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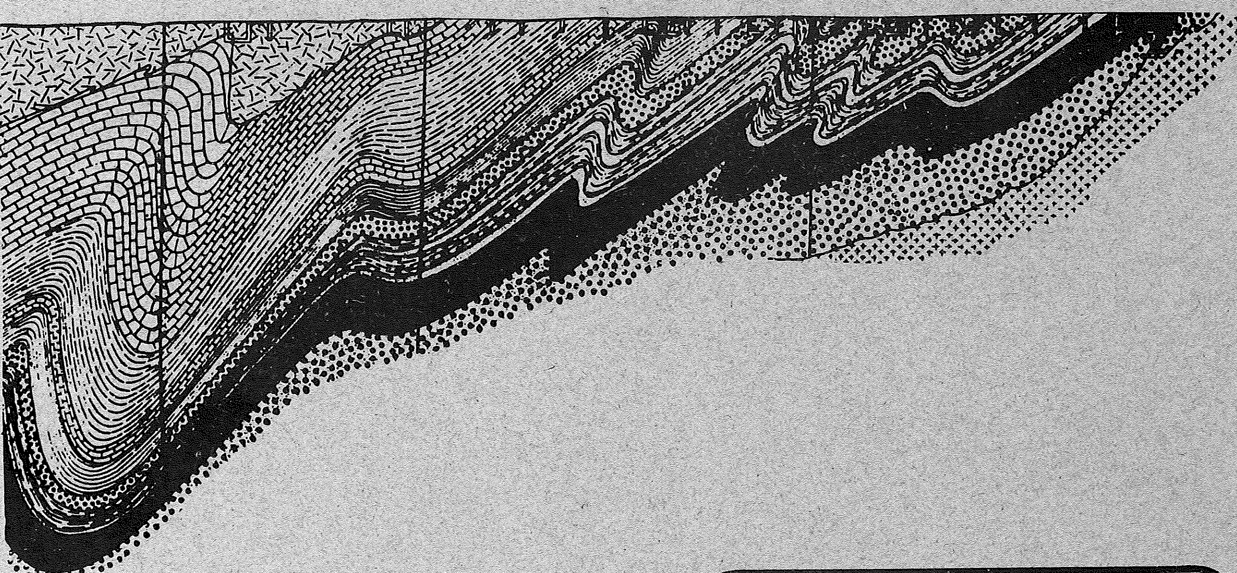

ECONOMIC GEOLOGY

RESEARCH UNIT

UNIVERSITY OF THE WITWATERSRAND

JOHANNESBURG

CROSS-BEDDING AND RIPPLE-MARKS IN MAIN-BIRD QUARTZITES IN THE EAST RAND AREA : A RECONNAISSANCE STUDY

by

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INFORMATION CIRCULAR NO. 5

JUNE, 1961.

"Geological field work involving the coarser clastic sediments can now be considered acceptable only if it includes mapping of the primary sedimentary structures of these rocks. Stratigraphical field studies omitting such features are as incomplete and unsatisfactory as geological maps of complex structures without observations of strike and dip of bedding, cleavage, lineation and so forth".

F.J. PETTIJOHN, 1957, p.578.

ABSTRACT

A brief review of the subject of cross-bedding is followed by a discussion of some of the techniques employed and problems involved in studies of this type.

Three hundred and twenty-four measurements of cross-bedding, made underground at ten mines and on surface outcrops at seven localities on the East Rand, indicate a consistent south-southeasterly direction of transport for the Main-Bird Series quartzites, continuing as far south and south-east of Heidelberg as the Series can be traced. No evidence of a limit to the Main-Bird depositional basin in this direction has been encountered.

The orientation of 39 ripple-marks measured underground, is anomalous, in that the ripple axes appear to be oriented <u>parallel</u> to the deduced direction of sediment transport, which is from northwest to southeast.

CONTENTS

I. INTRODUCTION.

Stratigraphical analysis has as its goal a thorough knowledge of the sedimentary rock material as such, the overall relations of the stratified rocks, and an understanding of the processes by which the sediments are formed, transported and deposited.

As emphasized in the preface, there is increasing realization that primary sedimentary structures are important attributes of any sediment. Laboratory experiments, the study of sedimentary structures in modern beaches and streams etc., are all leading toward a more precise interpretation of ancient sedimentary conditions.

Apart from the broad philosophic interest of study of the dynamic aspects of sedimentation, there is no doubt that much of the impetus for the current rapid advancement in the subject stems from its significant practical application particularly in the field of petroleum geology. Thus with reference to the ostensible aims of the Economic Geology Research Unit of the Witwatersrand University, the potential value of a study of primary structures in Witwatersrand System sediments requires no justification.

The contributions of PIROW (1920) and REINECKE (1927), on this aspect of Witwatersrand geology are outstanding both for their thoroughness in the accumulation of data, and for the fact that they constitute the only systematic studies of this type on the Witwatersrand System ever to have been published. There is an awareness on the part of many workers, of the environmental and directional significance of primary structures, but very often, interpretations are made on the basis of only a few scattered measurements. (For example, see BAIN, G.W., 1955, p.238).

Sedimentary structures require systematic measurement and cautious interpretation, and the results should, if possible, be integrated with as many different sedimentologic parameters as possible.

This paper reports the results of a reconnaissance study of cross-bedding and ripple-marking seen in Main-Bird quartzites underground in the East Rand basin, and in surface outcrops south and south-east of Heidelberg. In addition to the field work, however, considerable library research into the subject of cross-bedding was entailed. As a background to this presentation, a brief review of the subject is included and some

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of the practical problems encountered in this study are described.

(1) ACKNOWLEDGEMENTS:

The author would like to acknowledge the fruitful discussions with, and stimulation received from DR. A.O. FULLER, whose review of the manuscript has also resulted in considerable improvement.

The cross-bedding measurements on the Farm Tweefontein 98 were made by MR. M.J. MOUNTAIN; whose permission to utilise them in this study is much appreciated.

MR. H.C. MORRIS designed and drew the block diagrams to illustrate the method of measurement of cross-bedding.

II. REVIEW OF CROSS-BEDDING.

A variety of names are used to designate that feature of stratification described by MCKEE (1953, p.382) as "the arrangement of layers at one or more angles to the dip of the formation". Such terms as cross-bedding, cross-lamination, cross-stratification, current-bedding and false bedding are all encountered in the literature. "Cross-bedding" is the name most frequently used in recent years and will be used in this report.

Numerous terms have been used to describe different forms of cross-bedding - for example, "Angular" or "Tangential", "Torrential", "Festoon". "Angular" is a term applied to cross-bedding that appears in section as nearly straight lines meeting the underlying surface at relatively high angles (20° - 30°). "Torrential" and "Regular" are used as synonyms of "Angular". The term "Tangential" on the other hand is applied to cross-bedding that appears in section as smooth arcs meeting the underlying surface at low angles.

The supposed genetic distinction between "Angular" cross-bedding (deposition by water) and "Tangential" cross-bedding (deposition by wind) is considered by MCKEE (1953, p.385) to be quite unjustified. In the course of laboratory flume experiments, he has shown (MCKEE, 1957, p.131) that the straightness or concavity of cross-laminae is, at least in part, related to the degree of sorting of the sediment, and to the velocity of the transporting current.

In his experiments, for a given current velocity, well-

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sorted sand produced straight foreset beds, while poorly sorted ands, particularly clay-bearing sands produced concave foreset beds, tangential to the base. By increasing the velocity of the transporting current, concave foresets could be produced even in well sorted sands.

MCKEE contends (1953) that not enough criteria for determining the mode of formation of cross stratification are known, and that a classification based on presumed genesis is quite warranted.

F.J. PETTIJOHN (Public lecture, Princeton, N.J., Feb., 1959) made the proposition that there is no basic difference between aeolian, fluvial or marine cross-bedding. PETTIJOHN has also written (1957, p.166) "It now seems doubtful whether genetic types of cross-bedding exist, and whether the classifications now used have any genetic significance".

With a view to standardising description and eliminating terms with unwarranted genetic implications, MCKEE (1953, p.385) proposed a purely descriptive classification based primarily "on the character of the lower bounding surface of the set of cross-strata"* and in which there are three main types (see Fig. 1):-

1. Simple cross-stratification - any set of cross-strata whose lower bounding surface is not a surface of erosion, but one of non-deposition or change in character; it is formed by deposition alone.

2. Planar cross-stratification - any set of cross-strata whose lower bounding surface is a planar surface of erosion; results from bevelling and subsequent deposition.

3. Trough cross-stratification -any set of cross-strata whose lower bounding surface is a curved surface of erosion; results from channelling and subsequent deposition.

*Footnote: In his classification, MCKEE proposes the use of the qualitative term cross-stratification for the structure generally, and the restriction of the terms cross-bedding and cross-lamination, for the quantitative designation of cross-stratified layers respectively thicker and thinner than 1 cm. The use of "cross-bedding" for the structure generally is well entrenched, however, and seems likely to remain so.

