VI-37

SOME RESULTS ON SPURIOUS SCATTERING IN PHOTOGRAPHIC EMULSIONS.

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1. **Experimental Procedure:** 5 pellicles of G_5 emulsions (600μ thick) , T.S. 2, 3, 4, 5 & 7 , one pellicle of L_4 emulsion exposed to 27 Gev/C protons and one pellicle of K_5 emulsion exposed to 24 Gev/C protons, were used in the present investigation . The level of spurious scattering was extremely low in L_4 pellicle , that in G_5 pellicles , medium, and in a part of K_5 pellicle it was extremely severe. Thus the use of pellicles of such varying quality gave us the advantage of studying the characteristics of spurious scattering through a wide range of values .

Using the co-ordinate method1), Multiple Scattering measurements were made with basic cell 2mm, on 10 m. of flat beam tracks (dip angle θ =0.3° in unprocessed emulsion) in G_5 pellicles , 2 m. in K_5 pellicle (θ = 0.3°) and 2 m. in L_4 pellicles (θ =0.1°). In addition in G_5 emulsions on 0.5 m. of beam tracks of dip 1.3°, Scattering measurements were made with basic cell length 500μ .

A Leitz ortholux nuclear track microscope was used, the stage noise for which was found to be constant at 0.1μ between 500μ and 1cm. Cell length. The total noise (Stage noise + grain noise + reading errors) was found to be 0.15μ.

The second difference for cells 4, 6, 8, 10 & 12 mm.

VI-38

were constructed in the usual way. In T.S. pellicles the tracks invariably stayed in the field of view (Magnification X2500) for traversals of the order of 6 cms , beyond which they were abandoned. For this reason, construction of cells beyond 12 mm was not considered meaningful. For, at large cells, the omission of large angle scatters can possibly lead to biases in $D_{2(o)}$ (Observed second difference). This consideration appears to be important , for example in the variation of $D_{2(s)}$ with cell length. The claim of some authors[2] that D_s falls off at large cell length, we believe, is due to such biases.

2.1. Results: Break down of data: Tables I(a), (b) & (c) show various parameters for date on flat tracks in L_4 & G_5 pelliclea in various order of differences (n) for basic cell length 2 mm. The expected value of coulomb scattering $D_{n(c)}$ from standard scattering constant[3,4] K = 28, are indicated for various orders of differences. The value of spurious scattering $D_{n(s)}$ was obtained from

$$D_n^2\,(o) = D_n^2\,(s) + D_n^2\,(c) + D_n^2\,(N) \quad .....(1),$$

where $D_n\,(N)$ is the total noise for the nth difference. Also, equality (1) is strictly true for Gaussian distribution. In what follows we shall see that the observed distribution is Gaussian for low level of spurious scattering but non-Gaussian for high levels. However, for large levels of spurious scattering since the coulomb signal and noise would be too small , the quadratic subtraction would not be invalidated. ϕ_n is the distortion parameter for the nth difference and is defined by

TABLE I (a)

PLATE L_4 2 mm Cell

n	D_o	D_c	D_s	ϕ_n	x	$\frac{\mu_2(n)}{x}$	D_n/D_{n-1} expt. for cou.	D_n/D_{n-1} expt. for noise.	D_n/D_{n-1} for S.S.	β_2	m	a
2	0.298 ± 0.008	0.163	0.224 ±0.010	0.173	6	0.027	—	—	—	5.40 ±0.13	3.90	0.85
3	0.442 ± 0.012	0.199	0.339 ± 0.015	0.038	20	0.020	1.223	1.828	1.510 ±0.025	4.60 ±0.12	4.62	1.19
4	0.782 ± 0.021	0.326	0.604 ± 0.026	0.038	70	0.016	1.635	1.863	1.782 ±0.030	4.80 ±0.13	4.13	2.04
5	1.459 ± 0.040	0.575	1.140 ±0.049	0.033	252	0.015	1.765	1.890	1.887 ±0.032	4.00 ±0.11	5.50	3.40
6	2.784 ± 0.078	1.055	2.130 ±0.097	0.020	924	0.015	1.830	1.918	1.863 ± 0.035	4.00 ± 0.13	5.50	6.96
7	5.839 ±0.167	1.974	4.820 ±0.191	0.020	3424	0.015	1.871	1.925	2.263 ± 0.040	4.30 ± 0.13	4.80	14.91
8	10.498 ± 0.305	3.765	8.330 ±0.364	0.021	12780	0.015	1.900	1.962	1.728 ± 0.031	3.80 ± 0.12	6.25	23.00

