BRITISH GEOLOGICAL SURVEY

Overseas Directorate

BASEMENT AQUIFER PROJECT:

REPORT ON STRUCTURAL STUDIES 1987/88

Dr D Greenbaum

Technical Report WC/88/17

British Geological Survey
Keyworth
Nottingham NG12 5GG
UK

31 March 1988

1. INTRODUCTION

This report summarises additional remote sensing and structural studies carried out in the Masvingo region, Zimbabwe during the period April 1987 to March 1988. This has involved further fieldwork to identify sites for ground geophysical surveys and subsequent drilling; an assessment of the relationship between borehole yields and lineaments; and contributions to the groundwater workshop held in Harare.

2. FIELDWORK

Approximately 3 weeks were spent in Zimbabwe selecting sites for drilling and outlining a programme of investigation for the geophysical team in conjunction with Drs E P Wright and M McFarlane. This is reported on more fully in the main project report for 1987/88 by E P Wright which also includes the results of drilling.

3. HARARE WORKSHOP

A workshop sponsored by the Commonwealth Science Council entitled 'Groundwater exploration and development in regions underlain by crystalline basement' was held in Harare from 15 to 24 June 1987. Keynote lectures and case studies were given in two sessions, relating to Remote Sensing and Structure. Three papers were subsequently prepared for inclusion in the Workshop Proceedings. These were:

(1) Remote sensing studies in southeast Zimbabwe.

(2) Structural concepts in basement hydrogeology.

(3) Hydrogeological applications of remote sensing in areas of crystalline basement.

Review and editing of written contributions to these sessions by participants from other countries was additionally carried out and summaries prepared for the discussion sections of the Proceedings.

4. BOREHOLE CORRELATION STUDIES

4.1 INTRODUCTION

A basic assumption in groundwater exploration over crystalline basement terrains is that fractures are responsible for the porosity and permeability of the unweathered bedrock. Whereas the overlying regolith can provide groundwater storage, its permeability is generally low: consequently, the more productive boreholes are to be expected where a basement fracture is present and can be penetrated. Correlation studies were therefore carried out to assess whether the data from existing boreholes supported this theory. This assessment will eventually include all fourteen detailed study areas: as a starting point data was evaluated from the 5 sub-areas for which further drilling was to be carried out, i.e. areas C, E, F, G and J.

An earlier attempt by M Lewis to study the relationships between lineaments and borehole parameters for Area G proved inconclusive and it was thought at that time that this might be due in part to the incomplete nature of the lineament dataset. This had been produced primarily to define the major fracture patterns and did not include many of the more subtle or ill-defined lineaments. In this regard, fieldwork in the Masvingo region had demonstrated that local and specific community needs impose constraints on the siting of boreholes so that only rarely is it possible to site a borehole precisely on a strong lineament: in most cases a site near to a weaker lineament is the best that can be achieved. It was therefore necessary to carefully re-interpret the lineament pattern in the vicinity of each borehole much in the manner that the hydrogeologist responsible for determining the best site in the vicinity of a community would have had to do.

A limiting factor affecting such correlation studies is the poor locational accuracy of the borehole data. This is particularly significant since distances of a few metres, or tens of metres, are likely to affect the groundwater contribution of a fracture. With the exception of the most recent drought relief data, inaccuracies significant at the scale of the study, and some major errors, in grid references are known to occur.

The following information was determined at each borehole site:

- normal distance to lineament
- position relative to lineament (central, terminal or on an extension)
- lineament azimuth
- lineament length
- lineament type (fracture or dyke)
- inferred siting criteria

Information on up to 2 lineaments was noted for each site. Only lineaments falling within a normal distance of approximately 150 metres of a borehole were considered. If none occurred within this distance the borehole was assumed to have been sited on other criteria. It could be argued that a greater limit - perhaps even 500 m - should have been used bearing in mind the locational uncertainties, but this would increase the chance of relating some boreholes to a lineament when in fact they were sited on other grounds.

4.2 YIELD vs NORMAL DISTANCE

Stacked histograms were prepared for each of the 5 areas studied and for the total dataset. These record the frequency of boreholes, subdivided into 4 yield classes, falling within 5 categories of distance from a lineament. Fracture-related and dyke-related lineaments were not separated and where a borehole was spatially related to two lineaments both were counted separately. The results for individual areas are not discussed since the small size of the sample makes conclusions unreliable. The following remarks are based on the total data plot (Figure 1).