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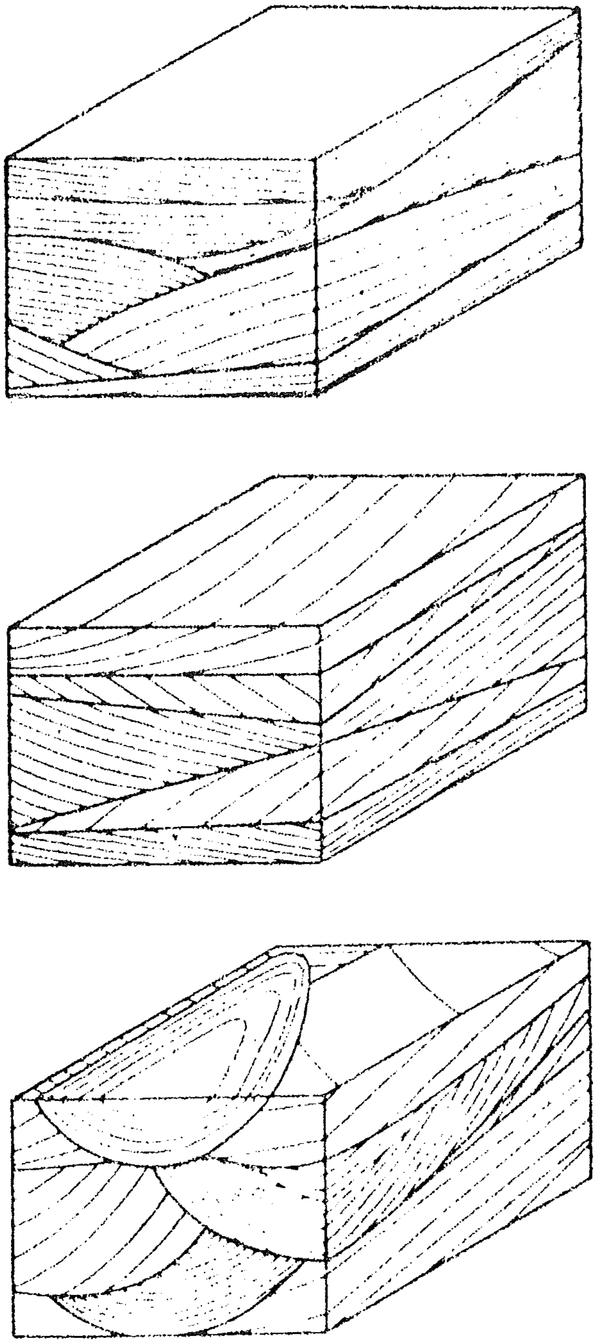

SIMPLE CROSS-STRATIFICATION
The lower bounding surfaces of sets are nonerosional surfaces.

PLANAR CROSS-STRATIFICATION
The lower bounding surfaces of sets are planar surfaces of erosion

TROUGH CROSS-STRATIFICATION
The lower bounding surfaces of sets are curved surfaces of erosion.

FIGURE 2. - BASIC ELEMENTS OF CLASSIFICATION OF CROSS-STRATIFICATION

Figure 1. Three main types of cross-bedding illustrated in Figure 2, of MCKEE, E.D., and WEIR, G.W. "Terminology for stratification and cross-stratification in Sedimentary Rocks". Bull. Geol. Soc. America, V.64, P.381-390.

It is the author's experience that the utilisation of this classification can sometimes present considerable difficulty. For example, MCKEE's illustration of "simple" cross-bedding (fig. 1) when turned upside down, looks almost identical with his illustration of "trough" cross-bedding. MCKEE in a later work (1957, p.132) is aware of this problem, for he states: "If, on the other hand, the forward-building sand body consists of two or more lobes, each being fed by a separate stream, strata forming these lobes appear in cross section as curving structure that are convex upward. (Note: no erosion, therefore simple). This type of structure is significant, for it is opposite in orientation to common channel fill or 'festoon' (trough) varieties, and might easily be mistaken for these in an upside down position."

Other features, such as possible grading, would need to be examined to ascertain which side is up, and the subsequent classification as simple or trough would inevitably have genetic implications, at least as regards formation in association with or without erosion. Consider an example in which the top-sets of a cross-bed have been bevelled, but normal sedimentation has continued for a short interval before another cross-bed was deposited. The lower bounding surface is non-erosional, and the cross-bed should presumably be classified as "simple". However, when horizontally stratified sand is interbedded between two cross-bedded units, it is difficult to decide whether the lower bounding surfaces of the cross-beds are erosional or non-erosional.

Some of the subordinate descriptive criteria recommended by MCKEE are as follows (op. cit. p.):

1. Shape---Lenticular, Tabular, Wedge-shaped.

2. Arching of cross-strata---Concave, Straight, Convex.

3. Length of cross-strata---Small Scale (<1 ft.)
   Medium Scale (1-20 ft.)
   Large Scale (>20 ft.)

With the exception of the use of "cross-stratification" as the general term, it appears from the literature that MCKEE's classification is being used with increasing frequency in descriptions of cross-bedding (see WHITAKER, 1955, NICKELSEN, 1958, PELLETIER, 1958).

PETTIJOHN (Public lecture, Princeton N.J., Feb. 1959) considered the two main types of cross-bedding as being "Torrential" and "Festoon".

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According to MCKEE's classification, these would be:-

Torrential = straight, tabular or wedge-shaped, planar.

Festoon = concave, lenticular, trough.

In Witwatersrand rocks, the author has found planar cross-bedding to be frequently concave, as well as straight.

III. QUANTITATIVE STUDY OF CROSS-BEDDING.

There being no justification, at our present state of knowledge, for genetic interpretations based on the qualitative aspects of the form of cross-bedding, there remains the important parameter of its orientation. The fundamental assumption underlying paleogeographic interpretations based on cross-bedding studies is that the dip direction of the fore-set beds in any cross-bedded unit indicate the local direction of transport of the sand forming that unit. If there is a marked preferred orientation of the measured dip directions of numerous cross-bedded units in a single formation in a particular area, then the predominant dip direction can be concluded to indicate the direction of transport of the sand forming that formation. As sand is presumed to be transported down slope, the mean regional up-dip direction is considered to point toward the source of the sediment.

The fundamental assumption cited above is not always justified:-

> Fore-set beds developed on the advancing bank of a meander or in a braided stream environment (WRIGHT, 1959) or on the sides of advancing barchan dunes will dip more or less perpendicularly to the main direction of transport.
>
> Likewise, cross-bedding resulting from transport by currents parallel to the shore in a marine environment will not indicate the regional slope and source of the sand. (TANNER, 1955).

Although the pattern or azimuthal spread of dip directions resulting from a systematic survey may vary, it must in some way reflect differences in manner and environment of deposition. It is a fingerprint which in conjunction with other sedimentologic features, can lead to a better understanding of genesis.

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A. EXPERIMENTAL TECHNIQUES.

(a) Sampling:

The problem of representative sampling of the cross-bedding available for measurement in a particular formation in an individual outcrop or area, is indeed complex. Much has been written on the subject, and the statistical rigour of the recommended procedures vary. (REICHE, 1938, RAUP and MIESCH, 1957, OLSON and POTTER, 1954). It appears to the author, that the majority of the statistical sampling procedures described in the literature were designed primarily for the study of individual, thin (200 - 300 feet), easily identifiable, well cross-bedded, sandstone units. In addition the techniques, both for field sampling and subsequent reduction of the data, presuppose one "predominant dip direction" ("mode").

TANNER (1955, 1959) has emphasized that in many instances there is more than one mode. The recognition of this is of great importance for paleogeographic reconstruction.

TANNER does not approve of statistical procedures designed to reduce the sample number, as he feels this "tends to mask polymodality". (W.F. TANNER, Florida State University, personal communication, 1959). As a consequence, TANNER "makes a conscious effort not to reduce the sample number,.....and.....tries to obtain every measurement possible, at every exposure possible".

The sampling procedure followed, while always striving toward being representative, must be governed to a certain extent by the nature and magnitude of the project undertaken. For example, in his reconnaissance mapping of cross-bedding and associated structures of Lake Superior precambrian quartzites, PETTIJOHN (1957, p.470) states: "two measurements of strike and dip of the cross-lamination per bed were made,........on two to five beds per outcrop. Outcrops were no less than a mile apart, and in general two to five outcrops were studied per six mile interval along the outcrop belt".

As far as more rigorous procedures are concerned, it is considered that, in any case, the need for such treatment would become apparent only after thorough reconnaissance of the type, abundance and general variation in azimuth of the cross-bedding.

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In the course of this study, measurements were made on every cross-bedding unit encountered underground, with not more than two measurements knowingly made on any individual unit.

Except in those outcrops where the orientation of cross-bedding is obviously very uniform, the author, as a general rule, attempted to make about 20 cross-bed measurements in the course of two traverses across the formation outcrop, at each locality.

(b) Bias in Sampling:

In most surface outcrops, cross-bedding with the same strike (but differing dip) as the true bedding is much less conspicuous than cross-bedding with oblique strike. In sampling outcrops, this factor may easily result in a bias in favour of those cross-sets dipping obliquely to the bedding.

In the course of study of cross-bedding at a locality south-east of Heidelberg, the distribution and orientation of outcrops was such as to permit measurements to be made with a view to testing this tendency toward bias.