TABLE I (b)

PLATE No. T. S.7. **2 mm cell**

n	D_o	D_c	D_s	ϕ_n	$\frac{\mu_2(n)}{x}$	D_n/D_{n-1}	β_2	m	a
2.	0.605 ±0.018	0.182	0.557 ±0.017	0.1094	0.1135	—	9.92 ±0.35	2.93	1.40
3.	0.953 ±0.029	0.222	0.887 ±0.029	0.0298	0.0842	1.592 ±0.029	9.61 ±0.33	2.95	2.21
4.	1.718 ±0.052	0.364	1.600 ±0.053	0.0298	0.0800	1.800 ±0.034	6.44 ±0.22	3.40	4.61
5.	3.394 ±0.105	0.642	3.180 ±0.105	0.0257	0.0728	1.987 ±0.038	6.47 ±0.23	3.36	8.26
6.	6.130 ±0.193	1.175	5.720 ±0.190	0.0252	0.0723	1.799 ±0.035	5.49 ±0.22	3.70	17.20
7 7.	12.068 ±0.386	2.204	11.300 ±0.385	0.0250	0.0701	1.975 ±0.039	5.25 ±0.21	3,83	33.40
8.	22.493 ±0.734	4.200	22.300 ±0.688	0.0247	0.0692	1.973 ±0.039	5.95 ±0.25	3.52	59.80

TABLE I (c)

PLATES NO. TS 4 & 5 2 mm cell

n	D_c	D_s	$\frac{\mu_2(n)}{x}$	D_n/D_{n-1}	β_2	m	a
2.	0.960 ± 0.035	0.931 ± 0.034	0.3500	—	6.75 ± 0.33	3.46	2.84
3.	1.380 ± 0.050	1.335 ± 0.049	0.1900	1.440 ± 0.033	6.07 ± 0.31	3.55	3.97
4.	2.300 ± 0.086	2.213 ± 0.084	0.1800	1.658 ± 0.038	5.90 ± 0.31	3.90	7.13
5.	4.180 ± 0.159	4.020 ± 0.155	0.1400	1.816 ± 0.043	6.00 ± 0.33	3.70	12.45
6.	7.650 ± 0.304	7.320 ± 0.293	0.1300	1.821 ± 0.043	6.30 ± 0.36	3.90	23.80
7.	14.72 ± 0.594	14.11 ± 0.572	0.1200	1.927 ± 0.047	6.08 ± 0.36	3.72	42.10

$\phi_n = \dfrac{\bar{D}_n\ (\text{alg})}{\bar{D}_n}$, where $\bar{D}_n$ (alg.) is the modulus of the algebraic mean for the individual tracks , and $\bar{D}_n$ is the arithmetic (observed) mean for the n^{th} difference.

The contours of a track can be represented by three components: (a) Distortion component which corresponds to the curvature of the track and can be represented by a polynomial , (b) Random or irregular component and (c) Oscillatory component which indicates the oscillating nature of the track.

The effect of randomization is represented by $\mu_2^{(n)}/x$ where $\mu_2^{(n)}$ is the second moment about zero for the n^{th} difference and x is an appropriate number for a particular difference n, as given in the theory of randomization$^{5)}$ and is indicated in the 6th column of table I (a). Clearly $\mu_2^{(n)}/x$ tends to become a constant from the fourth difference onwards; indicating the elimination of distortion component of spurious scattering . This result is corroborated by the value of distortion parameter , ϕ_n . It is apparent that ϕ_n tends to approach zero from the fourth difference onwards. However, the procedure of taking differences of higher order cannot eliminate the oscillatory component .

