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STRATIGRAPHIC ANALYSIS OF THE TRANSVAAL SEQUENCE IN THE IRENE-DELMAS-DEVON AREA, TRANSVAAL

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ABSTRACT

In the Irene-Delmas-Devon area, a number of boreholes have been drilled through the relatively undeformed Transvaal Sequence strata, which are older than 1,950 million years, in search of gold-uranium deposits associated with the ± 2,500 million-year-old Witwatersrand sediments that, in places, underlie the former. A series of stratigraphic maps prepared from the borehole logs shows that stratigraphic mapping techniques, normally used in Phanerozoic formations in the search for petroleum, may be used to advantage in a study of Proterozoic strata.

In some of the maps, observed patterns can be related to the mobility of a series of northwest-trending folds during Transvaal sedimentation and in post-Transvaal times. An independent study has indicated that the same folds controlled the distribution patterns of pre-Transvaal formations in the area. Stratigraphic mapping of Transvaal Sequence strata can thus be used as an aid in the prediction of the preservation patterns of Witwatersrand strata and other pre-Transvaal formations. Other stratigraphic maps, while providing information on the geometry and lithofacies characteristics of Transvaal sediments, do not help in the prediction of pre-Transvaal geology. Quartzites, in general, are not developed as sheet-like bodies, but are confined to channels.

The interpretation of selected stratigraphic maps was aided by the application of polynomial trend-surface analysis. The interplay of regional and more local controls on Transvaal sedimentation is illustrated. Some regional patterns can be related to the geometry of the Transvaal Basin as a whole. Local patterns, as revealed by residual maps, are of greatest importance in the prediction of the positions of folds which were active, continuously or intermittently, in the time span ranging from Witwatersrand to post-Transvaal times.

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<u>STRATIGRAPHIC ANALYSIS OF THE TRANSVAAL SEQUENCE IN THE IRENE-DELMAS-DEVON AREA, TRANSVAAL</u>

<u>CONTENTS</u>

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STRATIGRAPHIC ANALYSIS OF THE TRANSVAAL SEQUENCE IN THE IRENE-DELMAS-DEVON AREA, TRANSVAAL

INTRODUCTION

A. LOCATION OF AREA

The area studied is shown in Figure 1. It lies in the south-central Transvaal, between longitudes 28°09'E and 29°00'E and latitudes 25°50'S and 26°25'S. It stretches from the town of Irene, in the northwest, to Balmoral, in the northeast, and from Leslie, in the southeast, to the East Rand Goldfield, in the southwest. The area measures some 58 miles from east to west by 38 miles from north to south. The stratigraphic studies exclude the Johannesburg Dome, the East Rand Goldfield, and a triangular area in the northeast, in which no borehole control is available.

B. REGIONAL GEOLOGICAL SETTING

A number of large-scale structural features are present in the area. In the southwest is the East Rand Basin, a structural depression, open to the west-southwest, in which are preserved the Precambrian Witwatersrand Sequence, the Precambrian Transvaal Sequence, and the Palaeozoic Karroo Sequence. A similar depression, the Evander Basin, lies beyond the southeastern extremity of the area studied. The Devon Dome, composed of Basement granite and largely covered by Karroo strata, is the structural culmination which separates the above-mentioned basins. To the northwest of the East Rand Basin and due north of Johannesburg, lies the well-exposed granite-greenstone inlier which makes up the Johannesburg Dome.

The Transvaal Sequence crosses the area in a broad, northwest-southeast-trending outcrop belt which dips moderately to the northeast. Intrusive rocks, probably associated with the 1950 million-year-old Bushveld Igneous Complex, largely covered by Karroo strata, occur in the northwestern portion of the area under review. The Late Precambrian Waterberg Sequence strata make their appearance in the extreme north, near Balmoral. The somewhat ragged northwestern rim of the Karroo Basin passes through the area, roughly in a northeast-southwest direction.

C. PREVIOUS WORK

Investigations of the type employed in the present study have not been carried out previously. Isolated facts concerning quantitative aspects of the Transvaal Sequence stratigraphy are found in the explanations accompanying the geological maps which cover the area studied. These include Mellor's (1917) map of the Witwatersrand, Kynaston's (1907) map of the area surrounding Pretoria, Venter's (1934) map of the country between Springs and Bethal, and Visser and others's (1961) map of the area between Middelburg and Cullinan. Stratigraphic maps of the lower portion of the Transvaal Sequence have been presented by Papenfus (1964) and Armstrong (1965). Both authors noted the close similarity in the pattern of deformation of the Transvaal Sequence strata and the underlying Witwatersrand Sequence strata in the East Rand Basin.

D. SCOPE AND AIMS OF PRESENT INVESTIGATION

In the period between the early 1930's and 1968, a large number of boreholes have been drilled to the east, northeast, and north of the East Rand Basin, in search of extensions under cover, of the Witwatersrand Basin. The majority of these boreholes penetrated varying thicknesses of Transvaal Sequence strata. This has resulted in the accumulation of a volume of potentially useful stratigraphic data concerning the Transvaal Sequence. These data have been used, in the present investigation, in the preparation of a variety of stratigraphic maps.

The study was intended to test the applicability of various types of stratigraphic maps, to learn more of the geometry and lithofacies characteristics of Transvaal strata, and to investigate the pattern of folding active during the deposition of Transvaal sediments and in post-Transvaal times. It was hoped to confirm the suspected similarity of patterns of folding which affected Witwatersrand and Transvaal strata, and so to outline areas favourable for the preservation of Upper Witwatersrand sediments beneath a Transvaal cover.

E. ACKNOWLEDGEMENTS

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STRATIGRAPHY OF THE TRANSVAAL SEQUENCE

The stratigraphy of the Transvaal Sequence, as revealed by drilling and as reflected in the literature of the area, is briefly described as an introduction to the stratigraphic mapping of the sequence. The presently-accepted stratigraphic subdivision has been slightly amended, and stratigraphic nomenclature altered to conform with the recommendations of the 1961 code of the American Commission on Stratigraphic Nomenclature (Krumbein and Sloss, 1963). The amended stratigraphic subdivision and nomenclature are shown in Table 1. Where possible, presently-used geographic names have been retained, or names which have fallen into disuse have been resurrected. Only in unavoidable cases have new names been proposed.

The Malmani Dolomite, a name used by Draper in 1894 (Haughton, 1938), is the lowest formation in the sequence. It consists of alternations of dolomitic limestone, chert, and thin lenses of black, carbonaceous shale, and includes the Kromdraai Member (Molengraaff, 1904) at its base. The latter consists of alternations of quartzite, conglomerate, and carbonaceous shale, and has an intercalated contact with the overlying dolomitic limestone.

In the area under study, the Malmani Dolomite is invariably capped by the Fountains Formation. This formation consists of a chert breccia or conglomerate, and may include thin quartzitic lenses.

All the Transvaal Sequence strata above the Fountains Formation are grouped together as the Pretoria Group (Truswell, 1967). Within this unit, all sediments between the Fountains Formation and the Ongeluk Volcanic are considered to belong to the Timeball Hill Formation. This assemblage thus combines the former Timeball Hill Series and the Lower Daspoort Shale. These units have now been combined, since the quartzites which have been used to subdivide them are lenticular, and may be missing in some stratigraphic sections. The Timeball Hill Formation consists predominantly of shale, but includes zones of quartzite, tilloid-rock, and non-clastics. The Pologround Quartzite Member is the lowest horizon of quartzite which lies on, or is separated by a small thickness of shale from the underlying Fountains Formation. A limited number of chert or carbonate beds may be intercalated in the shales overlying the Pologround Quartzite.

The name "Timeball Hill Quartzite" has been replaced by Klapperkop Quartzite Member to avoid homonomy. This quartzite, which is situated near the centre of the formation, consists of a variable number of lenticular quartzite and ferruginous quartzite layers, with interbedded shale. About midway between the Klapperkop Quartzite and the Ongeluk Volcanic are developed lenticular bodies of an unbedded pebbly mudstone. These are jointly referred to as the Riet-fontein Tilloid Lentil. A third quartzite, the Mamre Quartzite Member, is commonly developed immediately below the Ongeluk Volcanic.

The Ongeluk Volcanic, consisting of andesitic lava and associated pyroclastics, is overlain by the Meintjes Kop Shale. This formation includes minor interbedded quartzites and ferruginous quartzites, the most prominent of which is the Tiegerpoort Lentil, at the base of the shale. The Daspoort Quartzite follows on this, and is, in turn, overlain by a great thickness of Silverton Shale. The latter formation carries intercalations of limestone, chert, carbonaceous shale, and volcanic agglomerate. The thick Magaliesberg Quartzite follows. The top of the sequence is marked by the heterogeneous assemblage of sediments and volcanics which make up the Smelterskop Formation.

Group	Formation	Member, Lentil, etc.
Pretoria Group	Smelterskop Formation	
	Magaliesberg Quartzite	
	Silverton Shale	
	Daspoort Quartzite	
	Meintjes Kop Shale	Tiegerpoort Lentil
	Ongeluk Volcanic	
	Timeball Hill Formation	Mamre Quartzite Member Rietfontein Tilloid Lentil Klapperkop Quartzite Member Pologround Quartzite Member
	Fountains Formation	
	Malmani Dolomite	Kromdraai Member

Table 1 : Proposed Lithostratigraphic Subdivision of the Transvaal Sequence

STRATIGRAPHIC ANALYSIS OF THE TRANSVAAL SEQUENCE

Stratigraphic maps are a major tool in the stratigraphic analysis of an assemblage of sediments. Such maps show the areal distribution, configuration, or aspect of a stratigraphic unit or surface (Krumbein and Sloss, 1963). A large number of different types of stratigraphic maps exist (Forgotson, 1960; Krumbein and Sloss, 1963), and attempts were made to employ the the majority of these in the present quantitative study of the Transvaal Sequence.