On the southern part of farm: Houtpoort 309, the principle Main-Bird outcrops west of the Heidelberg-Villiers road strike north-south and dip west at 15°-20°. (See: Geological Map of the Country around Heidelberg, by A.W. ROGERS). Several valleys incised on dip slopes provide good dip sections in addition to the strike outcrops. East of the road, there is a restricted outcrop of Main-Bird quartzites which strike east - west and dip north.

In a traverse across the principle outcrop west of the road, both strike and dip sections were examined for cross-bedding and measurements made. On the return traverse, cross-bedding seen in strike section (N-S) only was measured. Finally 10 measurements of cross-bedding were made in the low outcrop striking E-W on the east side of the road. The results of the three separate groups of measurements are plotted in Figure 2. (A) is considered representative of the Main-Bird quartzites in that area, but the bias in favour of cross-bedding oblique to strike is clearly evident in (B) and (C). This study emphasizes the particular care which must be exercised in sampling individual surface outcrops and a deliberate

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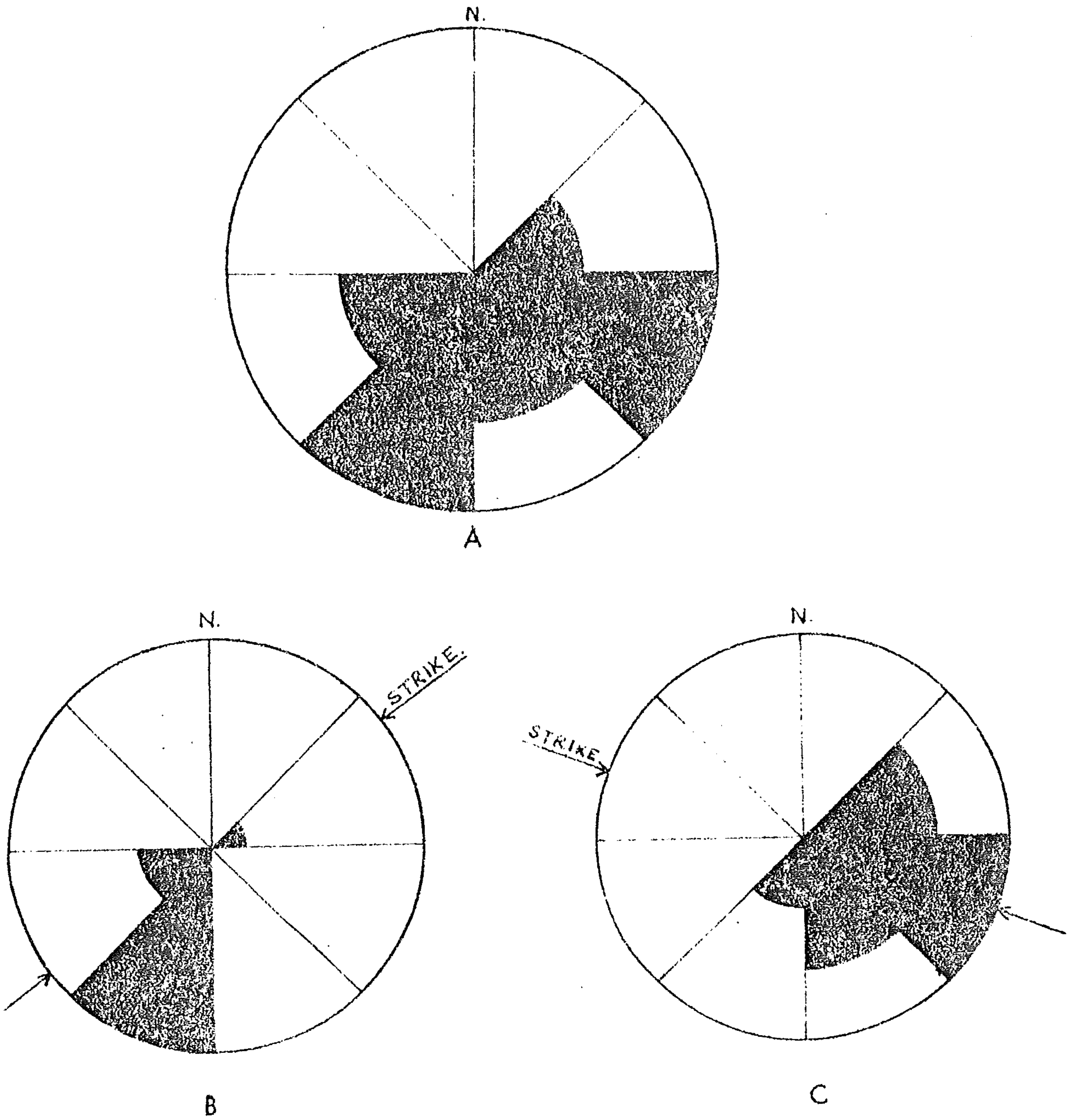

Figure 2:

Cross-bedding dip directions in Main Bird quartzites on Houtpoort 309 and Nooitgedacht 261, south east of Heidelberg. (See also Fig. 7.)

A. Collective plot of all measurements.

B. Nine measurements made on cross-bedding exposed in NE - SW strike section only.

C. Eight measurements made on cross-bedding exposed in NW - SE strike section only.

Contrast between B and C illustrates tendency toward sampling bias in favour of those cross-beds which dip at right angles to strike of outcrop.

search made for cross-bedding developed on the less frequent dip sections.

In underground work, however, measurements are made on exposures parallel to both strike and dip (drives, cross-cuts, etc.). This, coupled with structural deformations which cause local changes in dip and strike of the quartzites, is considered to minimise the possibility of bias.

(c) Method of Measurement:

In studies of this kind, it is essential to measure the true strike and dip of the cross-stratified planes. As stated by TANNER, (personal communication, 1959) "Apparent directions or 'components' are practically useless and shouldn't be bothered with inas-much as true directions (cross-bedding strike, dip, etc.) are easy to get".

Measurements are made with a Brunton compass. Magnetic orientations obtained underground with this instrument are considered to be of quite satisfactory accuracy provided measurements are not made in the immediate vicinity of electric cables, steel pipes, etc., or while locomotives are passing. As a check, if considered necessary, a magnetic traverse with back and fore sights, to two known survey pegs can be made. In this way, a compass may be used even in areas of moderate magnetic disturbance.

The measurement required is essentially one of strike and dip: of the cross-bedding and true bedding at each locality. The measurement of cross-bedding usually presents some difficulty however, because of the small areal and vertical extent of the unit, and the weak development of the cross-laminae.

In some instances, the rock has broken along the cross-laminae, and a plane surface is available for direct measurement. Usually, however, only the trace of the cross-laminae is visible on the irregular, natural or broken rock surface. Provided there is some relief on this surface, the strike and dip of the plane can be measured in the following manner:-

One's viewpoint is adjusted until the irregular trace of the cross-laminae appears in projection as a straight line. (See Fig. 3). Maintaining this aspect,

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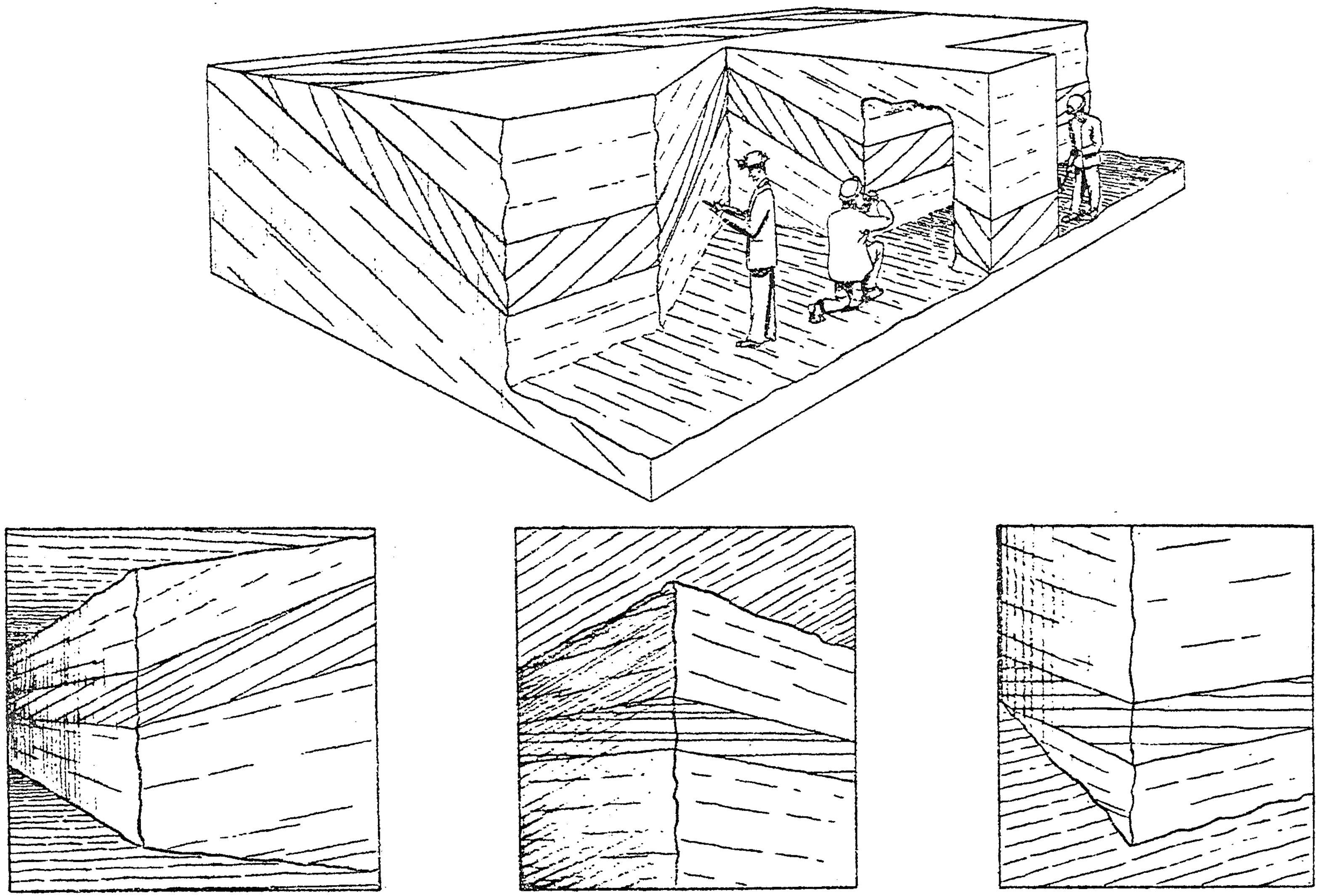

