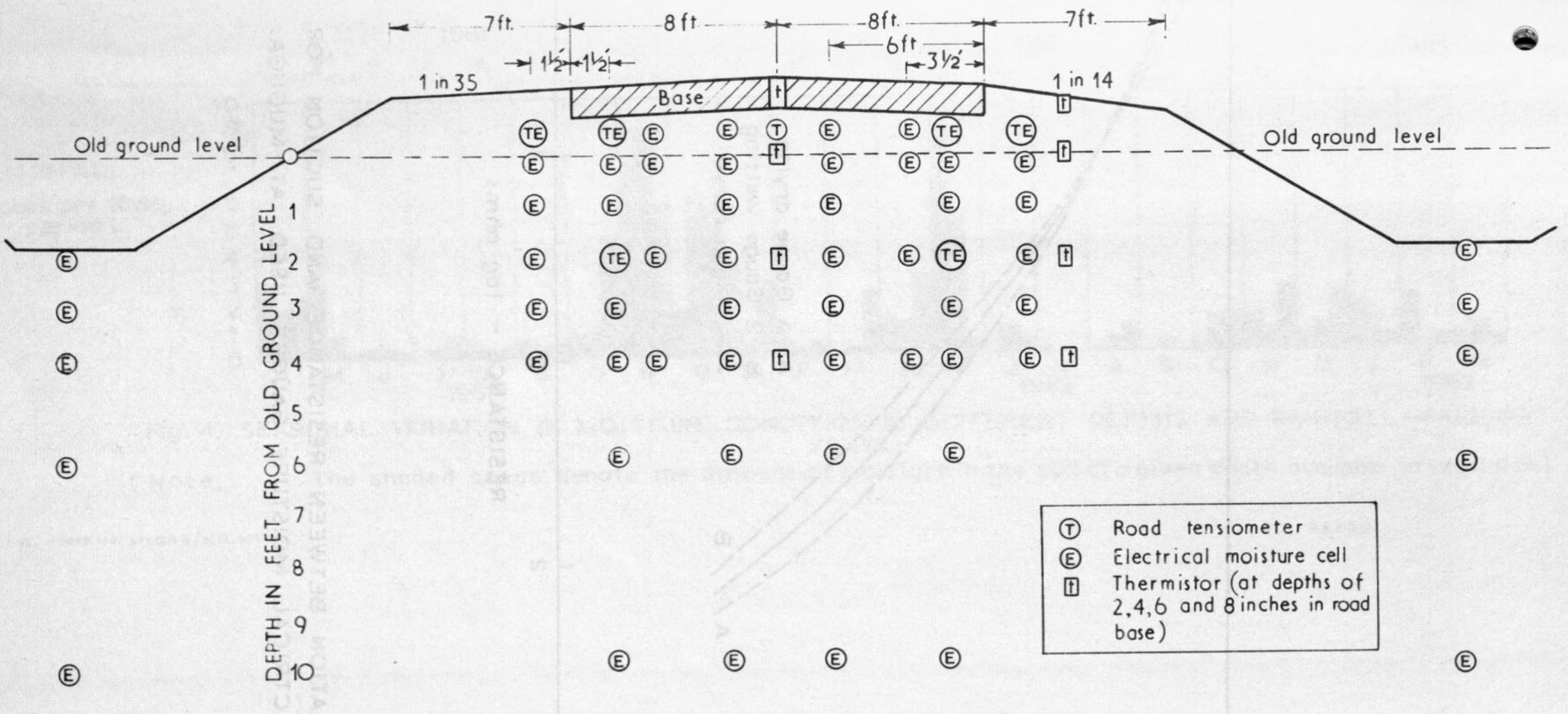

Fig. 2. DIAGRAMMATIC LAYOUT OF INSTRUMENTS AT TYPICAL ROAD SUBSITE – MUGUGA KENYA

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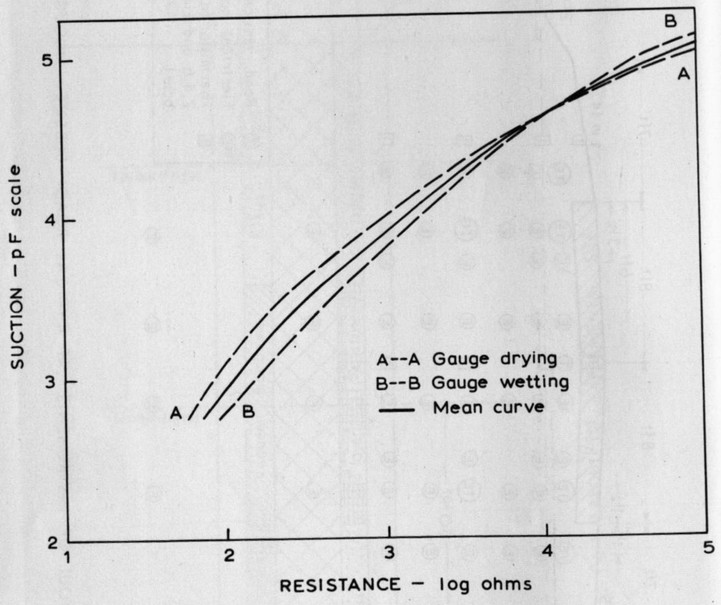

Fig.3 RELATION BETWEEN RESISTANCE AND SUCTION FOR ELECTRICAL MOISTURE GAUGES USED AT MUGUGA.