A. STRUCTURE-CONTOUR MAPS

A structure-contour map shows the geometric configuration of a rock surface by contour lines passed through points of equal elevation above or below a selected datum (Krumbein and Sloss, 1963). In this study, the datum used was sea-level; all elevations are in feet above or below datum. Control points include corrected borehole depths and the outcrop elevations of the key horizons. A contour interval of 250 feet was found to be convenient to the scale of mapping, the dips present, and the accuracy of control elevations. The principles of mechanical contouring (Bishop, 1960) were used, except in areas of poor control.

Figure 2 shows a structure-contour map constructed for the top of the Fountains Formation. Contours strike northwest-southeast across the area. The dip of the key horizon is at a minimum of 9°, to the north and northwest of Delmas. Further to the northwest, the dip increases to over 11°. To the east and southeast of Delmas, dips increase to over 15°, and the strike tends towards a north-south direction. In the west, a block of Transvaal strata is preserved on the downthrown side of the north-south-trending Witkoppies Fault Zone. A dip of 18° to the east-northeast was calculated for the key bed.

The second map (Figure 3) was constructed for the base of the Malmani Dolomite. The portion of this map southwest of a line joining Daveyton and Endicott was adapted from a structure-contour map presented by Papenfus (1964). In the northwest, the Witkoppies Fault Zone is seen to include an adjacent north-northwest-trending syncline and anticline. Papenfus (1964) suggested that the Marievale-Government Gold Mining Areas Syncline of the East Rand Basin might be uplifted and eroded east of Benoni, and that its continuation further to the north might be marked by the zone of preservation of dolomite to the east of Kaalfontein Station. Papenfus's conclusion is supported by the results of the present study. The adjacent anticline is marked by the granite outcrops to the east of Borehole THE.1. This anticline continues southwards into the East Rand Basin, passing between Geduld and Welgedag, and on, through Largo, further to the south. The Largo Anticline and Sundra Anticline are separated by a syncline, the presence of which is indicated by the basin structure near Welgedag.

The Sundra Anticline trends north-northwest through the village of Sundra. Its course is marked by two minor structural culminations, a shift to the north in the limit of preservation of the Malmani Dolomite, and structure-contours convex to the north. East of the Sundra Anticline, the Delmas Syncline is indicated by a swing to the south of the limit of preservation of the Malmani Dolomite, a possible structural depression, and contours concave to the north. The Winterhoek Anticline is delineated by a conspicuous shift to the north of the limit of dolomite preservation, and structure contours which are convex to the north. To the east of the Winterhoek Anticline, the limit of preservation of the Malmani Dolomite swings sharply towards the south, indicating an approach to a synclinal feature of appreciable proportions. The dip of the key horizon to the east of Leslie can be seen to be shallowing out, and the strike to be swinging back towards an east-west direction. It is probable that the synclinal feature indicated is associated with the Evander Basin.

A conspicuous feature of the map shown in Figure 3 is the area of low and reversible dips found to the south of a line joining Daveyton to Delmas. The western portion of this area coincides with the basin of dolomite preservation on the East Rand. To the east, a probable basin structure is located between Borehole SW.1 and the Middelbult group of boreholes. Since the same elevation of the key bed occurs in Boreholes SW.1, MB.1, and MB.2, the key bed is either flat-lying between these localities or, more likely, the two are separated by a structural depression.

The effects of post-Transvaal tectonism on the sediments of the Transvaal Sequence have been elucidated by structure-contour maps. On a broad scale, the pattern is one of steeper dips in the northwest of the area, shallower dips in the central area, and steeper dips combined with a swing towards a north-south strike in the southeast. In the extreme southeast, there are indications of a shallowing-out of dip and a swing of strike back towards an east-west direction. The interpretation placed on the above is that, in post-Transvaal times, the Johannesburg and Devon domes experienced a relative upward movement with respect to surrounding portions of the Transvaal Basin. Transvaal strata adjacent to the domes were dragged upwards, to produce a steeper dip as they were moulded about the domes. In the area between the domes, the Transvaal sediments were left draped with a lower angle of dip.

Greater detail was added to this broad picture by the structure-contours at the base of the Malmani Dolomite. A series of seven northwest- or north-northwest-trending anticlines and synclines was seen. These folds have wavelengths varying between five and ten miles. There are numerous examples of structural depressions and culminations along the traces of these folds, which possibly indicate that the folds were intersected by another set of folds. Notable is the probable structural depression developed to the south of Delmas, between Borehole SW.1 and the Middelbult group of boreholes.

B. ISOPACH MAPS

An isopach map shows the varying thickness of a stratigraphic unit by contour lines drawn through points of equal thickness (Krumbein and Sloss, 1963). Isopach maps are one of the most common types of maps used in deciphering the tectonic framework of a sedimentary basin or a portion of a basin. In the isopach maps prepared, drilled thicknesses were corrected for dip of strata, and the increased thicknesses due to the presence of intrusive sills were compensated for. In a number of cases, isolith maps were more convenient to prepare than isopach maps, and served the same purpose. For this reason, only a limited number of isopach maps were constructed.

Figure 4 is an isopach map of the Timeball Hill Formation. The thickness of the formation varies from 1,200 feet in the southeast, to over 1,800 feet in the northwest. Overprinted on this regional variation are two features of more local importance. The first is a thinning of sediments in the area around Boreholes VOK.1 and WP.1. The second is the marked increase in thickness to the north of Delmas, a maximum of over 1,800 feet being intersected in Borehole WK.1. The regional pattern has been interpreted as being due to an approach towards the depositional axis of the Transvaal Basin in a northwesterly direction. The localized thinning and thickening of sediments reflect the presence of tectonically positive and negative elements, respectively, of limited areal extent. These variations in thickness were due either to deformation of the floor of the Transvaal Basin during deposition, or to the combined effects of folding and erosion before the extrusion of the Ongeluk Volcanics. The fact that these local tectonic elements coincide with the traces of post-Transvaal folds (as indicated by structure-contour maps) is considered to be more than accidental. It has been concluded that folds which deformed the Transvaal strata in post-Transvaal times were active during, or immediately after, deposition of the Timeball Hill Formation, and so played a part in determining the thickness of sediments deposited in any place.

A total of seven boreholes fully penetrated the Ongeluk Volcanic. This number was considered too small for the construction of an isopach map. Nevertheless, a study of thicknesses reveals a regional pattern of thickening towards the northwest. The Ongeluk Volcanic shows a minimum thickness of 1,380 feet in the southeast, which increases, through 1,500 feet north of Delmas, to over 1,750 feet in the northwest. A sympathetic thickening of volcanics and the underlying sediments towards the depositional axis of the Transvaal Basin, is indicated.

The combined thicknesses of the Meintjes Kop Shale and the Daspoort Quartzite could be determined in only four boreholes. They range from a minimum of 619 feet in Borehole RH.1 in the southeast, to a maximum of 672 feet in Borehole VOK.1 in the northwest. The indications are that this unit thickens towards the northwest, in sympathy with underlying units.

C. ISOLITH MAPS

Isolith maps record the areal variation in net thickness of a certain lithologic type in a stratigraphic section. Their construction merely involves the calculation of the cumulative drilled thickness of a given rock type in a stratigraphic unit, the correction of net thickness for dip, and the contouring of control points.

The variation in cumulative thickness of coarse clastic sediments (conglomerate, grit, and quartzite) at the base of the Malmani Dolomite is shown in Figure 5. In this map, a well-defined trough of thicker coarse clastic sediments is seen to extend from Borehole RWv.1 in the south, through the Middelbult group of boreholes, northwestwards through Delmas. Coarse clastic sediments thin out rapidly on either side of this trough, and may, as in the eastern area, cease to be developed. Within the East Rand Basin, anomalously thick accumulations of conglomerate and quartzite have been found in original sedimentary channels which were cut in underlying strata (Papenfus, 1964). Furthermore, these channels are broadly coincident with post-Transvaal synclines. Using the East Rand Basin as a model, the trough of coarse clastic sediments outlined here is thought to be an original channel cut in the pre-Transvaal strata. It is believed that the positioning of this channel was probably influenced by the activity of the Delmas Syncline in earliest Transvaal times.

Figure 6 shows the variation in the cumulative thickness of dolomitic limestone and chert in the Malmani Dolomite. Since non-clastics make up by far the greatest percentage of rock types present in the Malmani Dolomite, this map must resemble closely an isopach map of the whole formation. In Figure 6, a regional increase in non-clastic thickness from 1,500 feet in the southeast to over 4,100 feet in the northwest is seen. This change probably reflects a northwestward increase in the space made available for sedimentation, and, in turn, indicates an approach towards the depositional axis of the Transvaal Basin. A local thickening of non-clastics is evident to the north and north-northwest of Delmas, while a local thinning to less than 2,500 feet is seen to the west of this. These changes reflect the activity of small-scale tectonic elements during the deposition of non-clastics, or in immediately post-Malmani times. The positioning of these local changes in thickness indicates that they owe their origin, once again, to the activity, during Transvaal sedimentation, of the Sundra Anticline and Delmas Syncline.