Despite locational uncertainties, it is apparent that the great majority of boreholes are sited near to lineaments. On the basis of data from the five areas studied, some 39 per cent of all boreholes are located within 25 m of a lineament and 75 percent within 75 m: only 15 per cent of boreholes would seem to have been sited entirely on other criteria.

A measure of borehole success rate (calculated as the number of boreholes with yields greater than a theshold of either 0.1 $l.sec^{-1}$ or 0.25 $l.sec^{-1}$ relative to total number of boreholes) in each distance category is also shown on Figure 1. The reliability of the results in the 50-75 and 76-100m classes is uncertain due to the small number of data values. However, when the success rate for all boreholes falling within 100m of a lineament is compared with that for boreholes at greater than 100m, the results are 66% and 70% respectively at the 0.1 $l.sec^{-1}$ cut off and 50% and 53% at the 0.26 $l.sec^{-1}$ cut off. On this basis it would appear that borehole success is very slightly better away from lineaments than close to them. Whether this is a valid result, or whether it is affected by locational uncertainties and the statistically small size of the sample for boreholes at greater than 100m is uncertain. This may be resolved when the remaining study areas are included in the analysis. The conclusion at this stage is that although the majority of boreholes are sited on the basis of lineaments, where other controls are utilised a similar level of uncertainty exists resulting in an overall comparable success rate.

4.3 YIELD vs LINEAMENT AZIMUTH

Stacked histograms for each area are given in Figures 2A to 2E and for the total data in Figures 2F and 2G. These show the frequency of boreholes in 4 yield classes occurring within each 10° azimuth sector between 270° and 90°. Separate plots are given for fractures and dykes. Because yield/azimuth correlations will be influenced by the frequency distribution of lineament directions, the dominant directions in each area, determined from the rose diagrams computed previously (Greenbaum 1987), are also shown.

Comments on the individual areas are as follows.

Area C: Correlation exists between the most abundant lineament direction (330°-340°) and some of the more successful boreholes related to fractures. However, successful boreholes occur also along a variety of other trends, e.g. sectors 310°-330° and 30°-50°.

Area E: The most successful fracture-related directions appear to be 280°-300° and do not correlate with the main fracture trends in the area. There is some suggestion of correlation between the 70°-80° direction and the frequency of dyke-related boreholes, although there is insufficient data to comment on successful directions.

<u>AreaF</u>: Both the fracture- and dyke-related datasets show some correlation with the dominant lineament directions.

<u>Area G</u>: Successful boreholes occur along various lineament trends: these only vaguely relate to the most prominent directions for the area.

<u>Area J</u>: A moderate correlation is apparent between both frequency and success of boreholes with dominant trends in this area. However, successful boreholes along other lineament directions are also apparent.

The small numbers of sites in individual areas brings into question the statistical validity of the separate datasets. A more reliable analysis might be expected from the combined data (Figs 2F & 2G). Figure 2F (fracture-related data) shows only a partial correlation between the frequency of boreholes and the main fracture directions. Success rate has again been calculated on the basis of greater than 0.1 $l.sec^{-1}$ and 0.25 $l.sec^{-1}$ yields and is also indicated on this plot. At the scale of individual 10° azimuth classes there is again the problem of sample size. Nevertheless, of possible significance are the 280°-290°, 30°-40° and 50°-60° azimuth directions which show a good success rate and do not correspond to major lineament trends, suggesting that they might be genuine indications of more productive lineament directions.

The corresponding plot for dykes (Fig 2G) contains fewer data and is more difficult to interpret. Successful boreholes are associated with several dyke trends: except for the 70°-80° sector, frequency of boreholes does not appear to correlate with the major directions, so that again results are apparently not biased by this effect.

4.4 YIELD vs LINEAMENT LENGTH

Fracture-related lineaments were sub-divided into three categories on the basis of length: less than 500m; 501-1000m and greater than 1000m. Dyke-related lineaments were excluded and data for the 5 areas were considered together (Fig 3).

Thirty-nine per cent of the boreholes studied are associated with lineaments less than 500 m, 32% with lineaments 501-1000 m and 29% with lineaments longer than 1000 m. This may merely indicate that the most common photolineaments are relatively short.

An indication of success rate in the three length categories is also given in Figure 3. At the 0.1 $l.sec^{-1}$ cut off, success rate is highest for boreholes associated with the shorter lineaments, ranging from 72% successful in the less than 500m class to 56% in the greater than 1000m class. However, at the

0.25 l.sec-1 theshold, this tendency is not maintained and success rate is more or less constant at 48 to 53 per cent.