Figure 3: Idealised block diagram of underground working with cross-bedded unit exposed. Insets show views from three positions, left to right, looking: (i) along strike, (ii) up-dip, (iii) down-dip of cross-bedding planes. From any of these positions, the true orientation of the cross-bedding can be measured with Brunton compass.

and with the aid of a Brunton or dip-needle, one's viewpoint is further adjusted until one is looking either along the strike of the plane, (Fig. 3b) or directly up (Fig. 3c) or down (Fig.3d) its maximum dip direction (whichever is most convenient). Measurement of strike and dip, or dip and dip direction are then made. With experience, this method is rapid and presents no difficulty. In the case of concave cross-bedding, the measurement is made on the steepest, straightest part of the surface.

(d) Precision and Accuracy:

The precision of this technique, as judged from repeated measurements by one operator, is approximately $\pm 3^{o}$. If measurements are made by more than one operator, the precision might drop to $\pm 5^{o}$, depending on the experience of the individuals concerned.

The accuracy, or the approach to the true value, will, ofcourse, depend on instrument settings, and due allowance for possible magnetic anomalies at the location at which the measurement is made.

For purposes of paleogeographic reconstruction, however, the detection of a particular source or transport direction to an accuracy exceeding an octant, is rarely feasible or desirable. Thus the possible error in individual measurements, is well within these limits. In-as-much as the mean is taken of numerous measurements, the technique is of quite satisfactory accuracy.

In certain studies, however, it may prove desirable to refine the measurement technique employed.

(e) Graphical Restoration:

When true bedding is itself inclined, the measured strike and dip of the cross-laminations need to be corrected for such deformation by appropriate rotation of the cross-laminated plane about the strike of the true bedding. The technique is described by PETTIJOHN (1957, p.470) as follows:-

> "The pole of the cross-bed, plotted on a stereonet is rotated through the angle of dip of the bed itself, about the strike and dip of the bed"---with the assumption that "the Azimuth and inclination of the cross-bedding

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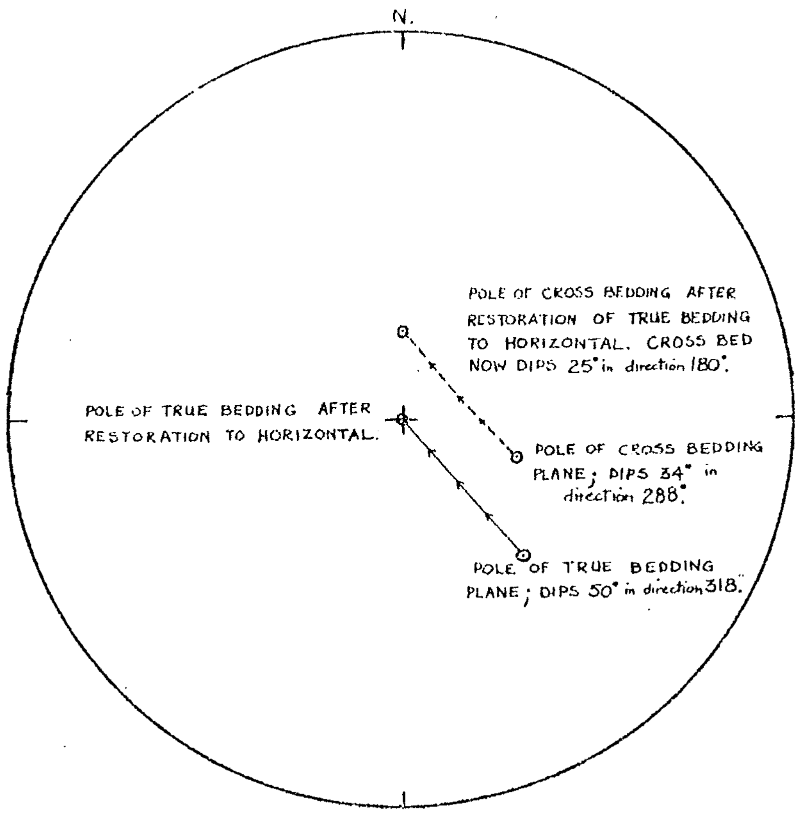

Figure 4: Diagram illustrating method of obtaining true cross-bedding orientations from measurements made in inclined strata, assuming strata to have been horizontal originally, and to have been folded about horizontal axis.

thus corrected, are essentially the same as at the time of deposition". This procedure is illustrated in Figure 4.

As has been pointed out by J.G. RAMSAY (1961), this procedure can cause a substantial error in orientation, particularly for steeply dipping beds, if the axis of the folding was not horizontal. However, in the absence of any evidence to the contrary, the assumption of horizontal fold axes has to be made.

(f) Presentation of Data:

Cross-bedding data are usually presented graphically in the form of Rose or Compass diagrams. In these, quadrants, octants, or smaller subdivisions are arbitrarily selected, and the limits of each division are drawn in proportion to the number of measurements falling into that division (for example, see Fig. 2). Visual examination of the resulting diagrams is usually sufficient to establish the existence of a mode or modes and/or a "minimum" direction. More rigorous statistical treatments, involving the calculation of the mean or vector sum, have been utilised in detailed studies of restricted stratigraphic units (POTTER and OLSON, 1954) and may ultimately have application on the Witwatersrand.

In this study, in view of the paucity of measurements made at individual underground localities, the following method of presentation has been used. A standard size circle has been subdivided into octants; that octant (or octants) into which the maximum number of measurements fall, is completely blackened. The remaining octants are blackened in proportion to the number of measurements which they contain, expressed as a fraction of the maximum. In addition, the actual number of measurements falling into each octant is indicated.

IV. RESULTS OF RECONNAISSANCE STUDY OF CROSS-BEDDING AND RIPPLE-MARKS IN MAIN-BIRD QUARTZITES IN THE EAST RAND BASIN:

A. CROSS-BEDDING:

(a) Location of measurements:

Cross-bedding was found to be quite common in Main-Bird Quartzites exposed underground (see PLATE I, Fig.1),

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and in the course of twelve mornings a total of 129 measurements were made at the following ten mines:

Geduld, East Geduld, Grootvlei, Van Dyk, Springs, S.A. Land, Marievale, Vogelstruisbult, Sub Nigel, Wit Nigel.

For the most part, these measurements were made in quartzite either directly overlying, or in the immediate vicinity of the Main Reef leader. At S.A. Land and Exploration Company Limited, however, a section up to the Bird Amygdaloid was studied.

On surface outcrops, 195 measurements were made, at seven localities (see ROGERS, Geological Map of the Country around Heidelberg, 1922), distributed as follows:-

General Locality	Farm Name	Stratigraphical Position
1. East of Nigel	Bultfontein 28	Vicinity of Main Reef Leader
2. East of Heidelberg	Houtpoort 309 and Poortje 123	Main Reef Leader up to Bird Amygdaloid
3. Southeast of Heidelberg	Houtpoort 309 and Nooitgedacht 261	Main Reef Leader up to Bird Amygdaloid
4. Southeast of Heidelberg	Malanskraal 73	Above (?) Bird Amygdaloid
5. Southeast of Heidelberg	Tweefontein 98*1	Main Reef Leader up to Bird Amygdaloid
6. South of Heidelberg	Elandsfontein 281	Vicinity of Main Reef Leader
7. Southeast of Greylingstad	Heidelberg-Roodepoort Mine	Bird Amygdaloid up to Kimberley Shale**2

Footnote: *1 Measurements on Tweefontein 98 made by MR. M.J. MOUNTAIN.

**2 cont./

(b) Form:

The form of the cross-bedding observed is almost invariably straight, rarely concave, and planar, the sets appearing to be thin almost tabular lenses (see terminology of MCKEE and WEIR, 1953). The greatest dimension of individual cross-bedded lenses as noted in strike-sections is approximately 200 feet. The true three-dimensional shape of individual lenses could not be ascertained. Measured thicknesses of individual cross-stratified units seen underground range from 4" to 60", with an average of 23". The original angle of dip of the cross-laminae, assuming true bedding to have been horizontal, averages 21° with recorded variations from 7° to 36°.