In Figure 7, the variation in the cumulative thickness of chert breccia in the Fountains Formation is shown. The gross pattern of variation appears to be a thinning towards the northwest. More locally, there is an increase in chert breccia thickness to 370 feet northeast of Delmas, and a decrease to less than 100 feet north of this town. It seems that both regional and local patterns of thickness variation are the inverse of the observed patterns in the various isopach and isolith maps presented thus far. It is evident that the thickness of chert breccia, as an indicator of the tectonic framework of deposition, behaves anomalously. It is thickest in tectonically positive areas and thinnest in negative areas. The most plausible explanation for these facts is that the chert breccia is the product of sub-aerial weathering of the Malmani Dolomite. Such a deposit might be expected to be thickest in areas of maximum exposure, such as tectonically positive elements.

A map showing the cumulative thickness of quartzite in the Timeball Hill Formation has been prepared, but has not been presented since it poses problems in interpretation. The patterns seen in this map are a reflection of the superimposed effects of three widely separated quartzite horizons. The three quartzites do not necessarily show the same pattern of development, with the result that the cumulative thickness pattern could well be meaningless. The problem is overcome by considering the three quartzites as separate entities, as is developed in a subsequent section of this paper.

About midway between the Klapperkop Quartzite and the top of the Timeball Hill Formation, lies a variable number of beds of a pebbly mudstone, here called "tilloid". The variation in net thickness of this rock type is shown in Figure 8. A marked and regular thickening from less than 20 feet in Boreholes KST.1 and WK.2 to 240 feet in Borehole ZT.1 can be seen. Eastwards of Borehole WK.2, the thickness appears to increase once more. Northwest of Borehole ZT.1, surface mapping indicates that the tilloid wedges fairly rapidly, and is not developed at distances greater than four miles northwest of Borehole ZT.1 (Kynaston, 1907). These figures indicate that the gross shape of the tilloid bodies is that of an asymmetrical lens which thins severely to the northwest and gradually to the southeast. The pattern might be explained on the tentative assumption that the tilloid is the product of turbidity flow sedimentation. Turbidity flows might have originated from the tectonically positive area northeast of Delmas. The flows might then have moved down the palaeoslope, leaving thicker deposits as they proceeded in a northwestward direction. On approaching the depositional axis of the Transvaal Basin, it is speculated that the depositional slope flattened and caused the rapid fall-off in the thickness of the turbidity flow deposits.

D. <u>PERCENTAGE MAPS</u>

In percentage maps, the percentage of one lithologic type is computed with respect to the total thickness of the stratigraphic unit. Isolith and percentage maps of the same phase of a stratigraphic unit may be similar or markedly different, depending on the variation in the total thickness of the stratigraphic unit in question. When the total thickness of the unit does not vary markedly, then the patterns revealed by isolith and percentage maps of the same rock type may be so similar as to render one of the maps redundant.

Since the Timeball Hill Formation does not vary much in its thickness over the area, no percentage maps are presented for those phases of the formation studied by isolith maps. One component of the formation, however, was investigated by means of percentage maps. The Pretoria Group is characterized by numerous, laterally extensive and conformable basic igneous bodies. The percentage of such igneous material is shown contoured in Figure 9. The percentage map reveals a striking increase in the percentage of igneous material from 6 per cent, in the northwest, to 36 per cent, at Borehole RH.1. Southeast of Borehole RH.1, the percentage decreases to 26 per cent. It is evident that there is a focal point of igneous activity to the north of Borehole RH.1. It is significant that, on a number of farms immediately north of Borehole RH.1, the upper and middle portions of the Pretoria Group are almost completely stoped away by a suite of intrusives allied to the Bushveld period of igneous activity (Venter, 1934). The conclusion that the igneous bodies developed in the Timeball Hill Formation in the area under study are related to the known centre of intrusion is strongly favoured. It would appear that the basic phase of the Bushveld Complex, in this area, transgressed its normal limits of intrusion, forcing its way into successively lower stratigraphic levels, while stoping and assimilating the higher ones. Cousins (1962) has suggested that a number of the igneous bodies referred to above represent lava flows. The percentage map presented here mitigates against this theory, and indicates that the majority of the igneous bodies are true intrusive sills associated with a known centre of intrusive activity.

E. <u>RATIO MAPS</u>

In ratio maps, the thickness ratio of one rock type to another provides an effective means of displaying the interrelationships between two lithologic components with a single set of contours (Krumbein and Sloss, 1963). As with the case of percentage maps, ratio maps may, under certain conditions, merely repeat patterns shown by isolith maps. This appears to be the case when, in addition to maintaining a relatively constant thickness, the stratigraphic unit is a binary one, or is made up of three or more rock types with one rock type developed in consistently major proportions. In the Timeball Hill Formation, the excessive amount of shale and the fact that the thickness of the formation does not vary markedly over the area indicate that ratio maps of the minor components of the formation with respect to shale will yield map patterns which do not differ significantly from isolith or percentage maps. For this reason, no ratio maps have been presented.

F. MAPS BASED ON THE FACIES TRIANGLE

A facies triangle is commonly used when a stratigraphic unit has three components, or when any three components in a stratigraphic unit of more than three components are selected for study. Krumbein and Sloss (1963) have recommended that three-component stratigraphic data be plotted on the percentage triangle. The plotted points can then be examined, to guage which of the many facies maps based on the facies triangle may be used to best advantage with the particular three-component system.

Figure 10(a) shows a triangular plot of the system shale-quartzite-tilloid in the Timeball Hill Formation. The severe clustering of control points in the shale corner of the triangle is a reflection on the fact that shale makes up from 81 to 94 per cent of the formation, while the percentage quartzite varies between 3 and 17 per cent, and that of tilloid between 0 and 13 per cent. To be effective, three-component studies require a spread of control points over the facies triangle. In the Timeball Hill Formation, one- and two-component studies are to be preferred, because of the predominance of shale.

A triangular plot of the system lava-agglomerate-tuff in the Ongeluk Volcanic is shown in Figure 10(b). The predominance of lava in the formation (69 to 93 per cent) causes a strong clustering of control points in the lava corner of the facies triangle. The abundance of agglomerate varies from 3 to 24 per cent, while that of tuff varies from 0 to 17 per cent. No facies maps were prepared for this system, because of the preponderance of lava and the small number of control points.

G. VERTICAL-VARIABILITY MAPS

Vertical-variability maps show the degree of differentiation of a stratigraphic unit, or the vertical distribution of rock types in a stratigraphic unit (Forgotson, 1960). In one type of vertical-variability map, the variation in the number of beds of a specific rock type in a stratigraphic unit is shown. In such maps, the minimum thickness of a bed and the minimum distance separating beds must be arbitrarily defined. A map showing the number of beds of tilloid in the Timeball Hill Formation has been prepared. Tilloid beds were defined as being a minimum of five feet in thickness and as being separated by at least five feet of non-tilloid material. In this map, which has not been presented, the number of tilloid beds varied from one in the northwestern portion of the area to four in the area east of Delmas. When considered in conjunction with the tilloid isolith map (Figure 8), it is evident that the thickest tilloid accumulations in the northwest feather out in a southeasterly direction, as the cumulative thickness decreases.

A second map, showing the number of intrusive sills in the Timeball Hill Formation, was prepared. The thickness and separation of sills was defined as for the tilloid beds. The number of sills varied from one, in the northwest, to six in the central and southeastern area, to four in the extreme southeast, in Borehole DSt.1. The pattern of variation is very similar to that shown in the percentage map in Figure 9. This map is not presented, since it merely confirms the conclusions drawn from the percentage map.

Centre-of-gravity maps are another class of vertical-variability maps. A centre-of-gravity map shows the relative weighted mean position of beds of a certain rock type in terms of their distance from the top of the unit, expressed as a percentage of the total thickness of the unit (Krumbein and Libby, 1957). The relative centre-of-gravity ranges from 0 to 100 per cent as the centre-of-gravity of a rock type moves from the top of a stratigraphic unit to its base.

A centre-of-gravity map showing the vertical variation of the development of quartzites in the Timeball Hill Formation is presented in Figure 11. The relative centre-of-gravity is seen to vary from 20 to over 85 per cent, and is contoured on a 10 per-cent interval. The map shows a well-defined maximum surrounding Boreholes WK.1, WK.2, and RH.1. This indicates that the centre-of-gravity of the quartzites is near the base of the stratigraphic unit, and, in turn, suggests that the Pologround Quartzite is particularly well-developed in the vicinity of these boreholes. Two minima, one around Boreholes KP.1, VOK.1, and WP.1, and the other around Borehole DSz.1, suggest that the Mamre Quartzite is best developed in these vicinities. The moderate values (between 30 and 70 per cent) for the remainder of the map indicate a centre-of-gravity for quartzite near the middle of the Timeball Hill Formation. This observation is difficult to interpret, since a relative centre-of-gravity near the middle of the stratigraphic unit could be brought about by one centrally placed quartzite or by a number of quartzite beds symmetrically distributed about the middle of the stratigraphic unit. This problem can be solved in a number of ways, one of which is the use of slice-isolith maps.