The correlation ratios between successive differences for spurious scattering is indicated by $D_{n(s)}/D_{n-1(s)}$. For comparison we have included in table I(a), $D_{n(c)}/D_{n-1(c)}$ and $D_{n(N)}/D_{n-1(N)}$ expected ratios for coulomb scattering and noise respectively . The form of distribution for difference of given order can be found out by the estimation of Kurtosis which is defined by $\beta_2 = \frac{\mu_4}{\mu_2^2}$ where μ_4 is the fourth moment

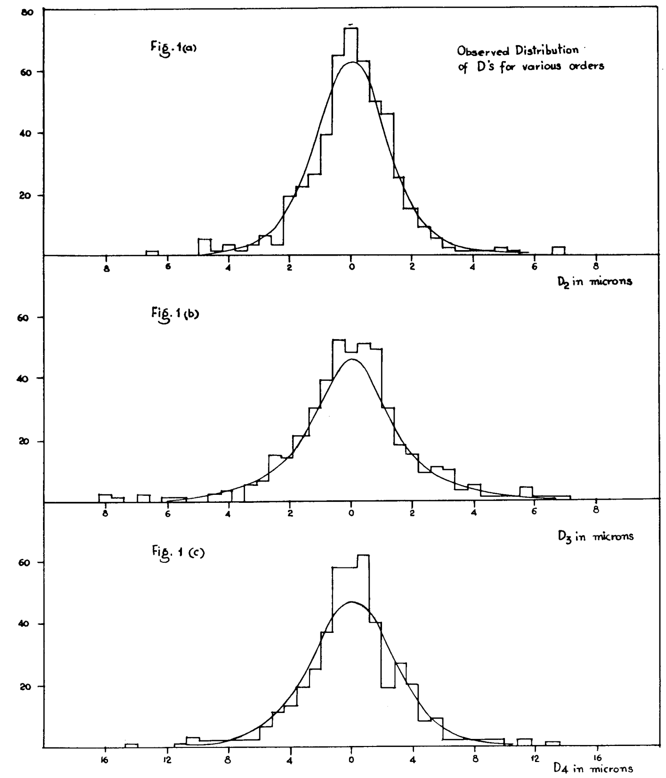
Fig. 1(a)

Observed Distribution of D's for various orders

Fig. 1(b)

Fig. 1 (c)

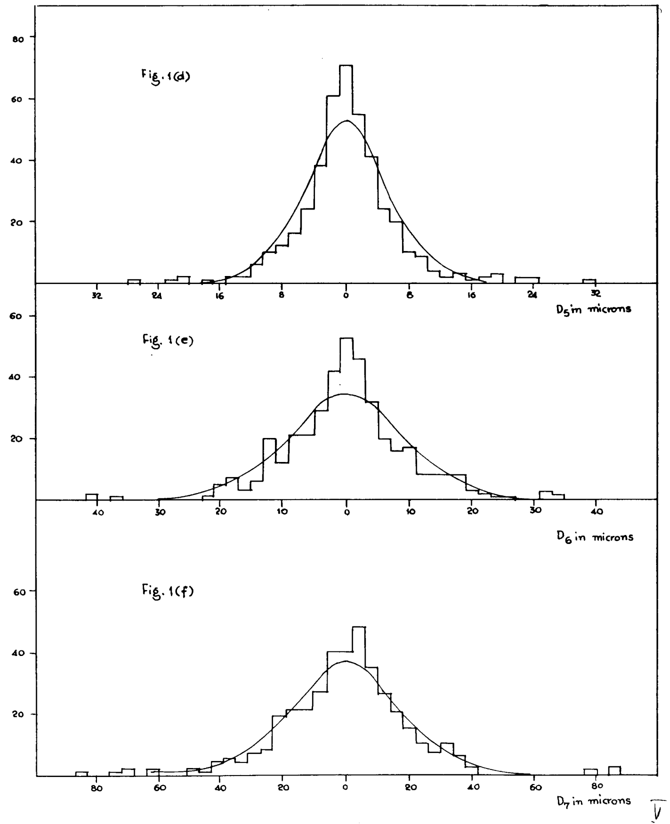
Fig. 1(d)

Fig. 1(e)

Fig. 1(f)