4.5 CONCLUSIONS

The 5 areas studied contain a total of 163 boreholes for which pump test data is available. This is a statistically small sample and may affect the validity of results, particularly when data from individual areas or within individual sub-classes are considered.

It is evident that a majority (85%) of all boreholes in these areas were sited at least partly on the basis of a fracture- or dyke-related photolineament. However, it is known from field studies that various factors influence the precise selection of a site and affect its success or failure, so that a high level of correlation with lineament data alone is perhaps not to be expected.

The results of the correlation studies to date permit few definite conclusions. Whereas most boreholes are located 'near' to a lineament, those apparently unrelated to lineaments show a comparable or even slightly better success rate. However, the locational accuracy of most boreholes is probably insufficient to obtain a reliable assessment of the detailed relationship between yield and proximity to a fracture. In fact it is not improbable that it is a 'hit or miss' situation: either a borehole intersects a fracture (which is likely to be a narrow feature no more than a few metres across) or it does not. Thus, even at a distance of 20 m from a lineament a borehole may have missed its target. Despite the inconclusive results so far there is no reason to believe that the role of fractures is unimportant.

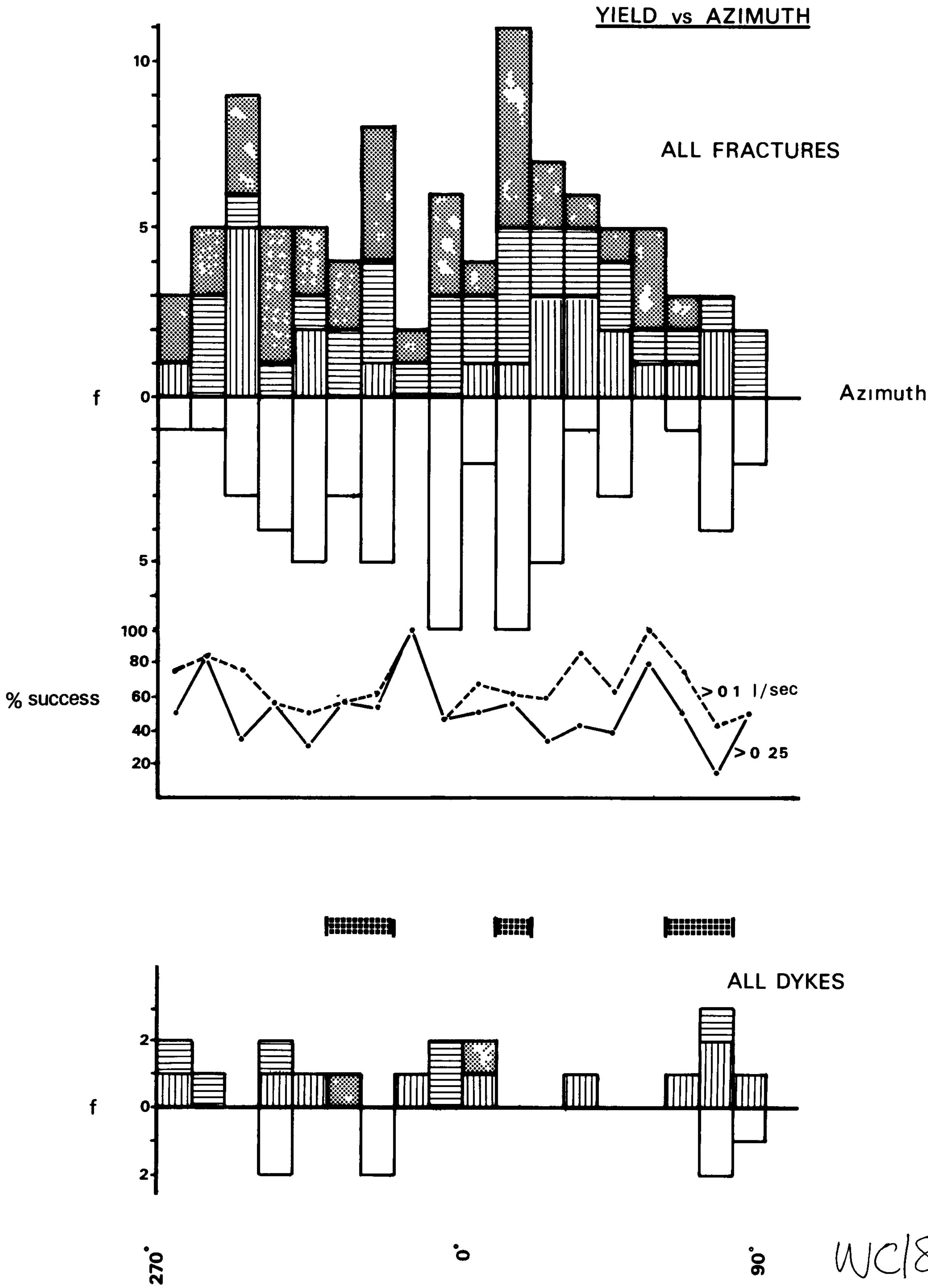
It is evident that successful boreholes may be drilled along a variety of fracture and dyke trends though there is some suggestion that particular trends produce a better success rate than others. It was previously suggested (Greenbaum 1986) that fractures of all origins (compressive and tensional) may open up and provide permeability in the near-surface zone due to erosional unloading. The present results might support that hypothesis.