(c) Orientation:

The data on azimuthal orientation of cross-bedding obtained in this study is presented in the form of compass diagrams in Figures 5, 6 and 7. Figure 5 is a collective plot of all measurements made in the East Rand area as a whole, and Figure 6 shows only those measurements made underground in the East Rand Basin. In Figure 7, separate compass diagrams of the measurements obtained at each mine and on the surface outcrops are presented.

In addition, an approximate mean azimuth for the cross-bedding at each locality was obtained, by taking an arithmetic average of the individual measurements.

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Footnote: **2 (cont. from page 15)
In the "Note on the Geological Column in the Balfour area", presented at the 4th Annual Congress of the Geological Society of South Africa, the Main-Bird Series is reported to be absent in the Balfour area, and to have "cut out....between Heidelberg and Balfour". However, no evidence is given as to why the quartzite and amygdaloid underlying the Kimberley Shale in this area should be correlated with the Jeppestown Series rather than with the Main-Bird Series. The orientation of cross-bedding in this quartzite is compatible with that to be expected from Main-Bird series. However, until conclusive evidence is presented the stratigraphic identity of this quartzite remains somewhat uncertain.

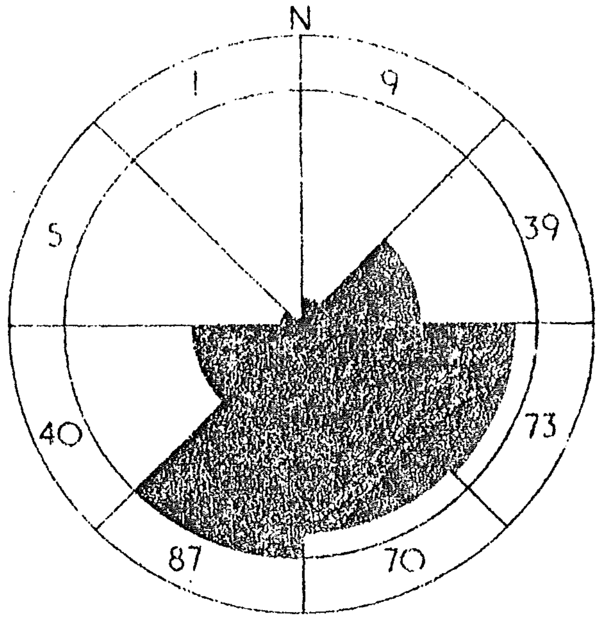

Figure 5: Collective plot of all cross-bedding measurements, surface and underground, made in East Rand area.

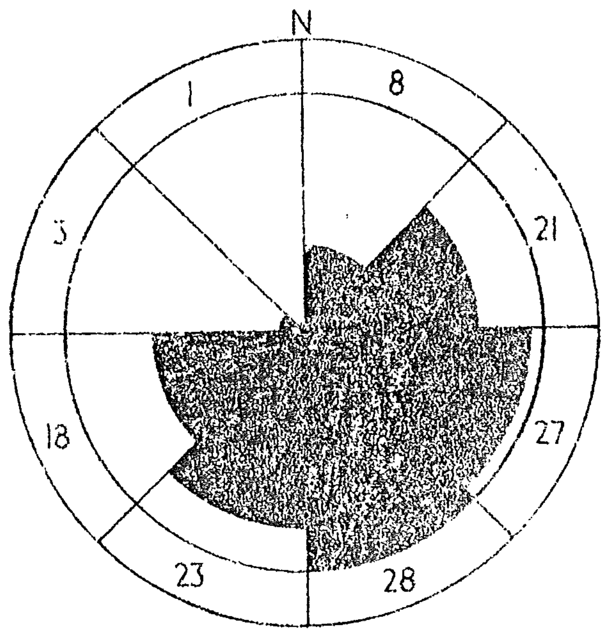

Figure 6: Collective plot of all cross-bedding measurements made underground in East Rand Basin.

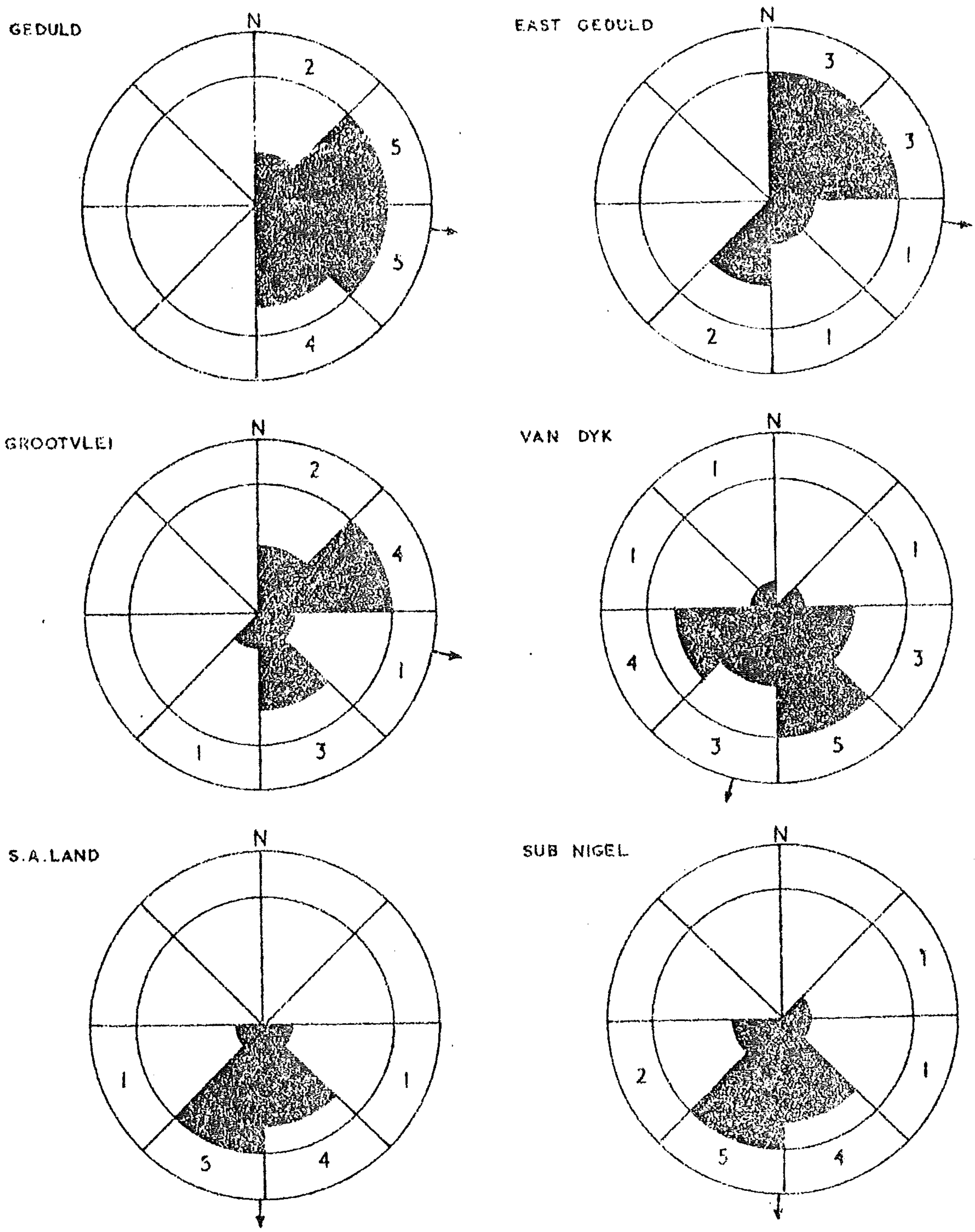

Figure 7. Plot of cross-bedding measurements made at individual localities.