In slice-isolith maps, the stratigraphic unit is subdivided into a number of arbitrary slices, and the thickness of a particular lithology in a chosen slice is calculated and contoured over the area. In the Timeball Hill Formation, three unequal slices were chosen. The uppermost slice made up 10 per cent of the total thickness of the formation, the middle slice 80 per cent, and the basal slice 10 per cent. The net thickness of quartzite in each slice was calculated, and is contoured in the three maps of Figure 12. The slices were chosen as outlined above to illustrate the variation in the development of the Mamre Quartzite (in the upper slice), the Klapperkop Quartzite (in the middle slice), and the Pologround Quartzite (in the basal slice).

In Figure 12(a), the thickness of quartzite in the upper slice varies 0 to over 60 feet. The Mamre Quartzite is seen to be well-developed in the northwestern part of the area under study and in two limited areas north-northwest and east-northeast of Delmas. Comparison of this map with the centre-of-gravity map (Figure 11) shows that the areas of well-developed Mamre Quartzite coincide with contoured lows in the centre-of-gravity map. This slice-isolith map confirms the pattern shown by the centre-of-gravity map, insofar as the Mamre Quartzite is concerned. The variation in net thickness of quartzite in the central slice of the Timeball Hill Formation is shown in Figure 12(b). The map reveals highs of over 100 feet in the northwestern portion of the area and of over 60 feet east of Delmas. These highs are separated by an area of exceptionally poorly developed quartzite to the north of Delmas. This map provides an explanation for the observation made by Venter (1934) that the Klapperkop Quartzite peters out in outcrop to the north-northwest of Delmas, but shows a prominent outcrop on either side of this. Venter offered no explanation for this feature. This map suggests that the absence of a prominent outcrop is due to the poorly developed nature of the quartzite, rather than to any factors relating to geomorphology and weathering. Figure 12(c) illustrates the variation in the thickness of quartzite in the basal slice of the Timeball Hill Formation. The quartzite is virtually confined to the area north of Delmas. This confirms the centre-of-gravity high shown in this position in Figure 11. The development of the Pologround Quartzite is irregular, varying from under 20 feet to over 100 feet over relatively short distances. The contour pattern is reminiscent of that of a meandering stream, and possibly suggests that the Pologround Quartzite was deposited in a fluvial environment which followed the period of exposure presumed to have been responsible for the production of the chert breccia in the Fountains Formation, and which preceeded the presumed deeper-water period responsible for deposition of the shales of the Timeball Hill Formation.

H. TREND-SURFACE MAPS

Polynomial trend-analysis is one of the mathematical methods devised for separating local fluctuations in areally distributed data from the broader regional pattern of variation. Trend-surface maps, when studied in conjunction with maps showing the deviation from the trend-surfaces, offer a greater insight into the interaction of local and regional effects in controlling the magnitude of an areally distributed variable.

The computer program used in this study was written by O'Leary, Lippert, and Spitz (1966) for an IBM. 7040 computer. It was modified for use in an IBM. 360/50 computer by Mr. P. A. Esselaar of the Economic Geology Research Unit. Three stratigraphic maps were subjected to trend-surface analysis.

The map showing the variation in coarse-clastic thickness at the base of the Malmani Dolomite was analyzed by surfaces up to and including the cubic. On the basis of the increase in the percentage variation explained by successive surfaces, the quadratic surface was selected as most closely approximating the trend-surface. The portion of this surface within the area of control is shown in Figure 13(a). The surface exhibits a north-south-elongated, saddle-like high, with thicknesses decreasing slowly towards the north and south and much more rapidly towards the east and west. In the east-west direction, the controlling factor would appear to be a buckling of the depositional floor, with a wavelength of some 35 miles. The positive element in the west could well have been an incipient form of the essentially post-Transvaal Johannesburg Dome, while the eastern arch could have been associated with the Devon Dome. The broad trough between the arches probably represented a mildly negative area, subsiding slightly faster than adjacent arches.

The residuals from the quadratic surface are shown in Figure 13(b). A conspicuous feature is the northwest trend of contours over most of the map. The zero contour outlines an area within which all residuals are positive. This elongate zone of excess coarse clastic thickness probably represents an original sedimentary channel. The fact that this channel trends northwest, parallel to the inferred palaeoslope during Malmani times, supports this idea. The channel roughly coincides with the trace of the Delmas Syncline, which suggests that this feature was operative in earliest Transvaal times, and was responsible for the siting of the channel. The channel is flanked on either side by areas in which anomalously thin accumulations of conglomerate and quartzite are present, suggesting the activity of the Winterhoek and Sundra anticlines during the initial phase of Transvaal sedimentation.

The second map to be considered was the non-clastic isolith map for the Malmani Dolomite, for which polynomial surfaces up to and including the cubic were computed. The extremely high percentage of the total variation explained by the linear surface (79 per cent) indicated that this surface best approximates the trend-surface. This surface is shown in Figure 14(a). The contours trend some 10° north of east, and the increase in thickness is towards the north-northwest at a rate of 93 feet per mile. The probable regional control for non-clastic thickness was the rate of subsidence during deposition, which increased in a more-or-less linear fashion towards the depositional axis of the Transvaal Basin. This argument is strengthened by the fact that the contour lines of the linear surface are approximately parallel to the depositional axis of the Transvaal Basin. The palaeoslope during Malmani times probably dipped gently towards the north-northwest.

Since low-order trend surfaces with a high degree of fit may be used as predictive devices over limited distances (Allen and Krumbein, 1962), the contours of Figure 14(a) were not limited to the area of control, but were extended over the whole area. It is evident that the thickness of non-clastics of the Malmani Dolomite in the East Rand Basin must have been of the order of 2,000 feet, before much of it was removed by post-Transvaal erosion.

The residuals from the linear surface are shown in Figure 14(b). A well-defined pattern of alternating areas containing positive and negative residuals can be seen. The first such area is one of positive residuals, and is situated north of Delmas. The residuals vary in magnitude from +34 feet to +409 feet, and average +178 feet for the eleven control points concerned. Contours in this area have a dominant northwest trend. This zone of excess thickness is added evidence of the activity of the northwest-trending Delmas Syncline during the deposition of the Malmani Dolomite, or immediately thereafter. The syncline is presumed to have caused more rapid subsidence during deposition, or less rapid elevation in a period of erosion following deposition. To the east of the Delmas Syncline is an area of negative residuals, in which the average residual for the five control points concerned is -252 feet. Once again, contours trend northwest or north-northwest. This anomalously thin sedimentation can be ascribed to the activity of the Winterhoek Anticline in the same timespan as that indicated above. The activity of the Sundra Anticline, to the west of the Delmas Syncline, is indicated by an area of negative residuals which average -247 feet for the four control points concerned.

According to Allen and Krumbein (1962), the residuals from a low-order surface with a very good fit (such as the linear surface under discussion) are mainly due to "noise", and have little or no geological significance. If residuals are due to random errors or "noise", then positive and negative residuals can be expected in close proximity. However, as has been shown, well-defined areas of positive or negative residuals exist, and it is doubtful whether the conclusion of Allen and Krumbein (1962) is applicable to the data from the area studied.

A third map subjected to trend-surface analysis was that showing the cumulative thickness of chert breccia in the Fountains Formation. The quadratic surface for this map is shown in Figure 15(a). The surface has the form of an "anticline", plunging to the west-northwest at a rate of 5 feet per mile. This map confirms the regional northwestward decrease in the thickness of chert breccia, suspected from a study of an earlier map.

The residual map from this surface is shown in Figure 15(b). An area of negative residuals north of Delmas indicates thinly developed chert breccia, and can be related to the activity of the Delmas Syncline which is thought to have protected the Malmani Dolomite from the full severity of a period of post-Malmani erosion, so decreasing the amount of chert detritus available. The area of negative residuals is flanked on either side by areas of positive residuals. These areas do not extend far enough to the west and east to be related to the Sundra and Winterhoek Anticlines. The large variability of the chert breccia thickness data and the difficulty encountered in interpreting the residual map could, in themselves, be significant. They might suggest the existence of an uneven karst topography in post-Malmani times. Excessive thicknesses of chert breccia might have accumulated in solution depressions, and thinner accumulations on pillars or ridges of unweathered non-clastics. In this way, local effects could be expected to predominate over regional ones, so producing data with a high variability.

CONCLUSIONS

The moulding of Transvaal strata about the emergent Johannesburg and Devon domes in post-Transvaal times has caused inflections in strike and a steepening of dip. In the inter-domal areas, strata are relatively undisturbed. On a smaller scale, Transvaal rocks have been deformed by a series of north-northwest-trending synclines and anticlines. Minor culminations and depressions are developed along the traces of these folds, possibly indicating the activity of another set of folds.

A series of isopach and isolith maps shows that at least three of the north-northwest-trending folds, the Sundra and Winterhoek anticlines and the Delmas Syncline, were active as tectonic elements which deformed the depositional floor of the Transvaal Basin for a time-span extending from the initial period of Transvaal sedimentation to at least the period of deposition of the Timeball Hill Formation. A study of the preservation patterns of pre-Transvaal rocks in the area (Button, 1968) has shown that the same three folds are a major controlling factor in the distribution patterns of these rocks. Upper Witwatersrand rocks are preserved exclusively along the trace of the Delmas Syncline, while Lower Witwatersrand strata and Basement granite were exposed along the anticlines in pre-Transvaal times.