Finally, there seems little evidence to suggest that length of fracture influences success rate or yield.

5. REFERENCES

GREENBAUM, D. 1986. Tectonic investigation of Masvingo Province: preliminary report. British Geological Survey Rpt, MP86/2/R, 35 pp.

GREENBAUM, D. 1987. Lineament studies in Masvingo Province, Zimbabwe. British Geological Survey Rpt MP/87/7/R, 29pp.



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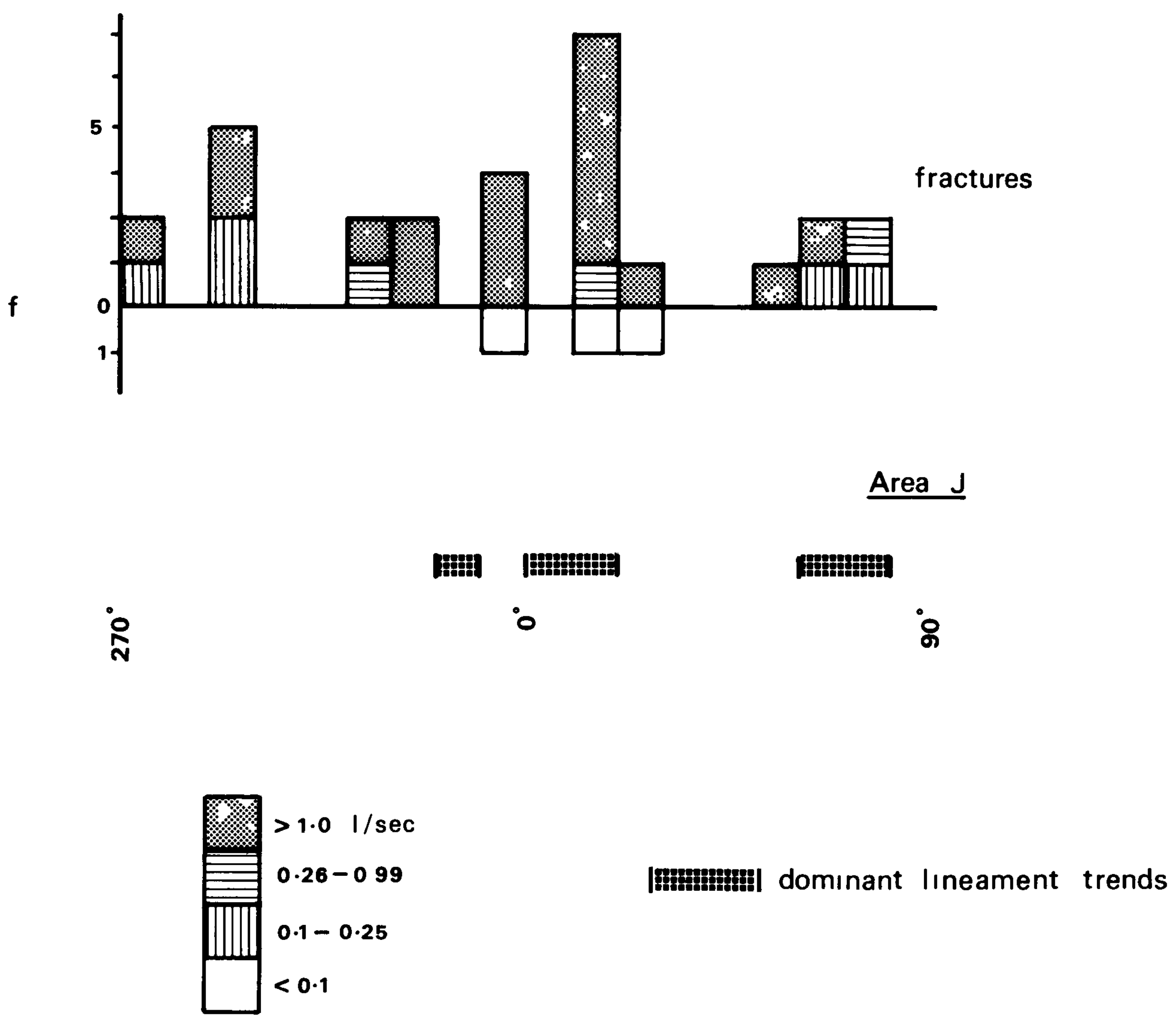
Figures 2F & 2G: Frequency histograms for combined data from areas C, E, F, G & J showing the relationship between yield and azimuth of fractures and dykes, as well as dominant lineament directions. The success rate for each 10° class is also shown. (For legend see caption to Figures 2A to E).