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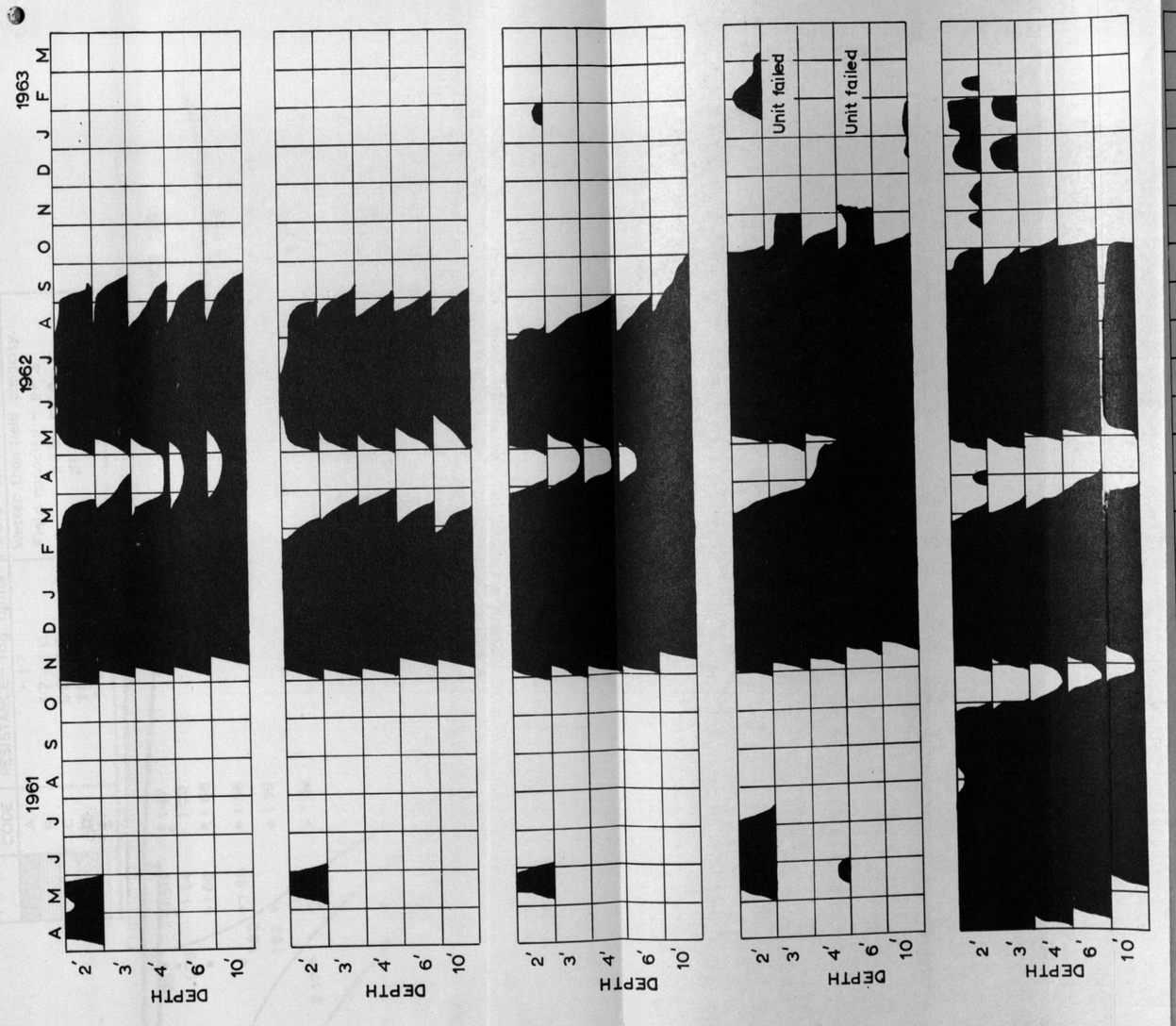