On a broader scale, a number of stratigraphic maps illustrate the control on sedimentation exerted by proximity to the depositional axis of the Transvaal Basin. In general, stratigraphic units become thicker towards this axis. It was deduced that, during Transvaal sedimentation, the palaeoslope dipped gently towards the northwest. A map showing the variation in the percentage of igneous material in the Timeball Hill Formation suggests that this material represents true intrusive sills which are related to a known centre of intrusive activity. A centre-of-gravity map was partially successful in showing the pattern of vertical variation in the development of quartzites in the Timeball Hill Formation. However, a series of three slice-isolith maps defined the pattern of development of the quartzites more clearly. The quartzites of the formation are not continuous, sheet-like bodies. They have a limited areal extent, and closer borehole control might well have shown that they are confined to relatively narrow channels. The pattern of thickness variation for the Pologround Quartzite is suggestive of a fluvial channel.

Polynomial trend-surface analysis has shown that the thickness of coarse clastic sediments at the base of the Malmani Dolomite was controlled by gentle warping of the depositional floor on which was superimposed a northwest-trending channel. The thickness of non-clastics in the Malmani Dolomite has been indicated to be primarily a function of the distance from the depositional axis of the Transvaal Basin. The three northwesterly-trending folds previously outlined have been clearly delineated in a residual map, pointing to the conclusion that these folds played a secondary role in controlling non-clastic thickness. On a regional scale, the thickness of chert breccia in the Fountains Formation decreases gradually towards the northwest. More locally, the highly variable nature of the data shown in the residual map suggests that a karst-like topography might have been a factor in controlling the thickness of chert breccia.

* *

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* *

KEY TO FIGURES

<u>Figure 1</u> : Locality map, indicating the position and extent of the Irene-Delmas-Devon area.

<u>Figure 2</u> : A depth contour map of the top of the Fountains Formation (Chert Breccia), Transvaal Sequence.

<u>Figure 3</u> : A depth contour map of the base of the Malmani Dolomite (Black Reef), Transvaal Sequence.

<u>Figure 4</u> : An isopach map of the Timeball Hill Formation, Transvaal Sequence.

<u>Figure 5</u> : A coarse clastic isolith map, Malmani Dolomite, Transvaal Sequence.

<u>Figure 6</u> : A non-clastic isolith map, Malmani Dolomite, Transvaal Sequence.

* *

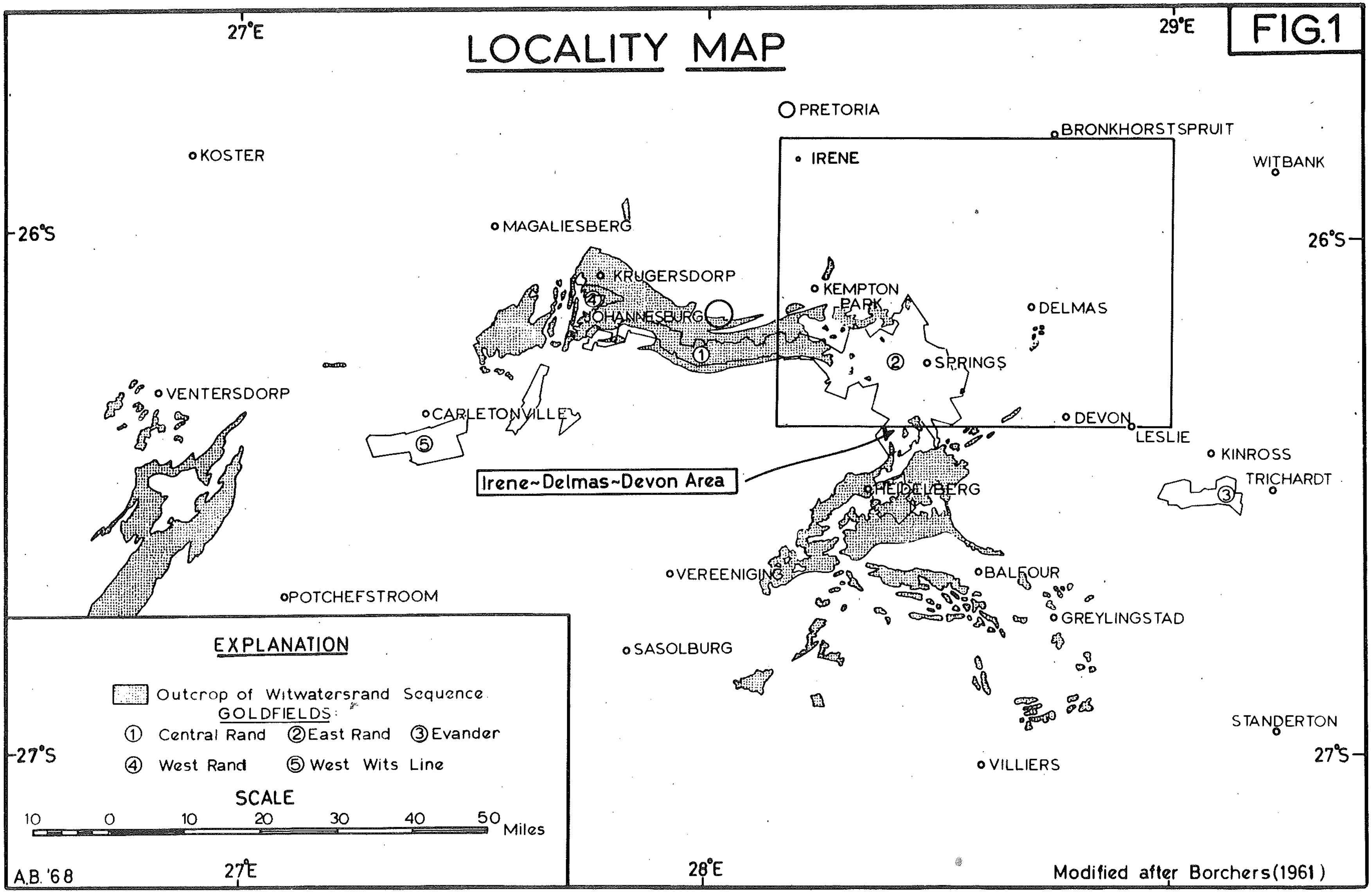
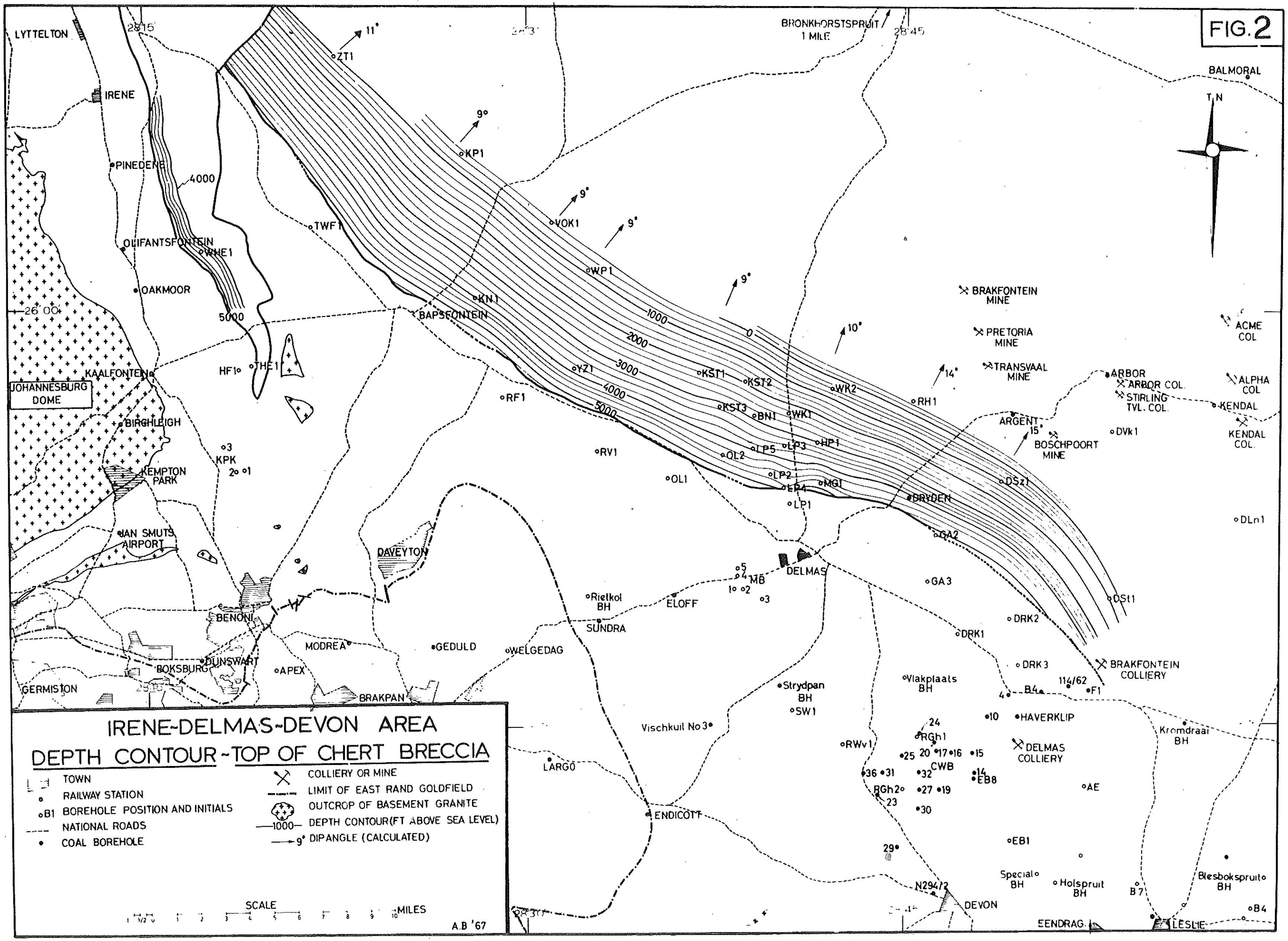