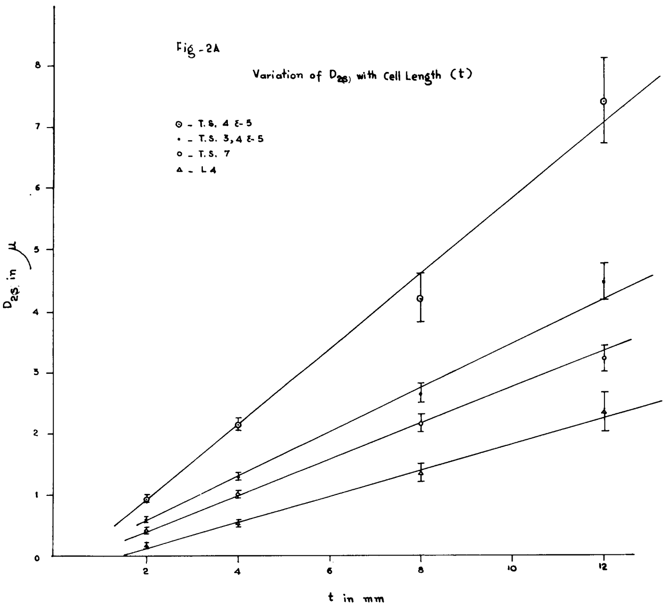
Fig-2A

Variation of D_{2S} with Cell Length (t)

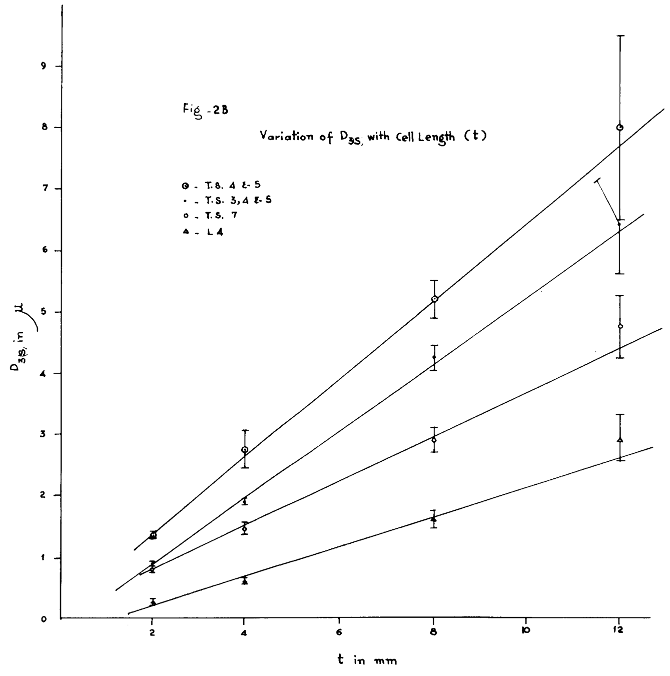
Fig-2B

Variation of D_{3S} with Cell Length (t) about zero. For Gaussian distribution (Meso-Kurtic) the expected value for β_2 is 3. If β_2 is less than 3, the curve is platy-Kurtic and if it is more , then it is lepto-Kurtic. In L_4 and K_5 pellicles which have got small level of spurious scattering , β_2 is little over 3 - a value compatible with the Gaussian distribution. In G_5 pellicles β_2 is much larger than 3. Thus in G_5 pellicles where the level of spurious scattering is high , the distribution of second and higher differences is non- Gaussian. In fig. 1(a) -(f) are shown the typical distributions of differences in various orders for one sample in plate Nos.TS 4 & 5 (G_5 pellicles) for which spurious scattering is moderately high. Clearly , the tail of the distribution extends much in excess of Gaussian distribution. The tail actually contributes a great deal to the value of β_2 . The arbitrary removal of very large values of the differences , tends to lower the β_2 value, but even then it does not lead to a value of 3 appropriate for Gaussian distribution . The distribution can be approximated by a function of the type $\frac{1}{a}\left(1+\frac{D_n^2}{a^2}\right)^{-m}$ where 'm' & 'a' are constants for a given sample . 'm' is related to the Kurtosis and 'a' to the variance . The values of 'm' & 'a' are separately indicated for differences of various order in table I (a), (b) & (c) . Typical curves corresponding to this frequency distribution are shown in Fig. 1(a)-(f). Biswas et al⁽⁶⁾ had obtained non-Gaussian distribution in their pellicles while Lohrmann & Teucher⁽⁷⁾ obtained nearly Gaussian distribution for the second differences of their observed distribution. From our investigation we conclude that for low level of spurious scattering the observed distribution of differences in various orders is nearly Gaussian ; while for high levels it is non-Gaussian.