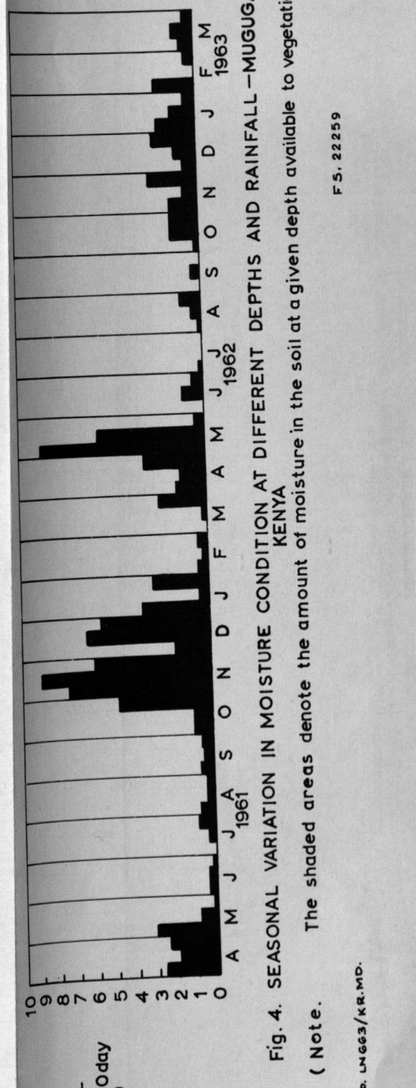

Fig. 4. SEASONAL VARIATION IN MOISTURE CONDITION AT DIFFERENT DEPTHS AND RAINFALL—MUGUGA KENYA

(Note. The shaded areas denote the amount of moisture in the soil at a given depth available to vegetation)

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	CODE	RESISTANCE – log ohms	SOIL MOISTURE CONDITION
	A	> 1·7	Wetter than field capacity.
	B	1·7 – 2·0	Field capacity – pF 3
	C	2·0 – 3·0	pF3 – pF 4
	D	3·0 – 4·0	pF4 – pF ·4·5
	E	> 4·0	pF 4·5

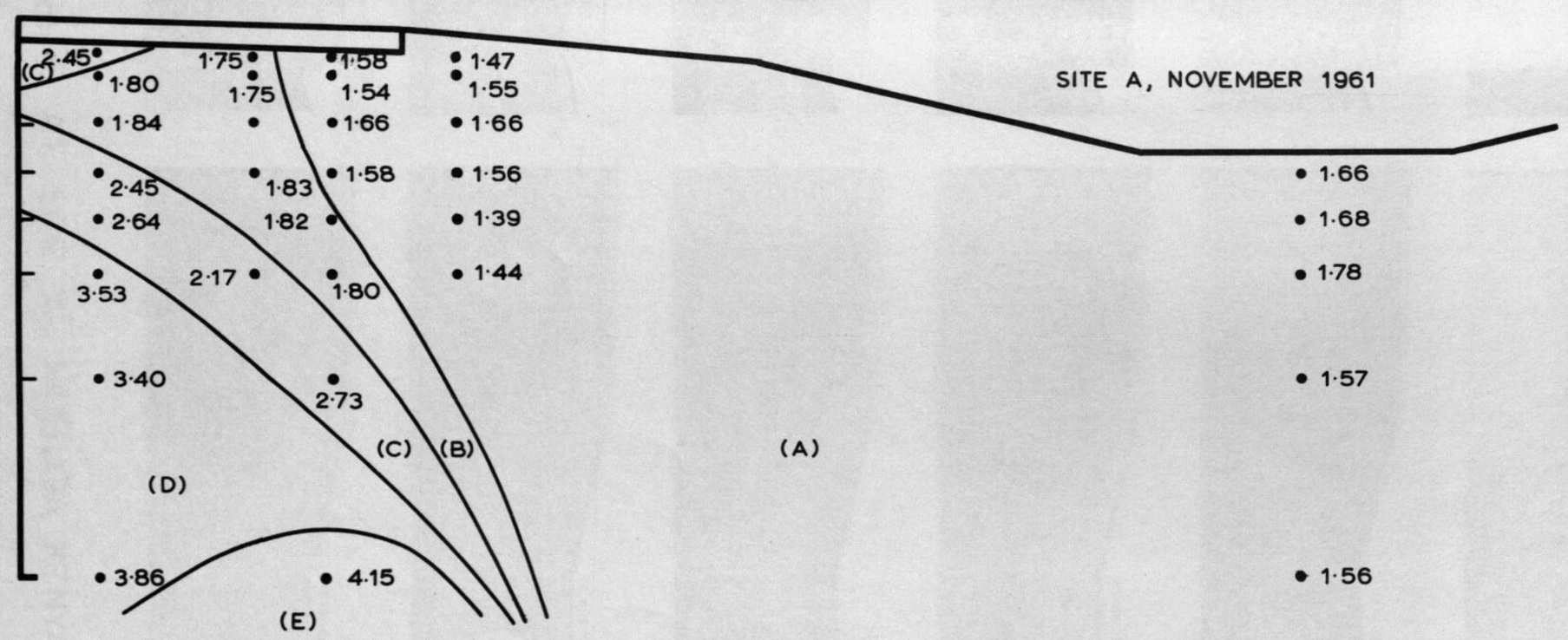

Fig. 5. DETAIL AND METHOD OF PRESENTATION OF MONTHLY AVERAGE DATA FROM EACH SITE – MUGUGA, KENYA.