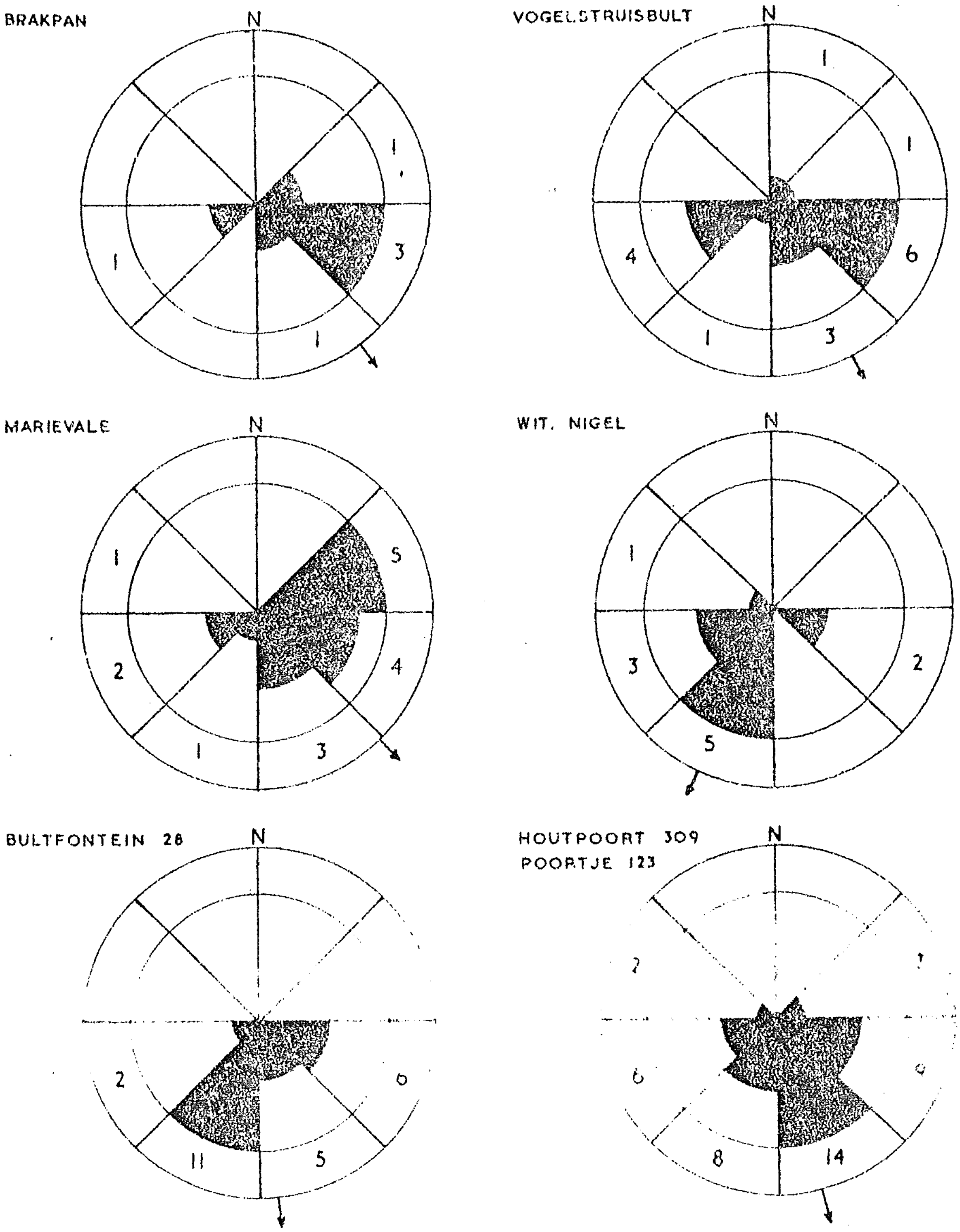

Figure 7. continued: Plot of cross-bedding measurements made at individual localities.

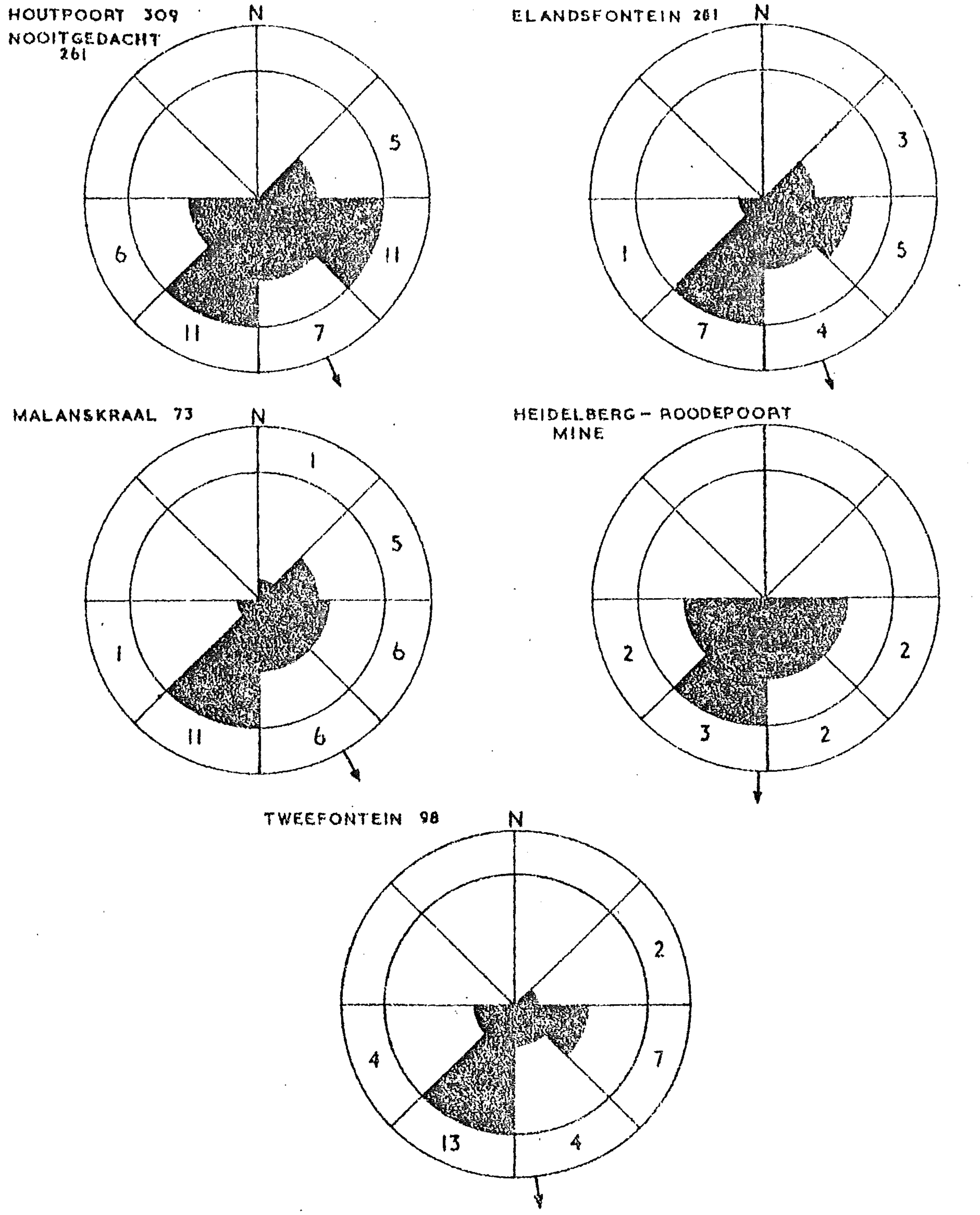

Figure 7. continued: Plot of cross-bedding measurements made at individual localities.

In Figure 8, these average azimuths are plotted as arrows on a mine-outline map of the East Rand Basin. The average thickness of the cross-bedded units at each locality is also indicated.

B. RIPPLE-MARKS:

(a) Wave and Current Ripples:

Measurements of the orientation of the average axis of ripple-markings were made at each exposure encountered. No ripple-marks were seen in surface outcrops. The structures were invariably casts of the original ripples, seen on the roofs of drives, stopes, etc., where the rock had broken along the bedding planes. An estimate of wave length and amplitude was generally made but it was not always possible to establish positively whether the ripples were symmetric or asymmetric. Definite examples of both types were seen and noted, but in the main, only the orientation of the average axis of the ripple-marks was recorded. The majority of ripples seen consist of one set only, but interference ripples were noted in some areas (see PLATE I, Fig. 2).

(b) Sand-waves:(?)

In the roofs of many stopes, much larger ripple-like structures have been observed, which are illustrated in PLATE I, Figures 3 and 4. These consist of a series of roughly parallel, smoothly rounded, symmetrical ridges or rolls. The rolls are convex downwards, with sharply-angled apical junctions.

The significance of these structures is uncertain. Despite careful examination, no evidence clearly associating them with tectonic movement or deformation (mullions?) could be found. Their symmetry is just sufficiently irregular, with occasional intersections and bifurcations, as to suggest that they are primary sedimentary structures. A section through one of these "waves" might reveal primary sedimentary structures, but unfortunately such an exposure was not encountered. Considered as wave-structures, they have an amplitude up to 9", and a wave-length up to 4 feet. As seen on the roof of the stope, they are presumably casts of some large scale oscillation-type ripple. No structures intermediate in size between these and