YIELD vs AZIMUTH



Figures 2A to 2E: Frequency histograms for areas C, E, F, G and J showing the relationship between yield and azimuth of fractures and dykes (in 10° classes). The dominant lineament trends in each area are also indicated.

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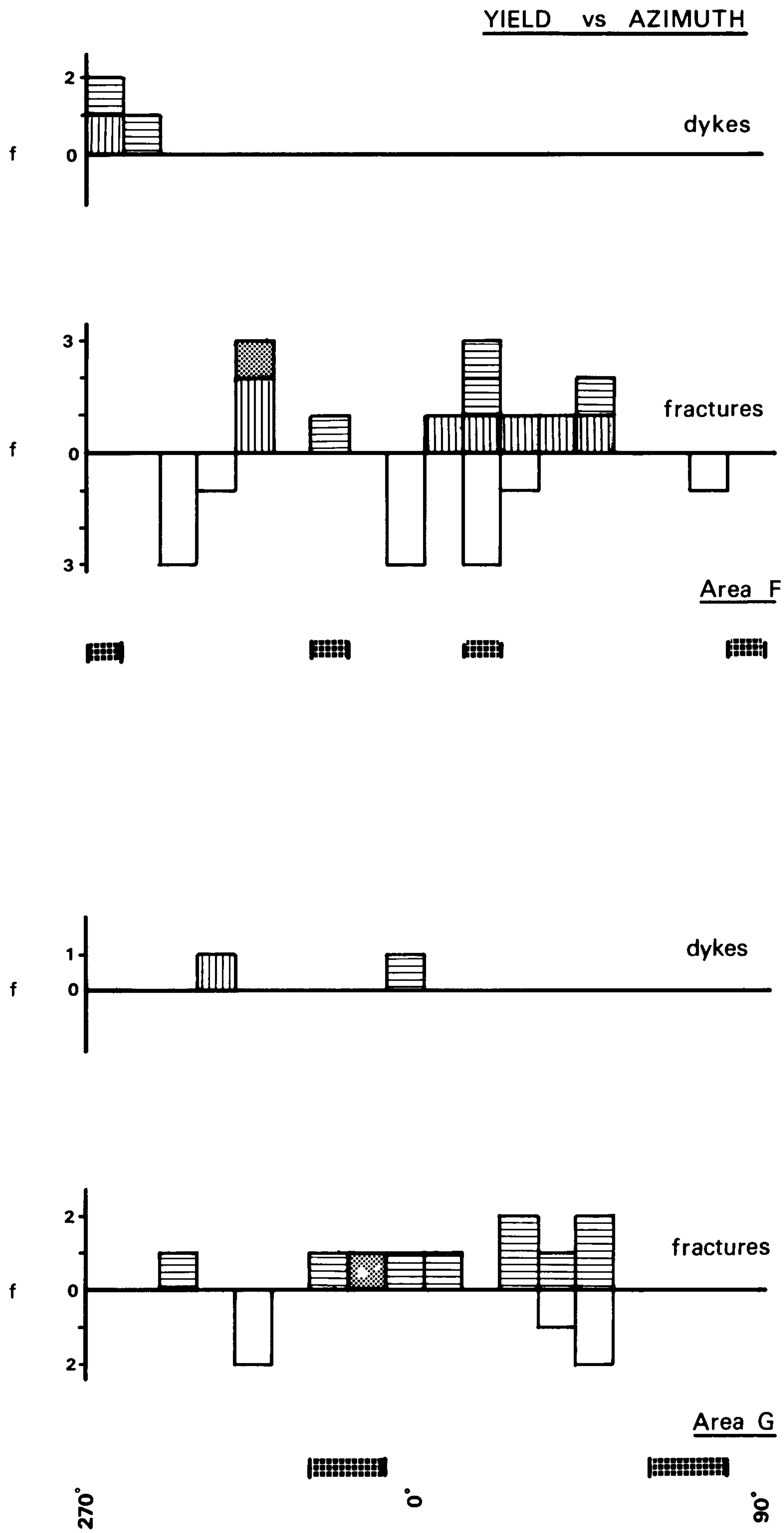