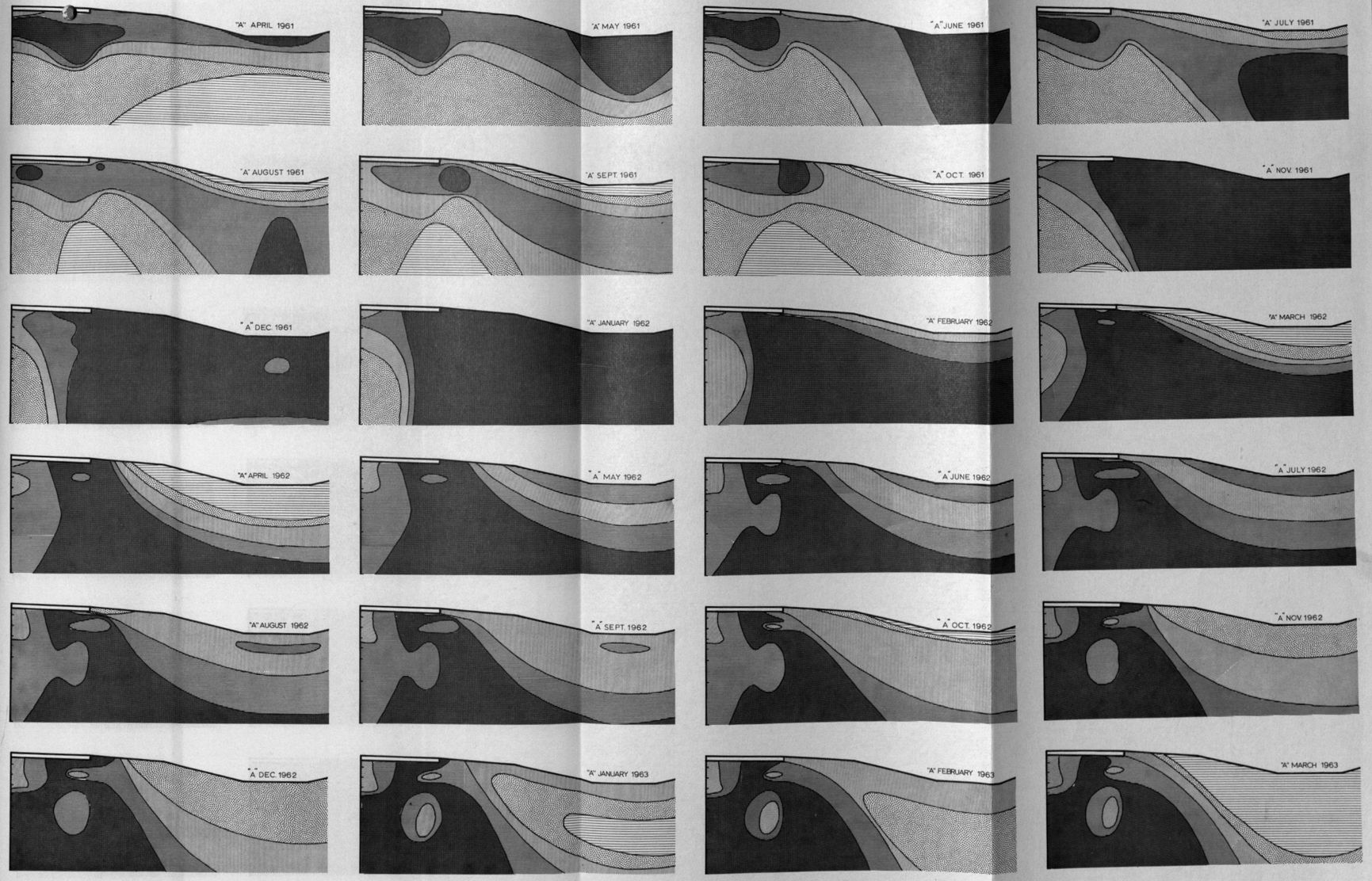

Fig. 6.(a). CHANGE IN MOISTURE CONDITION OF ROAD CROSS-SECTION WITH TIME AT SITE 'A', MUGUGA KENYA.
(VERGE COVER VISQUEEN MEMBRANE
VERGE SLOPE 1 in 35)