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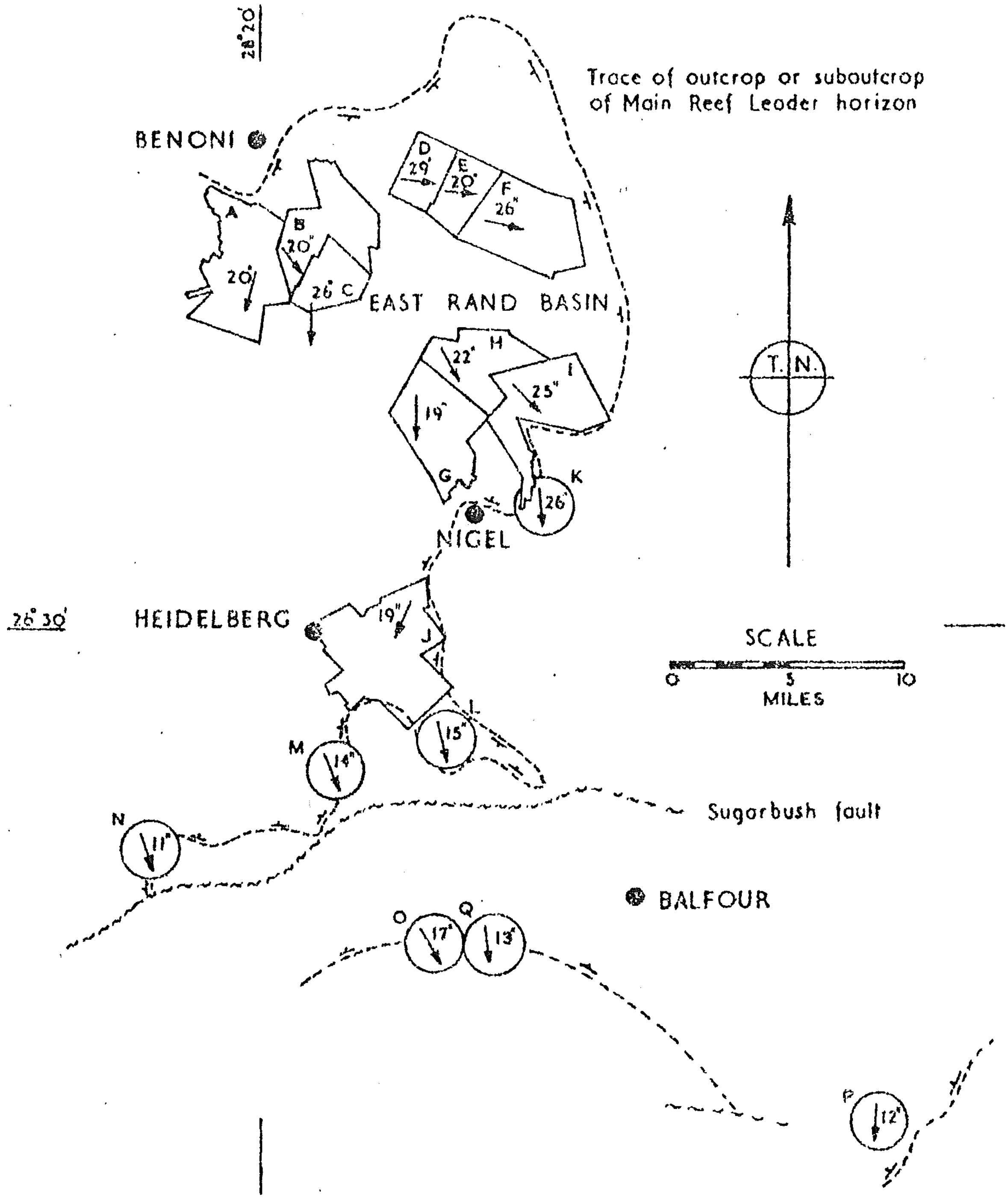

Figure 8 : Map of East Rand area showing average orientation of cross-bedding dip direction, and average thickness of cross-bedded units at each locality sampled. Note decrease in average thickness of beds to the south and southeast, which is the direction of transport indicated by cross-bedding.
A - Van Dyk, B. - Brakpan, C. - S.A. Land, D. - Geduld, E. - East Geduld, F. - Grootvlei, G. - Sub Nigel, H. - Vogelstruisbult, I. - Marievale, J. - Wit Nigel, K. - Bultfontein 28, L. - Houtpoort 309, Nooitgedacht 261, N. - Elandsfontein 281, O. - Malanskraal 73, P. - Heidelberg - Roodepoort Mine, Q. - Tweefontein 98.

the typical ripple-marks were seen.

(c) Orientation:

The orientation of the axis of the 39 ripple-marks and 12 "sand-waves" measured, is shown in Figure 9. The consistent and similar northwest orientation of both structures, is very conspicuous.

V. DISCUSSION OF RESULTS.

(a) Structural Setting:

The approximate trace of the present outcrop or suboutcrop of the Main Reef Leader horizon in the East Rand area is indicated in Figure 8. (See BORCHERS, 1961, Fig. 2). Within the area known as the East Rand Basin, which lies between latitudes 26^{o} 26' and 26^{o} 6', longitudes 28^{o}35' and 28^{o} 17', the Main Reef Leader in general dips south-southeast from the northern flank, west-southwest from the eastern flank and north-northwest from the southern flank. (See Fig.8). According to CLUVER (1957, p.87), "The western side of the basin presents as far as is known, no easterly dip,....and....dips fairly steeply to the west". This area constitutes the north eastern extremity of the large elliptical basin-shaped depression occupied by sediments of the Upper Witwatersrand System. (BROCK 1954, p.6).

While the East Rand basin is a structural reality now, was it a discrete basin during the deposition of the Upper Witwatersrand sediments? BROCK (1954, Caption to illustration No. 1, and p.7 and 8) implied that the basining took place both during and subsequent to the deposition of the Witwatersrand sediments.

In the only detailed structural analysis of the Far East Rand area, however, CLUVER (1957, p.104) concluded that "The deformation of the Witwatersrand System did not commence during the deposition of these beds....but took place in post-Ventersdorp time, or rather post that phase of the Ventersdorp System present" .....in this area. In other words, while the East Rand now constitutes a structural basin, it was not, according to CLUVER, in its present limited extent, a sedimentary basin.

The problem of dating tectonic movements with respect to a sedimentary cycle, can only be solved by a study of primary sedimentary lithologic characteristics and structures. If

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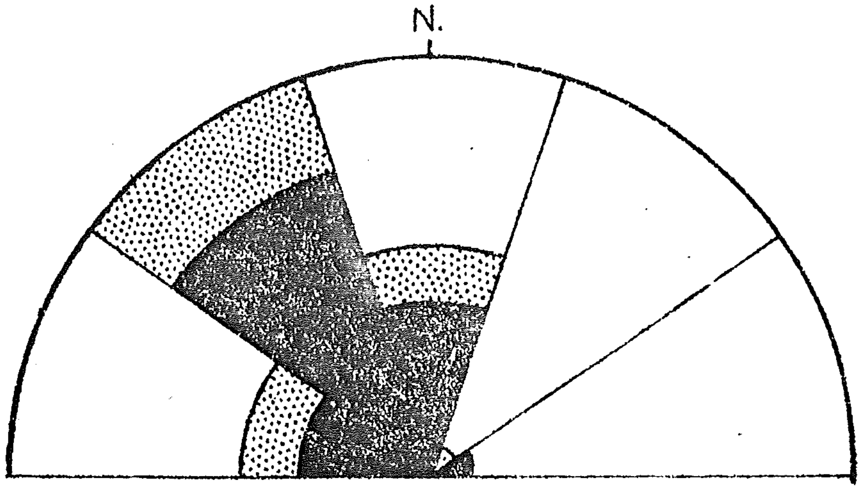

Figure 9: Collective plot of orientation of axes of 39 ripple marks (solid black) and 12 sand waves or "rolls" (stippled).

the East Rand area was a structurally controlled topographic basin during deposition of the Upper Witwatersrand sediments, as is implied by BROCK (1954), then corroboratory sedimentological evidence of radial infilling should be expected, even if the bulk of the sediment was introduced from one side only. It is in this respect that the study of cross-bedding in the Main-Bird quartzites in the East Rand Basin bears directly on the question of its structural and topographic environment during deposition of the Upper Witwatersrand series. In this study, measurements have been extended to outcrops of Main-Bird quartzites situated far south and south east of the East Rand basin proper. (See Fig. 8).

(b) Cross-bedding:

In Figure 8, the results of all cross-bedding measurements made in the East Rand area are summarised. The pattern is simple, and clearly seems to indicate a consistent south easterly direction of transport continuing as far south and south east of Heidelberg as the series can be identified. No suggestion of a limit to the Main-Bird depositional basin in this direction has been encountered. (c.f. BROCK, 1954).

The fanning to the south and east, in the East Rand Basin, needs verification by the accumulation of much more data. If the pattern is confirmed, it would appear to constitute a useful clue to the depositional environment.

(c) Ripple-Marks:

The orientation of the ripple-marks measured in the course of this study is very exceptional, both with regard to their comparative uniformity, and their orientation relative to the direction of sediment transport. As the average ripple axis is generally parallel to the direction of transport, they can presumably be called longitudinal ripples. Longitudinal ripples have been described quite frequently in the literature, but usually occur in association with more abundant, normal transverse ripples. (VAN STRAATEN, 1951). The consistency in orientation of the ripples is particularly remarkable. It is felt that the ripple-marks in these quartzites must be indicative of some particular aspect of the environment of deposition, the interpretation of which is at present obscure. A strong and consistently oriented wave or current system, oscillating along a northeast-southwest axis, is suggested. One can speculate that this may be due either to strong prevailing winds, or flooding by tidal currents.

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VI. COMPARISON OF RESULTS WITH PREVIOUS STUDIES.

A northerly or northwesterly source for the sediments composing the Main-Bird Series has long been accepted. The early evidence supporting this came from (a) PIROW's (1920) study of the pebbles in the Main Reef Leader, whereby he showed a decrease in average pebble size from north or northwest to south or southeast, and (b) REINECKE's (1927) study of pebble and payshoot orientations.