This may be explained by asserting that the distribution for spurious scattering alone is non-Gaussian. In badly distorted pellicles the observed distribution would be non-Gaussian . But when the level of spurious scattering is low , the observed distribution which is largely due to coulomb and noise , and is therefore expected to be Gaussian , would be practically unmodified.

2.2. D_2 (s) in various pellicles:

Spurious scattering is thus present in all pellicles investigated , but the level could be different from pellicle to pellicle . In L_4 pellicle it is low ($D_s \backsim 0.2\mu$). In G_5 pellicles (TS 2, 3, 4 & 7) it is moderately large ($\bar{D}_s = 0.4\mu \div 0.8\mu$ at 2 mm cell). In the K_5 pellicle $\bar{D}_s$ is small for the most part , but in the central region it is abnormally high(Mean value 2μ and Max: value 5μ). This suggests that in this pellicle it is unlikely that spurious scattering would have come about due to processing regime. Since measurements in most of the pellicles suggest that $\bar{D}_s$ is constant in a pellicle within a factor of 2. In the K_5 pellicle spurious scattering might therefore exist due to reasons other than that of processing . It may very well arise from gelatin giving way due to defects in pouring.

2.3. D_2 (s) & D_3 (s) Variation with cell length:

In Fig. 2(a) and (b) are shown the variation of D_2(s) and D_3(s) with cell lengths between 2mm and 12mm . To a good approximation both D_2(s) & D_3(s) may be represented by a straight line. The straight line fit was previously pointed out by Yashpal & Ray 8). The slopes appear to be different in various pellicles.

2.4. Variation of D_2 (s) with depth:

Biswas et al 9) had shown that in one stack there was significant variation of $\bar{D}_2$(s) with respect to the depth, being more near the surface and less near the glass, while another stack had similar variation but to a smaller extent. Table II shows that in L_4 pellicle $\bar{D}_2$(s) is practically constant; while in G_5 pellicles it appears to increase from glass to surface . In Ortholux microscope, it is found that grain noise varies with grain density because of the limited length of filar. This factor has been taken into account . It is possible that mechanical stresses such as those which are caused in mounting the pellicle on the glass by a light roller, can distort the emulsion more on the surface.

2.5. Variation of $\bar{D}_2$ (s) with dip:

Neighbouring beam tracks of different dip angles were compared. Fig 3 shows the variation of $\bar{D}_s$ with cell length for two sets of dip angles in G_5 pellicles. In general the level of spurious scattering rises with the dip of the track. This result is in agreement with that of Biswas et al 6) and Jones & Kalbach 10).

2.6. Variation of D_s in z - direction:

Aditya at al 11) have found that the z-component of $\bar{D}_s$ is larger than the corresponding y-component (which is usually measured) by a factor of 4. Similar observations

TABLE II.

PLATE		Depth from glass in processed emulsion		
		0 - 100 μ	100 - 200 μ	200 μ - 250 μ
L_4	$\overline{D}_{2(s)}$	0·235 ~~0.[illegible]35~~ ± 0.022	0.254 ±0.016	0.266 ±0.038
G_5	$\overline{D}_{2(s)}$	0.425 ± 0.020	0.518 ±0.025	0.541 ±0.061

TABLE III.

Plate TS 4.

Separation in projected plane.	* 0 μ	500 μ	1000 μ	1500 μ	2000 μ	2500 μ	3000 μ
$\overline{D}_2r$ (ob) in microns	0.20	0.21	0.30	0.22	0.22	0.35	0.50

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yielded the following results. In the bad region of K_5 pellicles the ratio $\bar{D}_2(z) / \bar{D}_2(y)$ is 0.5. In L_4 pellicle it is about unity. In G_5 pellicles, however, it is about 1.8, for 4 mm cell length. The focussing errors in the dip screw measurements are about 0.7 μ, but do not interfere with the measurements since the observed signal at 4 mm cell is much above this value. It is thus clear that the ratio between the two components can be different in different pellicles. In the G_5 pellicles, which is a part of the stack used by Aditya at al[11), presumably mechanical stresses during exposure, have resulted in increasing this ratio. We therefore conclude that the larger component of spurious scattering in vertical direction than in the horizontal one, is not of a general nature.