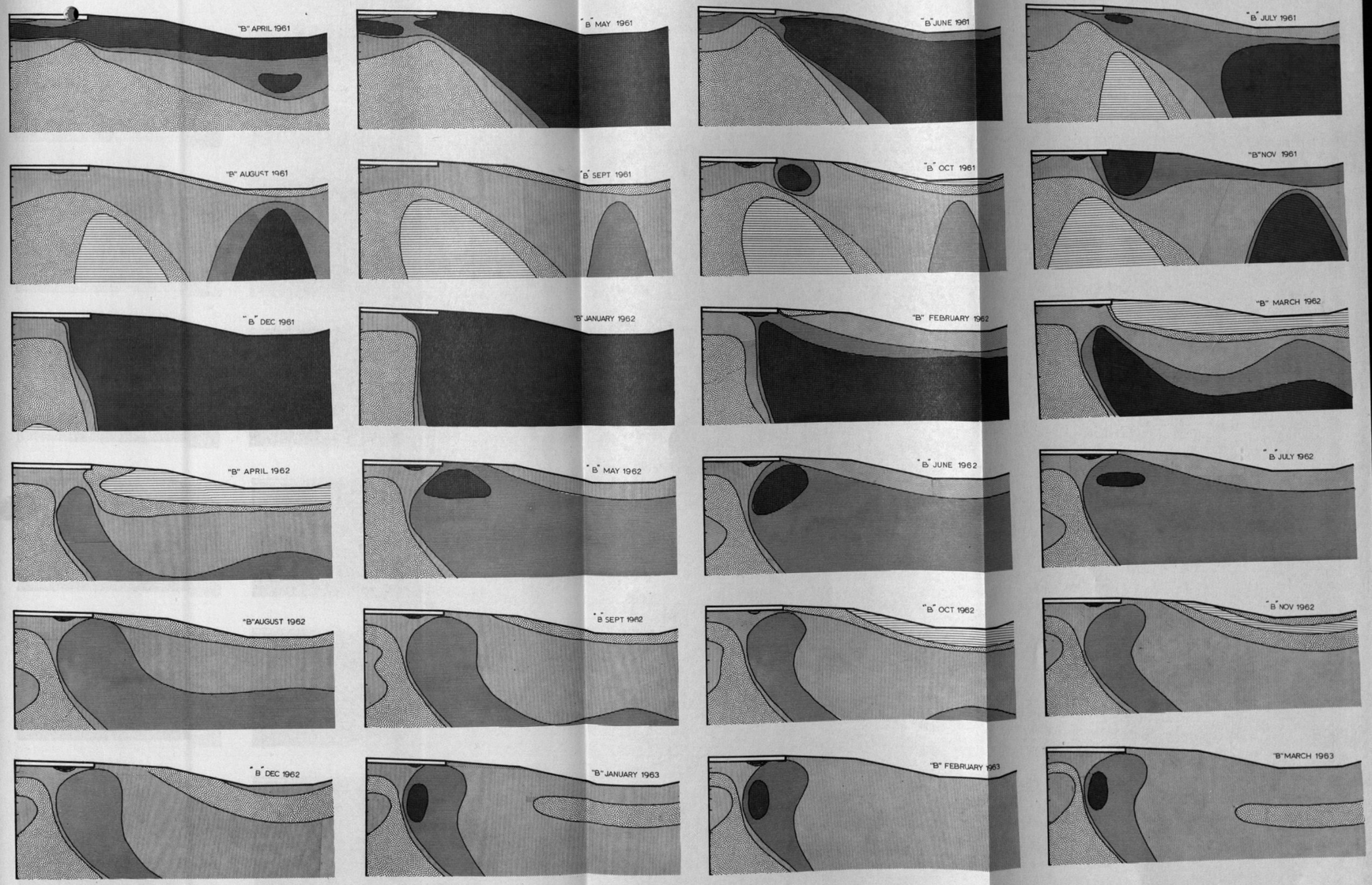

Fig. 6.(b). CHANGE IN MOISTURE CONDITION OF ROAD CROSS-SECTION WITH TIME AT SITE 'B', MUGUGA KENYA.
(VERGE COVER KIKUYU GRASS VERGE
SLOPE 1 in 14)