With reference to more recent work, in the "Notes on the Geological Column of the East Rand", presented at the 4th Annual Congress of the Geological Society of South Africa, the following statement is made: "The thickness of the Witwatersrand Column is greatest in the north-west and western part of the area, in the vicinity of Brakpan and Van Dyk, and all divisions show a thinning in an easterly and south-easterly direction. Concomitant with this thinning there is a decrease in the grain size of the sediments, and in the number of auriferous conglomerate bands". With regard to the Main Reef Leader in particular, it "varies greatly in thickness, being as much as 20 feet thick in the north-western part of the area, and thinning fairly regularly in a south-easterly direction to 12 inches or less and becoming sporadic in occurrence and payability". The evidence of south-easterly sediment transport provided by the cross-bedding measurements made in this study are in complete agreement with these isopach trends.

In his study of pebble and payshoot orientations, REINECKE (1927) found that the long axes of the pebbles were oriented parallel to the long axes of the pay shoots and concluded that the payshoots represented primary stream channels (distributaries) in which longitudinal pebble orientation was deemed to occur. Furthermore, the pattern of the payshoots:- fanning to the south east, was interpreted to indicate a south easterly direction of flow. The similarity in the fanning pattern of cross-bedding (Fig. 8) and the payshoot pattern shown by DU TOIT (1954, Fig. p.108) does much to confirm REINECKE's basic interpretation.

ROBERTS and KRANSDORFF (1938, p.244) have suggested that REINECKE's data should rather be interpreted as indicating a shallow marine environment at the time of formation of the Main Reef Leader in which the payshoots represent "Pebble bars", the long axis of the bars and their constituent pebbles being parallel to the shore line.

A high tide flowing north-east to south-west inundating periodically an area being filled with debris from the north-

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west might explain the orientation both of cross-bedding and ripple-marking. It is, therefore, possible that the truth lies somewhere between the respective interpretations of REINECKE and ROBERTS and KRANSDORFF.

VII. PRINCIPLE OF UNIFORMITARIANISM.

In serious attempts to reconstruct Witwatersrand sedimentary environments, one is frequently driven to questioning the detailed validity of the rule: "The present is key to the past".

As has been pointed out (A.O. FULLER, personal communication) there is no present day environment in which desert conditions (i.e. no vegetation) are coupled with high rainfall. Yet such must have existed in Witwatersrand times. (BROCK, 1954; p.8). The consequences of such circumstances as regards the entire process of sedimentation are difficult to conceive.

Likewise, 2,000 million years ago, the moon was an unknown distance closer to the earth (JEFFREYS 1952, p.233 and 310) so that tides must have been higher and more frequent. Furthermore, it has been suggested by WIEBOLS (1955) that glacial conditions played a conspicuous part in the sedimentary history of the Witwatersrand.

The probability that climatic, atmospheric and oceanographic conditions were substantially different from those encountered anywhere on the earth at present make genetic interpretations of sedimentary features very difficult.

The study reported here is of reconnaissance nature. The structures measured, however, are fingerprints of the depositional environment. As indications of Witwatersrand sedimentary history, they will become increasingly valuable as more good observations become available.

VIII. POTENTIAL ECONOMIC SIGNIFICANCE.

1. In-as-much as the gold in Witwatersrand conglomerates is considered to be primarily of alluvial origin, information bearing directly on the direction of alluvial transport must be of fundamental practical economic importance. Cross-bedding in sediments is one of the most important indicators of transport direction.

2. The cross-bedding measurements made underground in the East Rand Basin suggest that there may be a sym-

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pathetic relation between average orientation of pay-shoots in the banket and that of the cross-bedding in the overlying quartzite. As measurement of cross-bedding is considerably more practicable than measurement of pebble orientations (REINECKE, 1927), the relationship, if confirmed by systematic measurement, may prove of practical advantage in certain circumstances.

3. In the course of this study, and work on other Witwatersrand sediments, certain broad differences in the nature of the bedding and cross-bedding in different series have been noted. Apart from variations in mean orientation between units, there are differences in the average thickness of beds and in the form of the cross-bedding. Such features are visible in borehole core, and careful systematic study of them may reveal significant differences which could be an aid in identification and correlation of quartzite units in boreholes in new areas.

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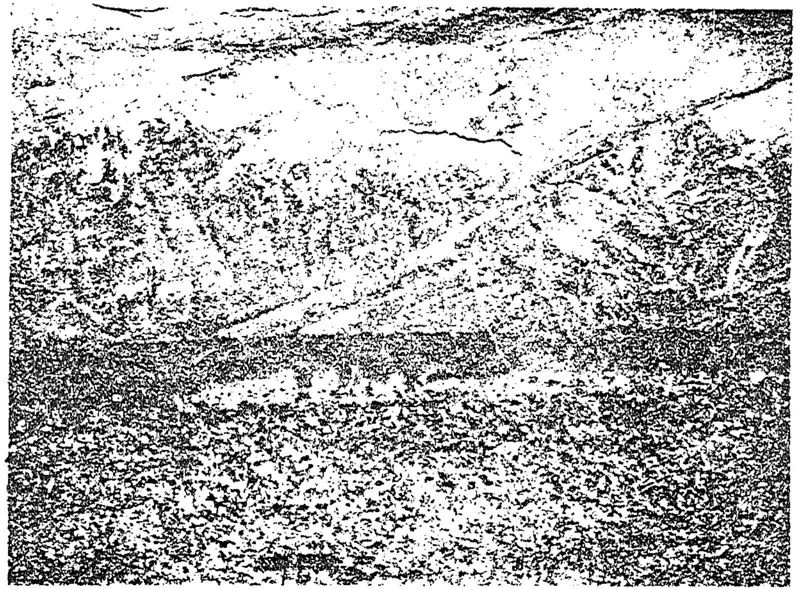

FIG. 1.

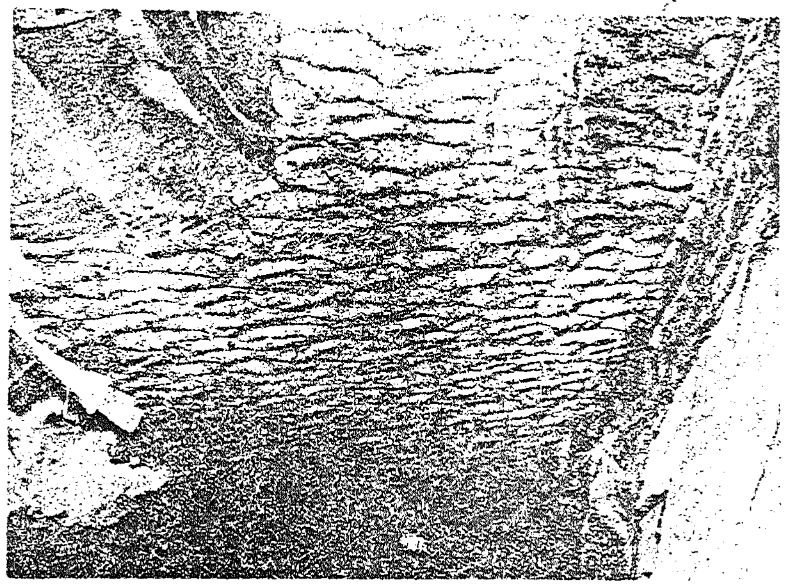

FIG. 2.

FIG. 3.

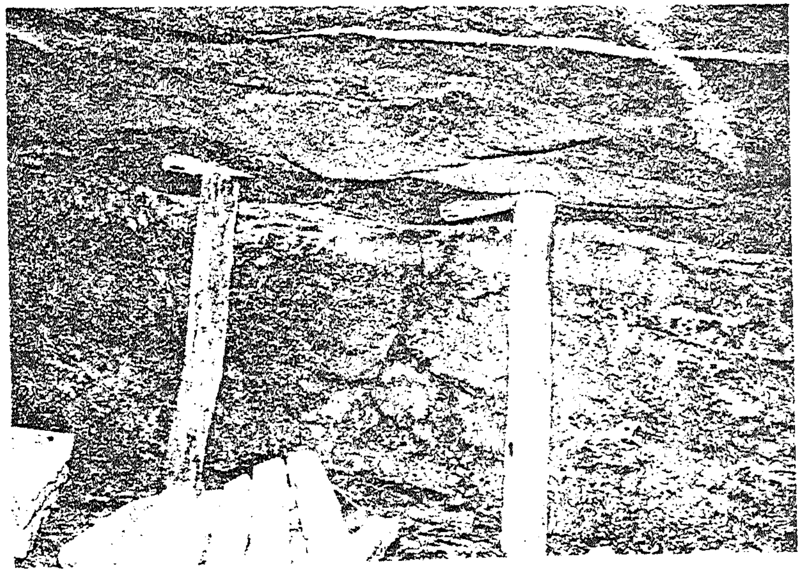

FIG. 4.

PLATE

Figure 1: Cross-bedding in Main Bird quartzite, overlying Main Reef Leader. Loc: 5 Level N., ex No. 1 Shaft, East Geduld.

Figure 2: Ripple Marks (Casts) in Main Bird quartzite. Loc: X-Cut from No. 1 Shaft to 4 Level Drives, East Geduld.

Figs. 3 and 4: Sand Waves or Rolls (?) on roof of stope on Main Reef Leader. Loc: Stope between 4 and 5 Levels, just South of No. 1 Shaft, East Geduld.