FIG.1
LOCALITY MAP
27°E
29°E
28°E
26°S
27°S
PRETORIA
BRONKHORSTSPRUIT
WITBANK
KOSTER
IRENE
MAGALIESBERG
KRUGERSDORP
KEMPTON PARK
JOHANNESBURG
DELMAS
SPRINGS
VENTERSDORP
CARLETONVILLE
DEVON
LESLIE
KINROSS
TRICHARDT
Irene~Delmas~Devon Area
HEIDELBERG
VEREENIGING
BALFOUR
GREYLINGSTAD
POTCHEFSTROOM
SASOLBURG
STANDERTON
VILLIERS
EXPLANATION
Outcrop of Witwatersrand Sequence
GOLDFIELDS:
① Central Rand ② East Rand ③ Evander
④ West Rand ⑤ West Wits Line
SCALE
10 0 10 20 30 40 50 Miles
A.B.'68
Modified after Borchers (1961)

FIG. 2



IRENE-DELMAS-DEVON AREA
DEPTH CONTOUR - TOP OF CHERT BRECCIA
TOWN
RAILWAY STATION
B1 BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COAL BOREHOLE
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
1000 DEPTH CONTOUR (FT ABOVE SEA LEVEL)
9° DIPANGLE (CALCULATED)
SCALE
MILES
A.B '67
T.N
LYTTELTON
IRENE
PINEDENE
OLIFANTSFONTEIN
OAKMOOR
KAALFONTEIN
JOHANNESBURG DOME
BIRCHLEIGH
KEMPTON PARK
JAN SMUTS AIRPORT
BENONI
BOKSBURG
DUNSWART
GERMISTON
APEX
MODREA
BRAKPAN
DAVEYTON
GEDULD
WELGEDAG
SUNDRA
Rietkol BH
ELOFF
DELMAS
LARGO
ENDICOTT
Vischkuil No3
Strydpan BH
SW1
Vlakplaats BH
HAVERKLIP
DELMAS COLLIERY
BRAKFONTEIN COLLIERY
Kromdraai BH
Blesboksprult BH
LESLIE
EENDRAG
DEVON
N294/2
Special BH
Holspruit BH
BALMORAL
BRONKHORSTSPRUIT 1 MILE
BRAKFONTEIN MINE
PRETORIA MINE
TRANSVAAL MINE
ARBOR
ARBOR COL.
STIRLING TVL. COL.
ACME COL
ALPHA COL
KENDAL
KENDAL COL.
ARGENT
BOSCHPOORT MINE
DRYDEN
BAPSFONTEIN
ZT1
KP1
VOK1
WP1
TWF1
WHE1
KN1
HF1
THE1
KPK
RF1
RV1
YZ1
OL1
OL2
KST1
KST2
KST3
BN1
WK1
WR2
RH1
LP1
LP2
LP3
LP5
EP4
MG1
HP1
DSz1
DSt1
DLn1
DVk1
GA2
GA3
DRK1
DRK2
DRK3
B4
114/62
F1
RGh1
RGh2
CWB
EB8
EB1
AE
RWv1
B7
MB
0
1000
2000
3000
4000
5000

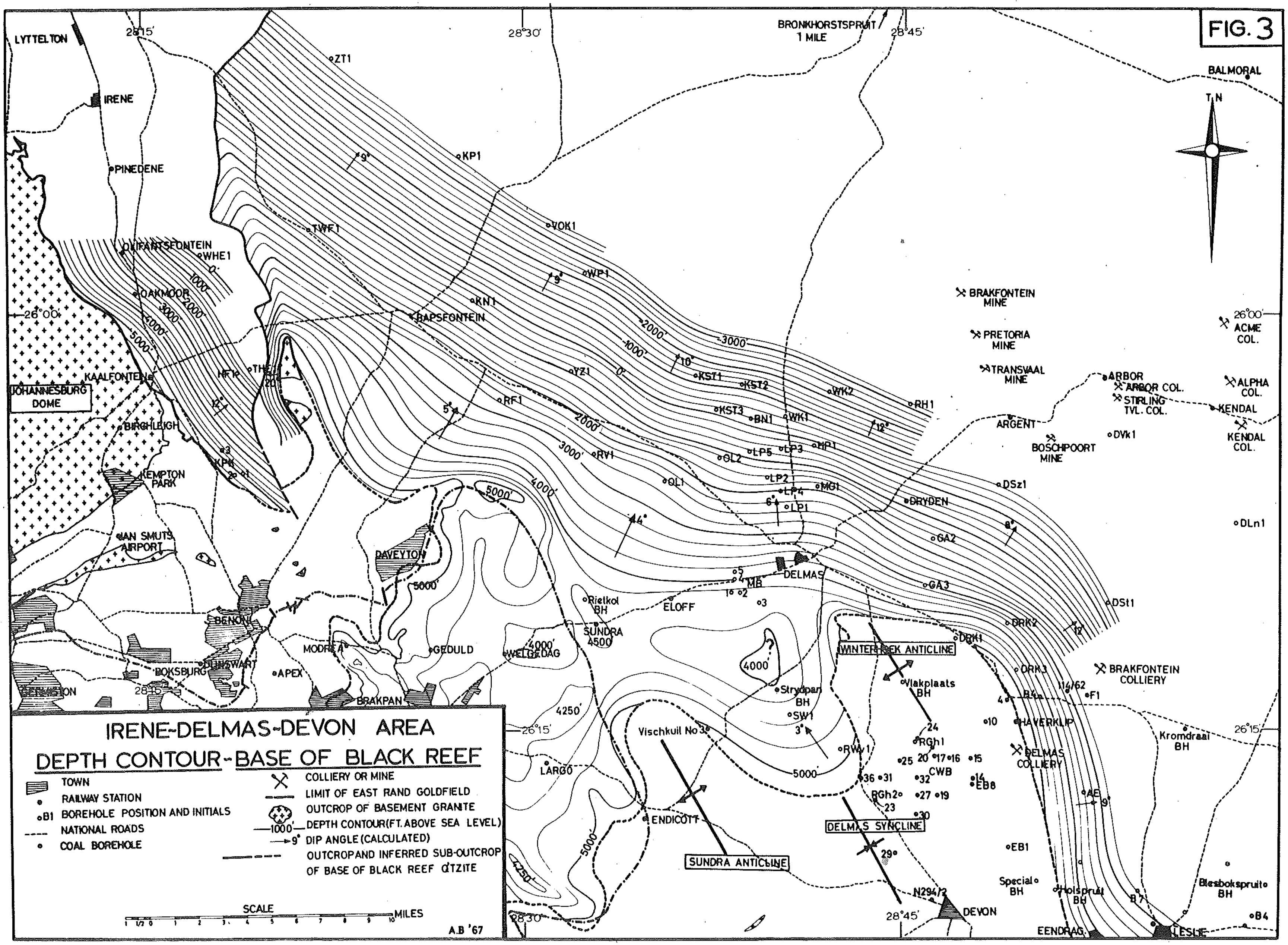


FIG. 3
IRENE-DELMAS-DEVON AREA
DEPTH CONTOUR - BASE OF BLACK REEF
TOWN
RAILWAY STATION
B1 BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COAL BOREHOLE
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
1000' DEPTH CONTOUR (FT. ABOVE SEA LEVEL)
9° DIP ANGLE (CALCULATED)
OUTCROP AND INFERRED SUB-OUTCROP OF BASE OF BLACK REEF Q'TZITE
SCALE
MILES
A.B '67
LYTTELTON
IRENE
PINEDENE
OLIFANTSFONTEIN
OAKMOOR
KAALFONTEIN
JOHANNESBURG DOME
BIRCHLEIGH
KEMPTON PARK
JAN SMUTS AIRPORT
BENONI
BOKSBURG
DUNSWART
APEX
MODDER A
GEDULD
BRAKPAN
DAVEYTON
RAPSFONTEIN
WELTEVDAG
SUNDRA 4500
Rietkol BH
ELOFF
DELMAS
LARGO
ENDICOTT
Vischkuil No 3
SUNDRA ANTICLINE
DELMAS SYNCLINE
WINTERHOEK ANTICLINE
Strydpan BH
Vlakplaats BH
CWB
HAVERKLIP
DELMAS COLLIERY
DEVON
EENDRAAG
LESLIE
Special BH
Holspruit BH
Blesbokspruit BH
Kromdraai BH
BRAKFONTEIN COLLIERY
BRAKFONTEIN MINE
PRETORIA MINE
TRANSVAAL MINE
ARGENT
BOSCHPOORT MINE
ARBOR
ARBOR COL.
STIRLING TVL. COL.
ACME COL.
ALPHA COL.
KENDAL
KENDAL COL.
BALMORAL
BRONKHORSTSPRUIT 1 MILE
T.N
DRYDEN
28°15'
28°30'
28°45'
26°00'
26°15'
ZT1
KP1
TWF1
VOK1
WP1
WHE1
KN1
YZ1
RF1
RV1
OL1
OL2
KST1
KST2
KST3
BN1
WK1
WK2
RH1
LP1
LP2
LP3
LP4
LP5
HP1
MG1
DSz1
GA2
GA3
DSt1
DRK1
DRK2
DRK3
DVk1
DLn1
F1
AE
EB1
EB8
RGh1
RGh2
RW1
SW1
MB
N294/2
B4
B7
HF1
TH
KPK
3000'
2000'
1000'
0'
4000'
5000'
4250'