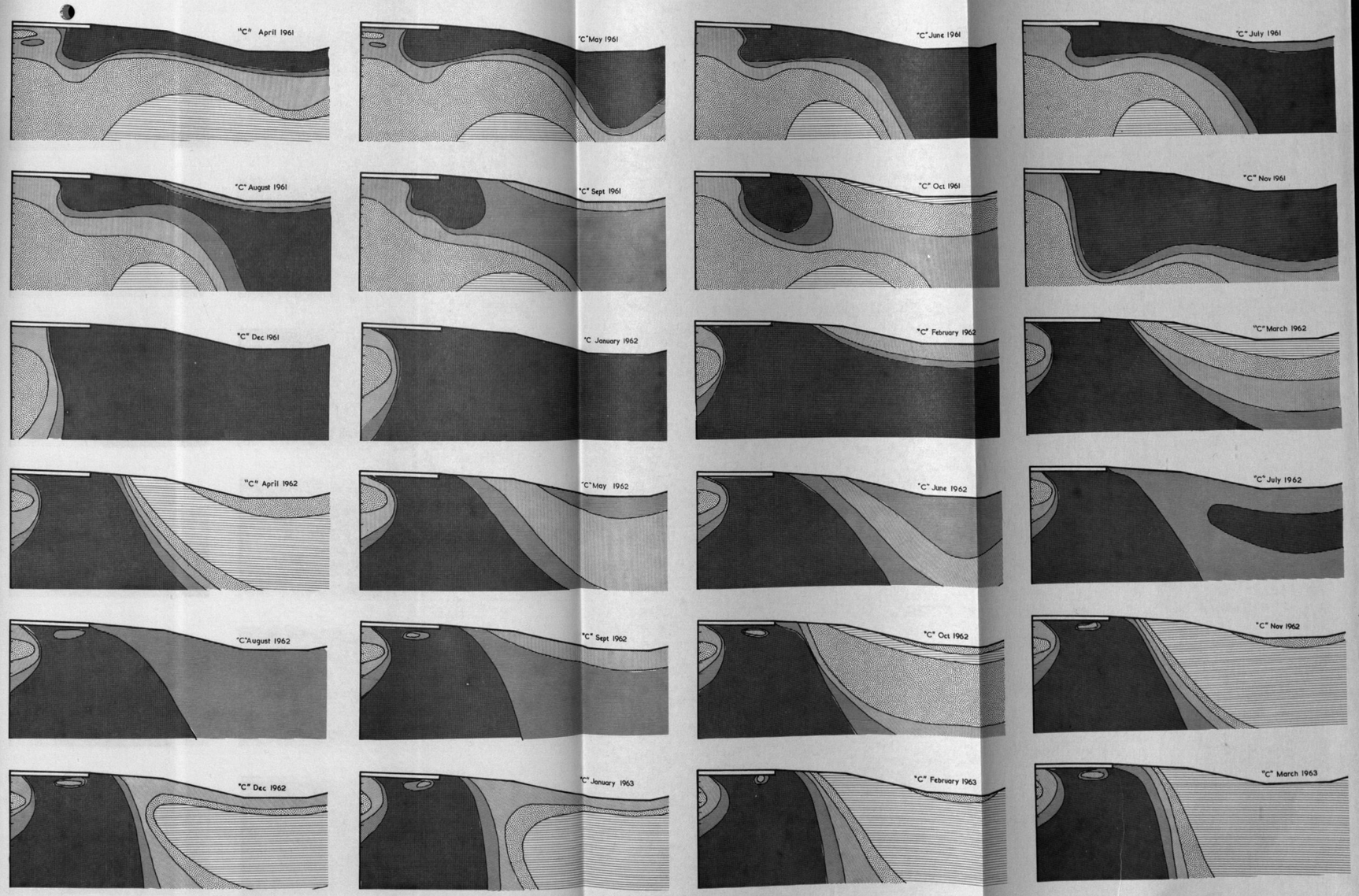

Fig. 6. (c) CHANGE IN MOISTURE CONDITION OF ROAD CROSS SECTION WITH TIME AT SITE 'C', MUGUGA KENYA. (VERGE COVER 2" LAYER OF STONES. VERGE SLOPE 1 in 35.)