Figures 2C & 2D

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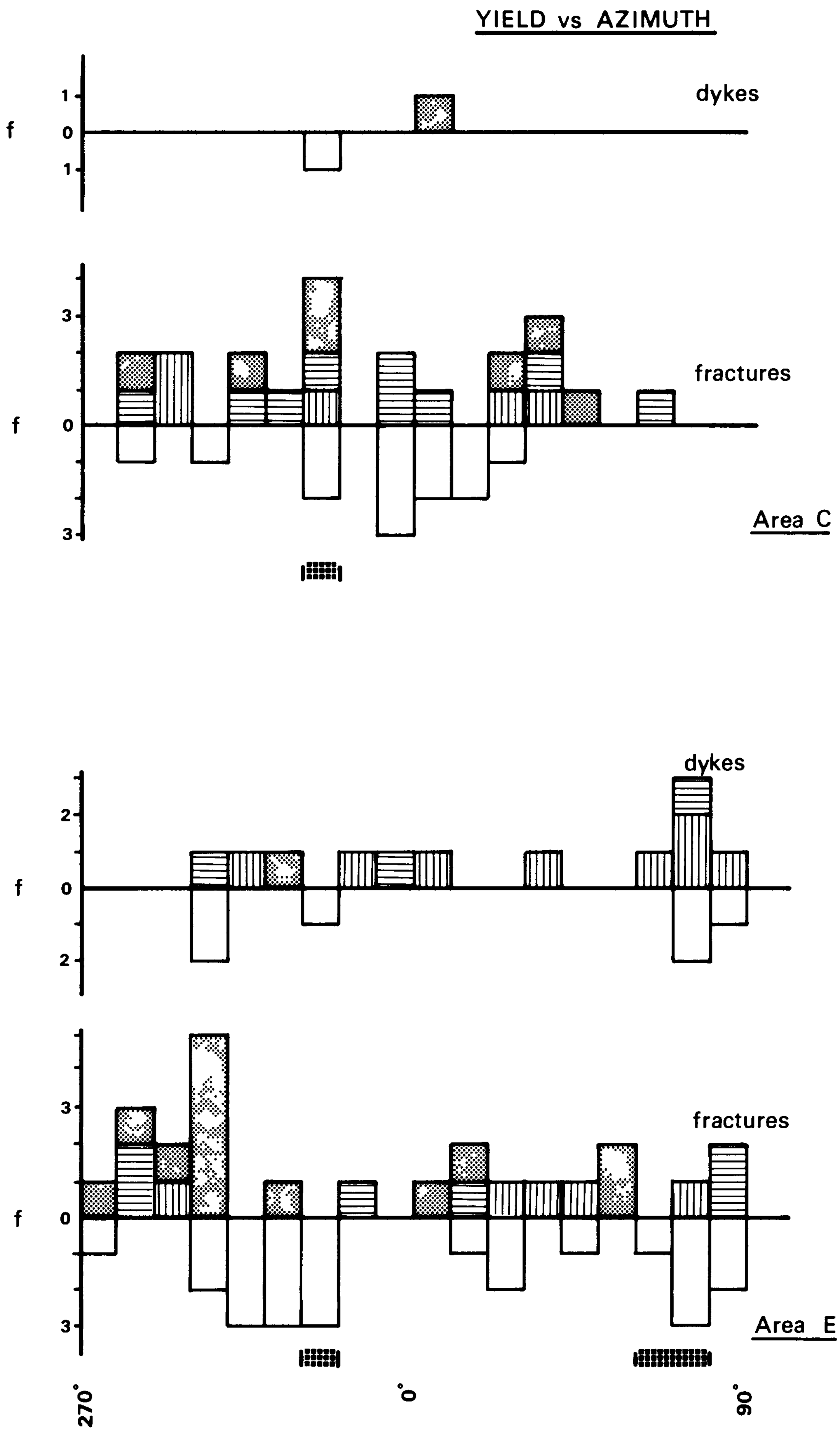