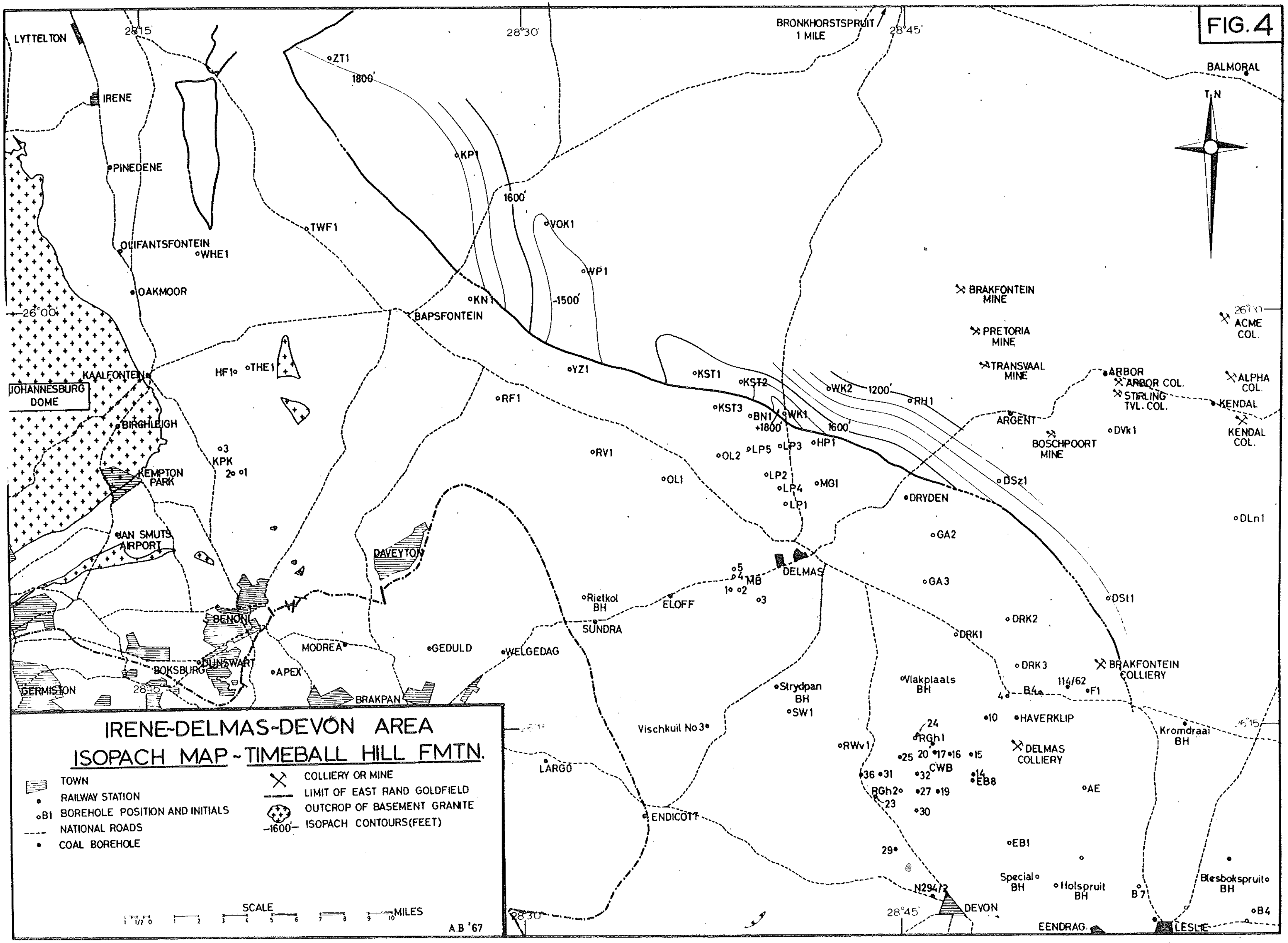
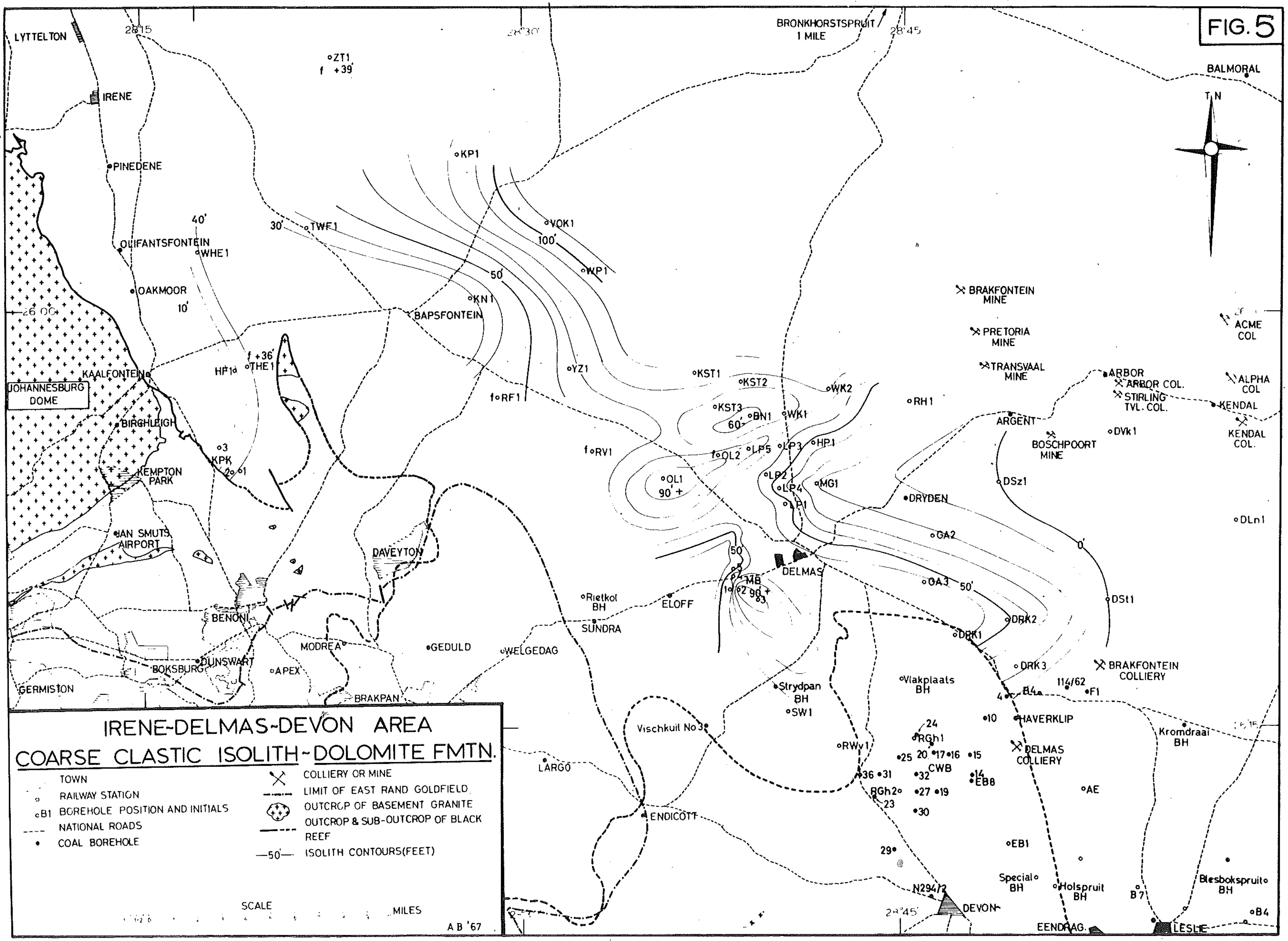