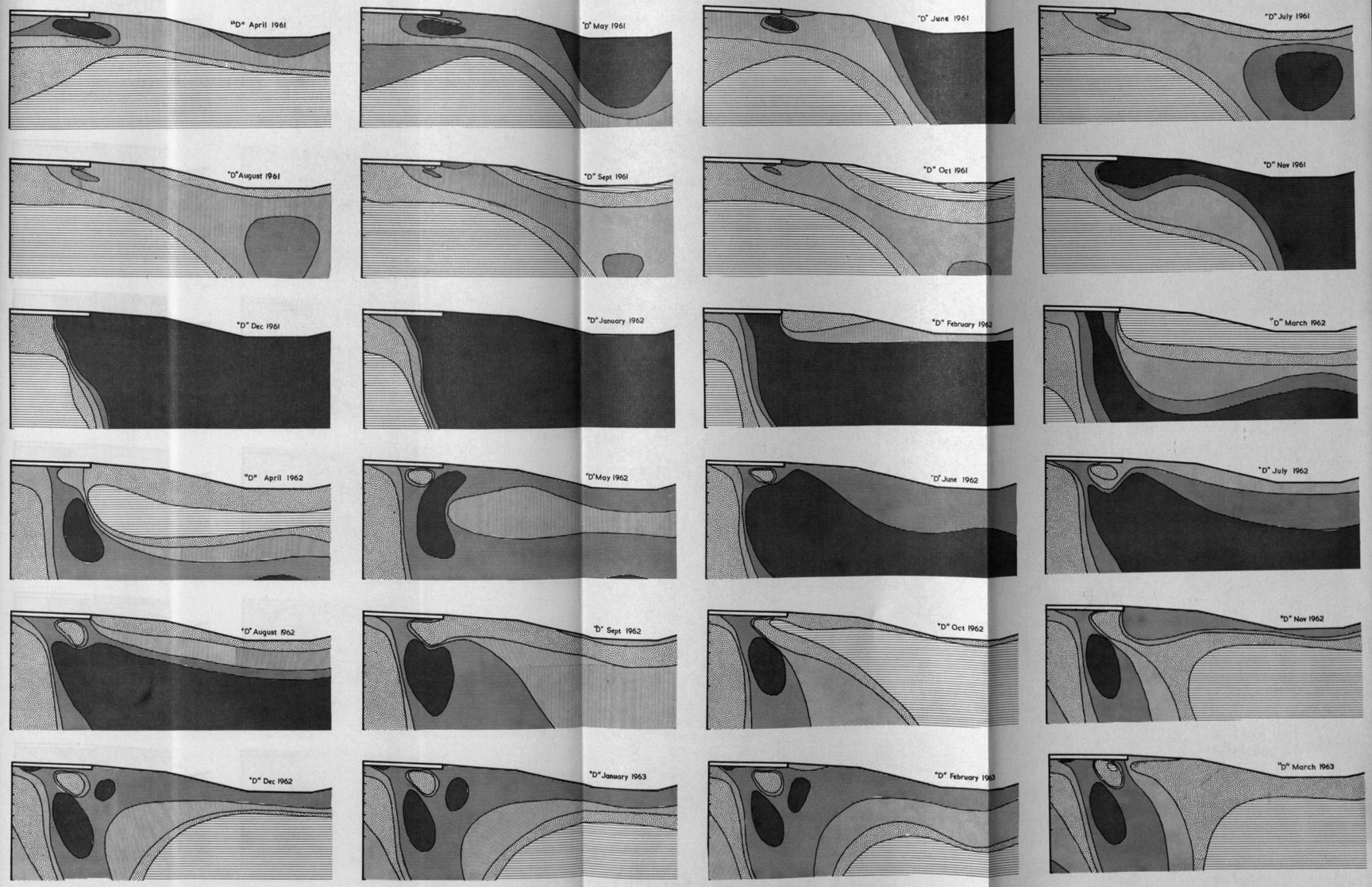

Fig. 6 (d) CHANGE IN MOISTURE CONDITION OF ROAD CROSS-SECTION WITH TIME AT SITE 'D' MUGUGA KENYA.
(VERGE COVER VISQUEEN MEMBRANE. VERGE SLOPE 1 in 14)