Figures 2A & 2B

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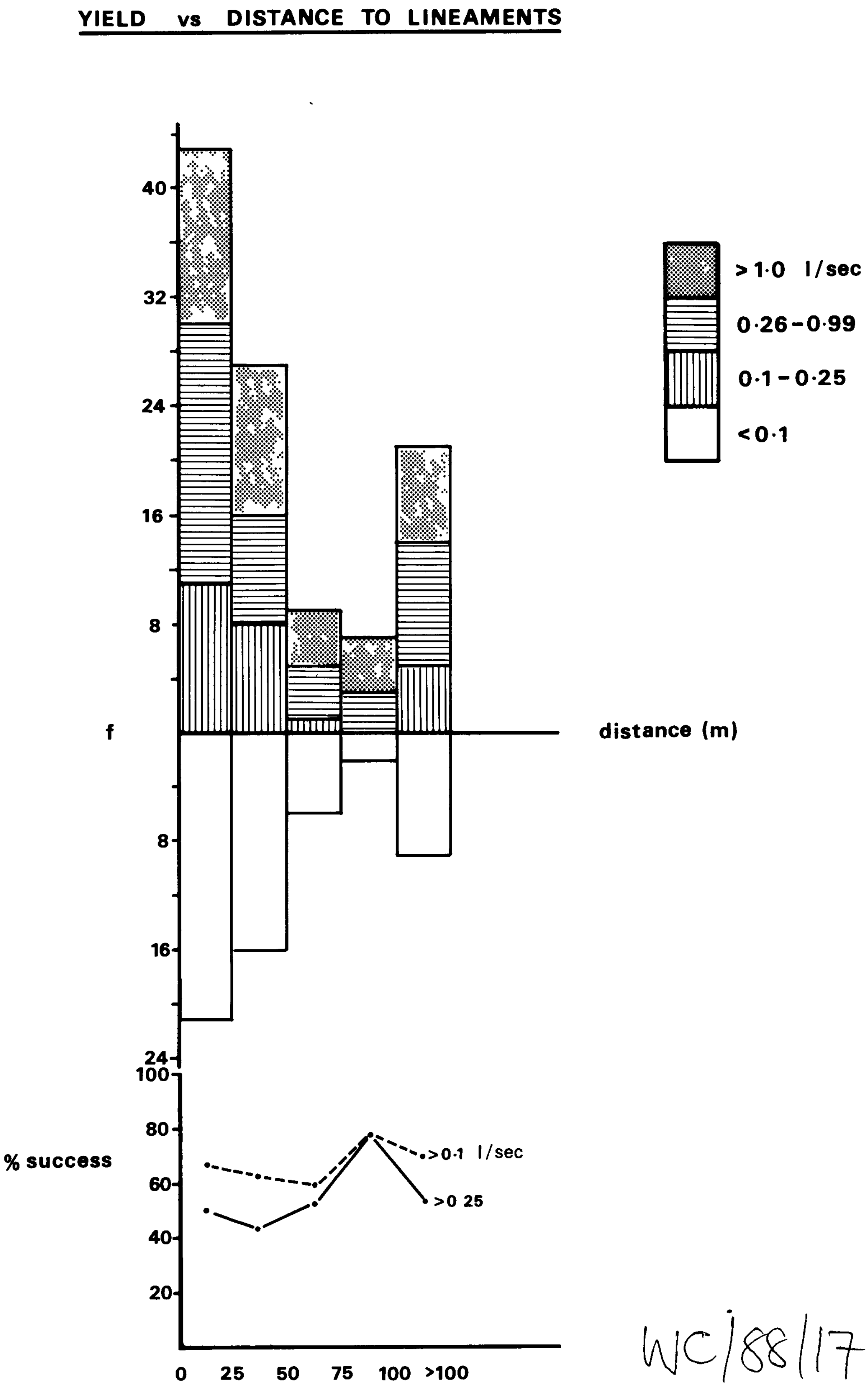

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Figure 1: Frequency histogram showing the relationship between borehole yield and normal distance to lineaments. Combined data from areas C, E, F, G and J. Success rate is also indicated.