2.7. Correlation between pairs of tracks:

Scattering measurements were made on neighbouring beam tracks, starting always from the same point on the grid. The separation between various tracks in y-direction and the average depth of each track was recorded. Table III shows that correlations exist upto 2 mm. for tracks which lie within 50 μ in depth. Beyond this there are practically no correlations. In Fig. 4 are shown the contours of tracks which were picked up in the same field of view (within 50 μ) but at different depths. Clearly, the correlations are lost even when tracks are separated by 100 μ in depth. Similar results were obtained by Biswas et al[9) . Morover from the contours one notices strong changes in the directions of dislocations themselves from layer to layer in the same pellicle.

2.8. $\rho_{3,2}(s)$ for dipping tracks:

Our results show that $\rho_{3,2}(s)$, the correlation ratio for spurious scattering between second and third difference for dipping tracks, in general, is small (1 ÷ 1.2) compared to flat tracks for which it is typically between (1.4 ÷ 1.6) for the same cell length. This then means that the curvature component in the dipping tracks is more important than in flat tracks.

3. Discussion and Conclusions:

If spurious scattering was merely a random phenomenon arising from independent microscopic dislocations then clearly it should be dip independent. The dip dependence together with the loss in correlation between tracks in depth does suggest that spurious scattering is mainly a layer phenomenon. Morover, the low observed value of $\rho_{3,2}(s)$ for dipping tracks indicates the marked presence of the curvature component in spurious scattering . Also the study of contours (Sec: 2.6) of tracks at various depths shows that the grain movement can change their direction fairly rapidly throughout the depth. Thus for steep tracks the tendency would be to bend around in one direction. If the tracks are sufficiently steep then the contours may appear c-shaped , specially when observed over small distances; and s-shaped if the tracks have penetrated large depths of emulsions over which the gradients might change in the opposite direction. On the other hand the less steep tracks would not traverse too many layers of the same pellicle . Furthermore, for very long tracks , the correlations between regions along x-direction (which are expected to be similar in y-direction) will be lost; so that there will be certain amount of randomness associated in regions widely separated which would tend to mask out the curvature effect , and the track would invariably appear wavy. It appears that in studying the properties of spurious scattering the effects arising from the processing regime must be separated from those which result from mechanical stresses , like rolling and stacking.

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VI-52

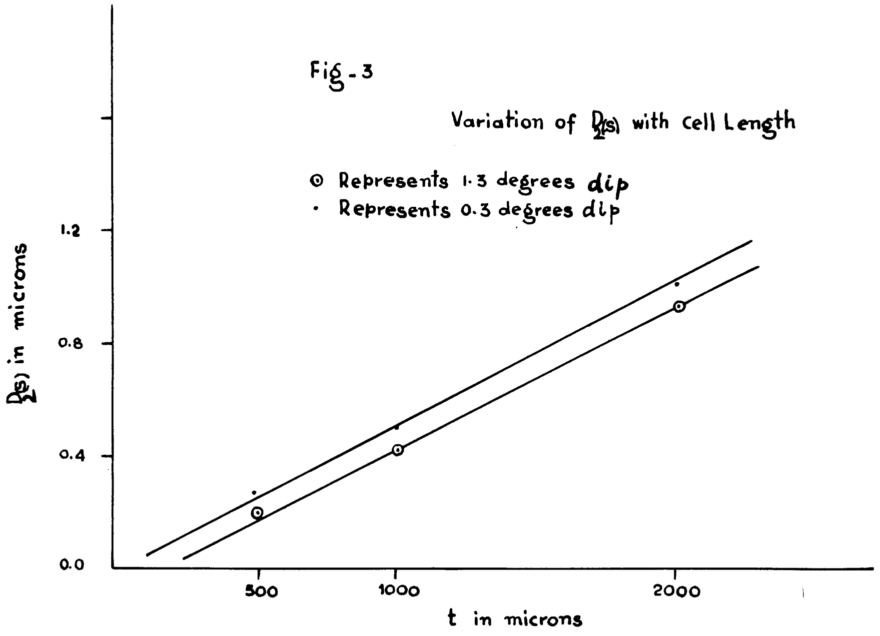
Fig-3
Variation of D2(s) with cell Length
⊙ Represents 1·3 degrees dip
· Represents 0·3 degrees dip
D2(s) in microns
1.2
0.8
0.4
0.0
500
1000
2000
t in microns