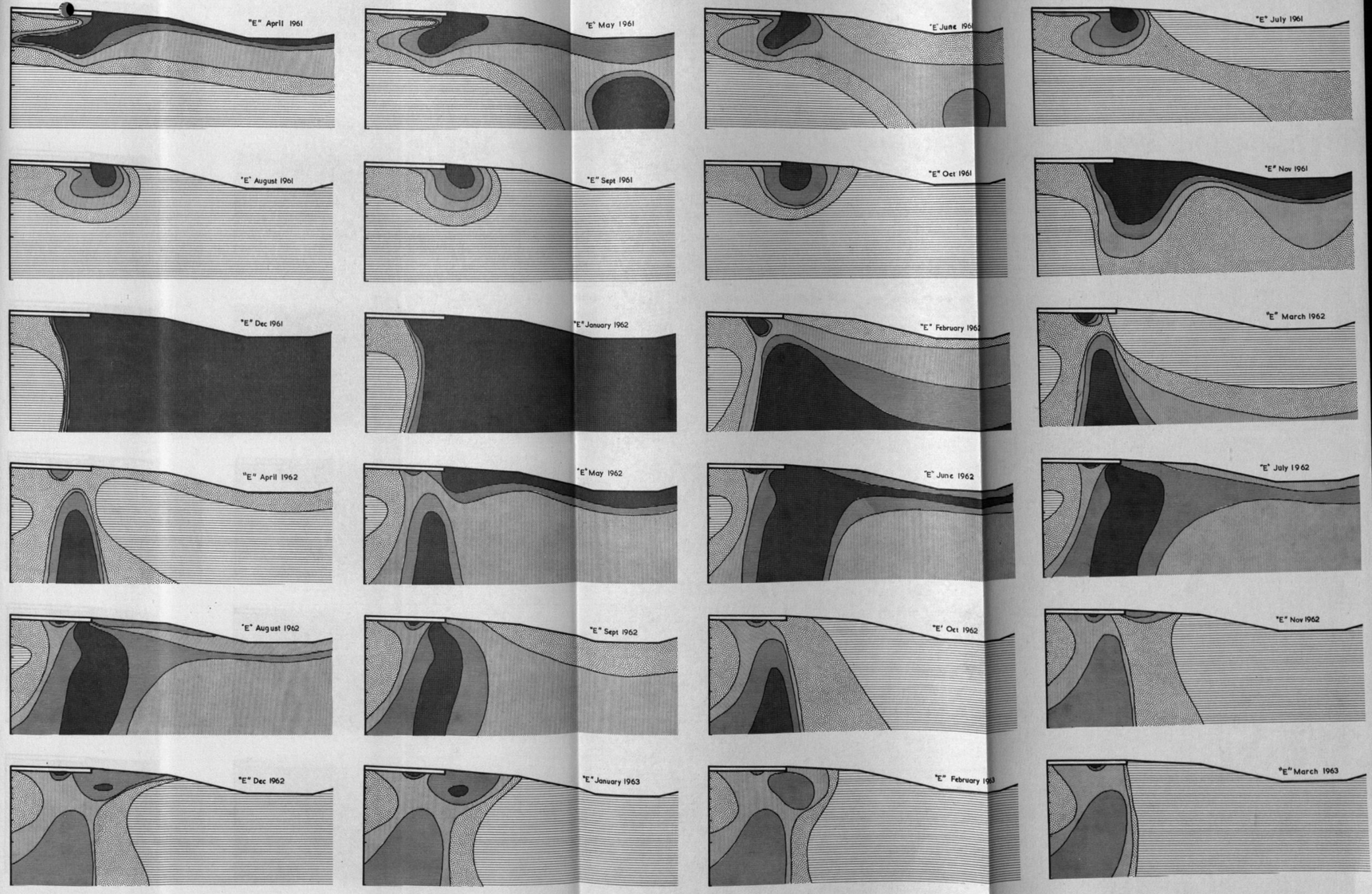

Fig. 6.(e) CHANGE IN MOISTURE CONDITION OF ROAD CROSS-SECTION WITH TIME AT SITE 'E' MUGUGA KENYA.
(VERGE COVER KIKUYU GRASS VERGE SLOPE 1 in 35)

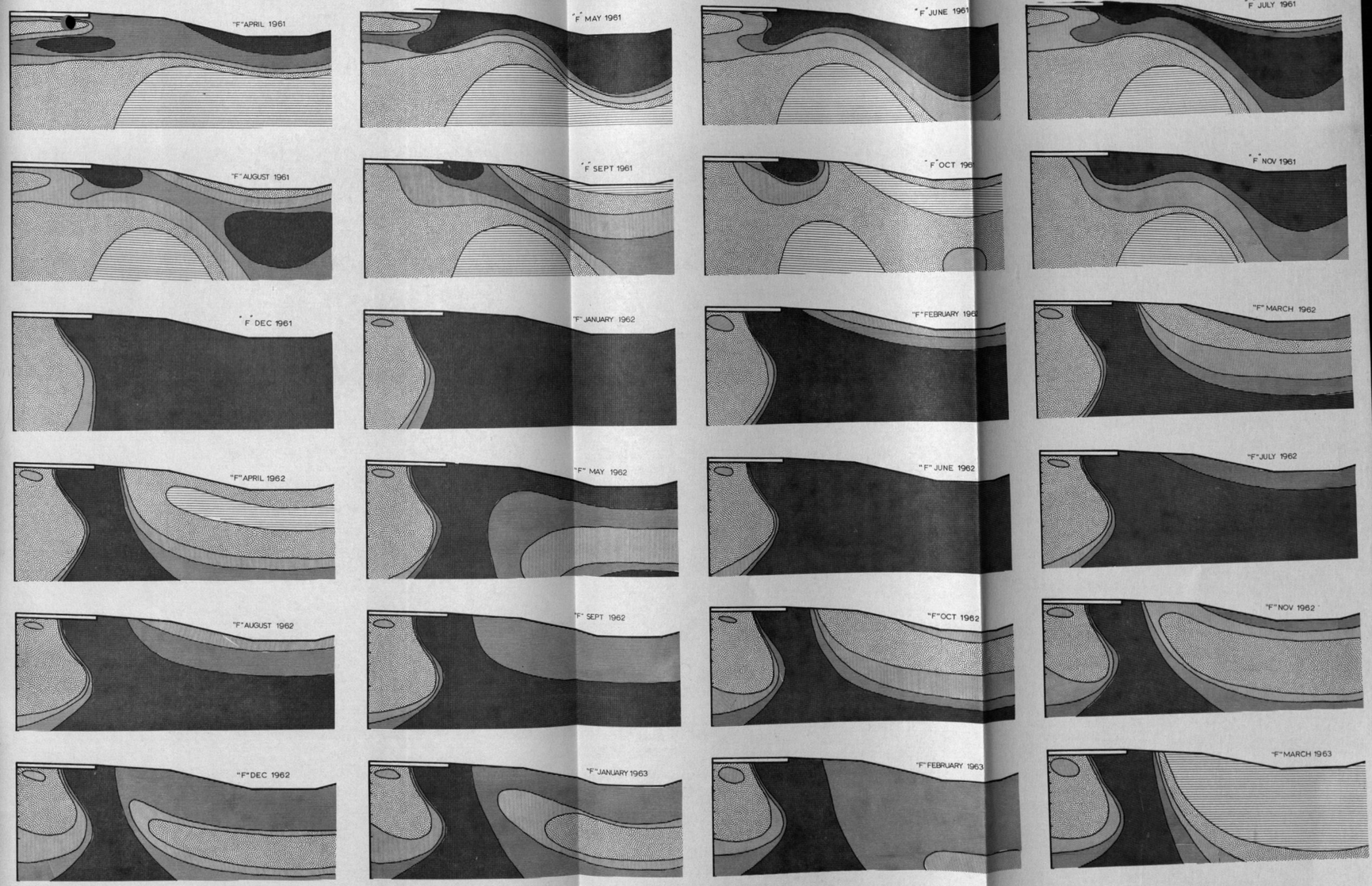

Fig. 6 (f) CHANGE IN MOISTURE CONDITION OF ROAD CROSS-SECTION WITH TIME AT SITE 'F,' MUGUGA KENYA.
(VERGE COVER 2" LAYER OF STONES. VERGE SLOPE 1 in 14)