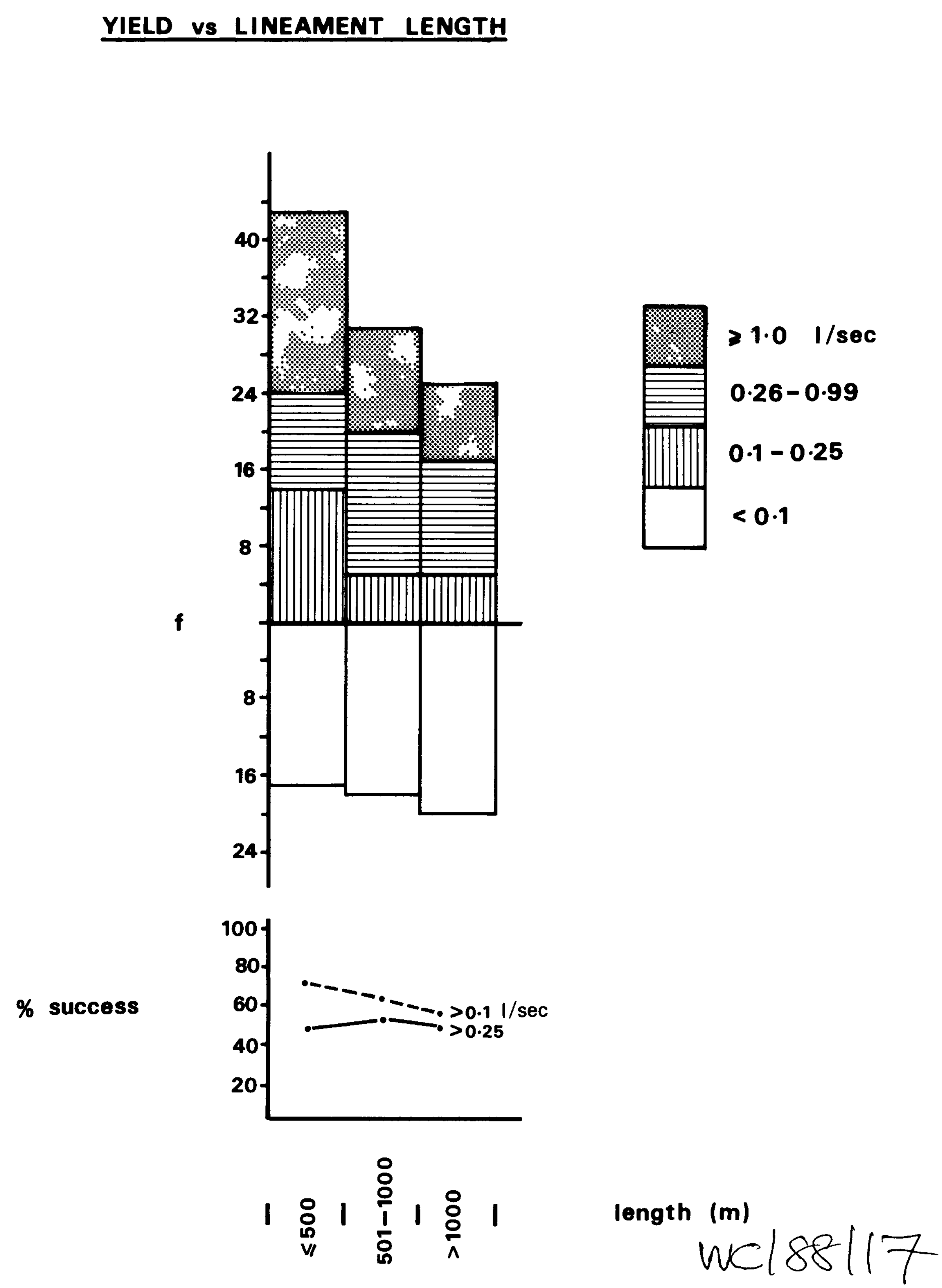

Figure 3: Frequency histogram for combined data from areas C, E, F, G & J showing the relationship between borehole yield and length of lineament in 3 length categories.