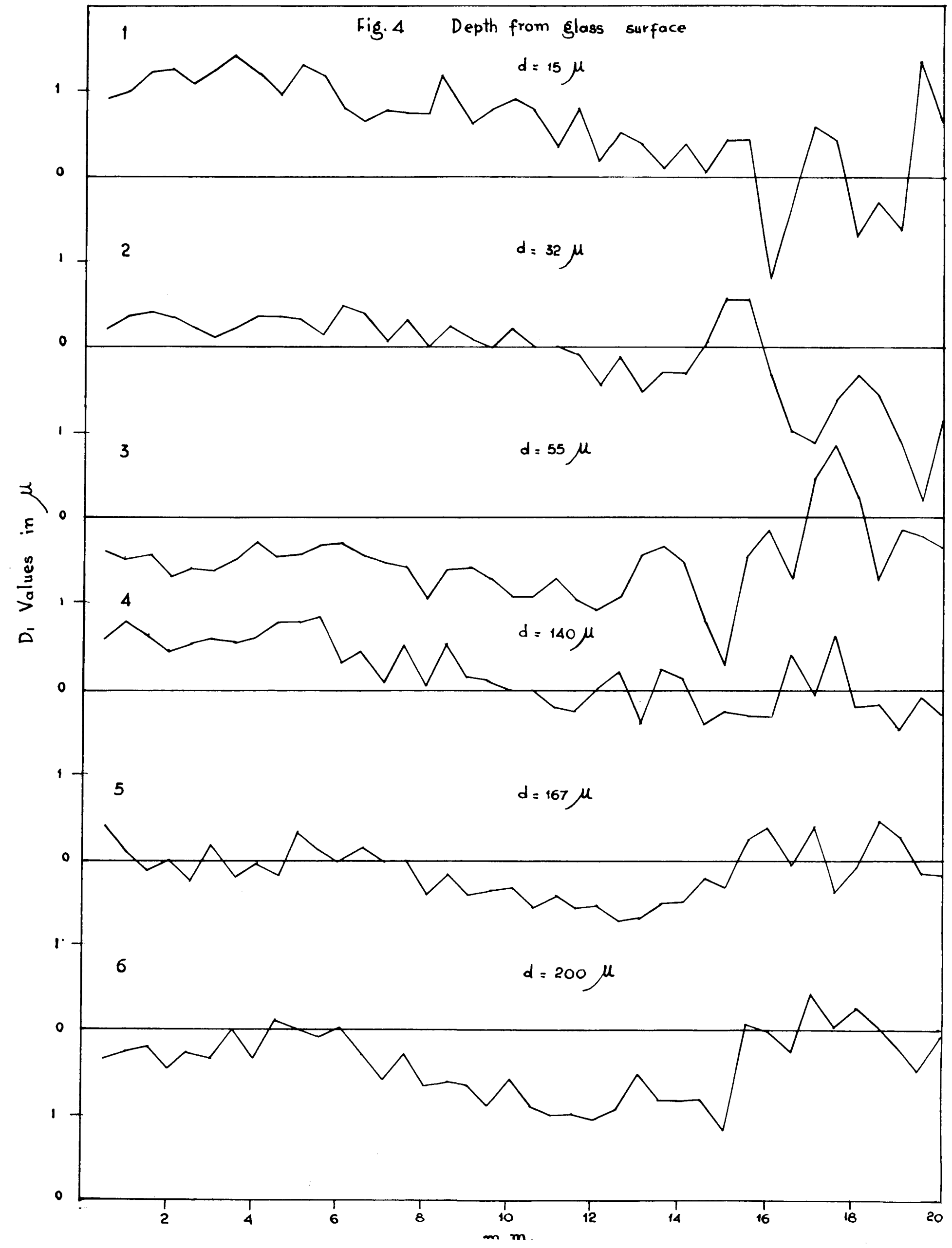
Fig. 4 Depth from glass surface
1
d = 15 μ
2
d = 32 μ
3
d = 55 μ
4
d = 140 μ
5
d = 167 μ
6
d = 200 μ
D1 Values in μ
1
0
2
4
6
8
10
12
14
16
18
20
m m.