IRENE-DELMAS-DEVON AREA
ISOPACH MAP - TIMEBALL HILL FMTN.
TOWN
RAILWAY STATION
B1 BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COAL BOREHOLE
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
-1600'- ISOPACH CONTOURS(FEET)
SCALE
MILES
A.B '67
T.N
28°15'
28°30'
28°45'
26°00'
BRONKHORSTSPRUIT 1 MILE
LYTTELTON
IRENE
PINEDENE
OLIFANTSFONTEIN
WHE1
OAKMOOR
JOHANNESBURG DOME
KAALFONTEIN
BIRCHLEIGH
KEMPTON PARK
JAN SMUTS AIRPORT
GERMISTON
BOKSBURG
DUNSWART
BENONI
APEX
MODREA
BRAKPAN
DAVEYTON
GEDULD
WELGEDAG
LARGO
ENDICOTT
SUNDRA
Rietkol BH
ELOFF
Vischkuil No3
Strydpan BH
SW1
DELMAS
MB
BAPSFONTEIN
ZT1
1800'
KP1
1600'
TWF1
VOK1
WP1
-1500'
KN1
YZ1
RF1
RV1
OL1
OL2
HF1
THE1
KPK
KST1
KST2
KST3
BN1
+1800
WK1
WK2
1200'
RH1
1600'
LP1
LP2
LP3
LP4
LP5
HP1
MG1
DRYDEN
GA2
GA3
DSz1
DS11
DLn1
DRK1
DRK2
DRK3
BRAKFONTEIN MINE
PRETORIA MINE
TRANSVAAL MINE
ARBOR
ARBOR COL.
STIRLING TVL. COL.
ARGENT
BOSCHPOORT MINE
DVk1
ACME COL.
ALPHA COL.
KENDAL
KENDAL COL.
BALMORAL
BRAKFONTEIN COLLIERY
114/62
F1
B4
HAVERKLIP
DELMAS COLLIERY
Vlakplaats BH
RGh1
RGh2
CWB
EB8
RWv1
AE
EB1
Special BH
Holspruit BH
N294/2
DEVON
EENDRAG.
LESLIE
B7
Kromdraai BH
Blesbokspruit BH

FIG. 4



LYTTELTON
IRENE
PINEDENE
OLIFANTSFONTEIN
OAKMOOR
KAALFONTEIN
JOHANNESBURG DOME
BIRCHLEIGH
KEMPTON PARK
JAN SMUTS AIRPORT
GERMISTON
BOKSBURG
DUNSWART
BENONI
APEX
MODREA
BRAKPAN
DAVEYTON
GEDULD
WELGEDAG
LARGO
ENDICOTT
SUNDRA
Rietkol BH
ELOFF
DELMAS
Strydpan BH
SW1
Vischkuil No3
RWy1
Vlakplaats BH
RGh1
RGh2
CWB
EB8
EB1
HAVERKLIP
DELMAS COLLIERY
BRAKFONTEIN COLLIERY
Kromdraai BH
AE
Special BH
Holspruit BH
B7
Blesbokspruit BH
B4
LESLIE
EENDRAG.
DEVON
N294/2
BRONKHORSTSPRUIT 1 MILE
BALMORAL
T.N
BRAKFONTEIN MINE
PRETORIA MINE
TRANSVAAL MINE
ARBOR
ARBOR COL.
STIRLING TVL. COL.
ACME COL
ALPHA COL
KENDAL
KENDAL COL.
ARGENT
BOSCHPOORT MINE
DVk1
RH1
DSz1
DRYDEN
GA2
OA3
DRK1
DRK2
DRK3
DSt1
DLn1
ZT1
KP1
TWF1
WHE1
VOK1
WP1
KN1
BAPSFONTEIN
YZ1
RF1
RV1
HF1a
THE1
KPK
KST1
KST2
KST3
BN1
WK1
WK2
LP1
LP2
LP3
LP4
LP5
HP1
MG1
OL1
OL2
MB
F1
114/62
28°15
28°30
28°45
26°00
26°15
IRENE-DELMAS-DEVON AREA
COARSE CLASTIC ISOLITH-DOLOMITE FMTN.
TOWN
RAILWAY STATION
BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COAL BOREHOLE
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
OUTCROP & SUB-OUTCROP OF BLACK REEF
ISOLITH CONTOURS(FEET)
SCALE
MILES
A B '67

FIG. 5

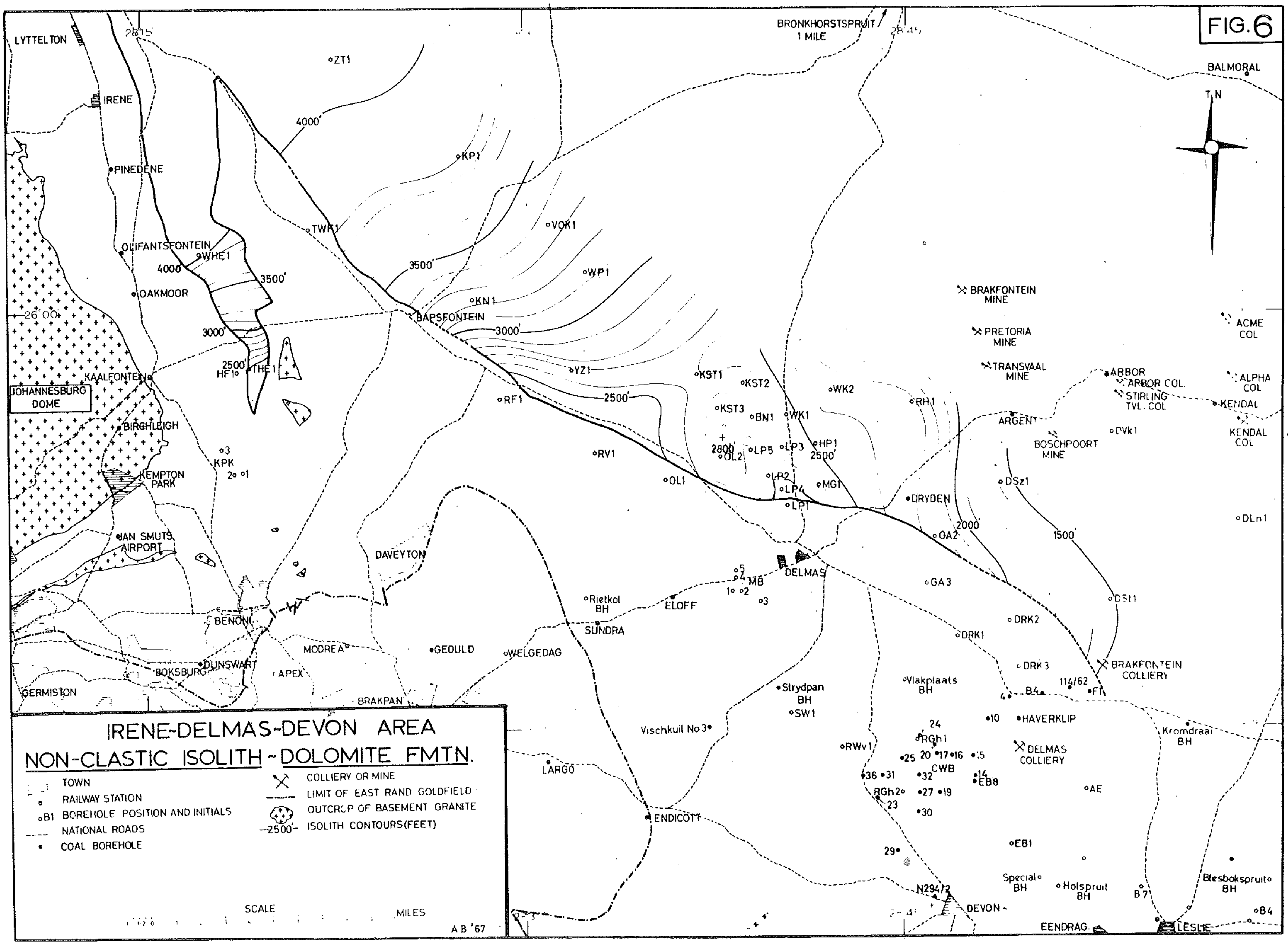


FIG. 6
IRENE-DELMAS-DEVON AREA
NON-CLASTIC ISOLITH - DOLOMITE FMTN.
TOWN
RAILWAY STATION
B1 BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COAL BOREHOLE
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
-2500- ISOLITH CONTOURS (FEET)
SCALE
MILES
A B '67
T.N
LYTTELTON
IRENE
PINEDENE
OLIFANTSFONTEIN
OAKMOOR
KAALFONTEIN
JOHANNESBURG DOME
BIRCHLEIGH
KEMPTON PARK
JAN SMUTS AIRPORT
GERMISTON
BOKSBURG
DUNSWART
BENONI
APEX
MODDER A
BRAKPAN
DAVEYTON
GEDULD
WELGEDAG
SUNDRA
ELOFF
Rietkol BH
DELMAS
BAPSFONTEIN
BRONKHORSTSPRUIT 1 MILE
BALMORAL
BRAKFONTEIN MINE
PRETORIA MINE
TRANSVAAL MINE
ARBOR
ARBOR COL.
STIRLING TVL. COL
ACME COL
ALPHA COL
KENDAL
KENDAL COL
ARGENT
BOSCHPOORT MINE
DRYDEN
BRAKFONTEIN COLLIERY
Kromdraai BH
HAVERKLIP
DELMAS COLLIERY
Vlakplaats BH
Strydpan BH
Vischkuil No 3
LARGO
ENDICOTT
DEVON
EENDRAG
LESLIE
Special BH
Holspruit BH
Blesbokspruit BH
4000'
3500'
3000'
2500'
2800'
2000'
1500'
ZT1
KP1
TWF1
VOK1
WP1
WHE1
KN1
THE1
HF1
KPK
YZ1
RF1
RV1
OL1
KST1
KST2
KST3
BN1
WK1
WK2
OL2
LP5
LP3
HP1
LP2
LP4
LP1
MG1
RH1
DSz1
DSt1
DLn1
CVk1
GA2
GA3
DRK1
DRK2
DRK3
B4
F1
114/62
MB
RGh1
RGh2
CWB
EB8
EB1
AE
RWv1
SW1
N294/2
B7

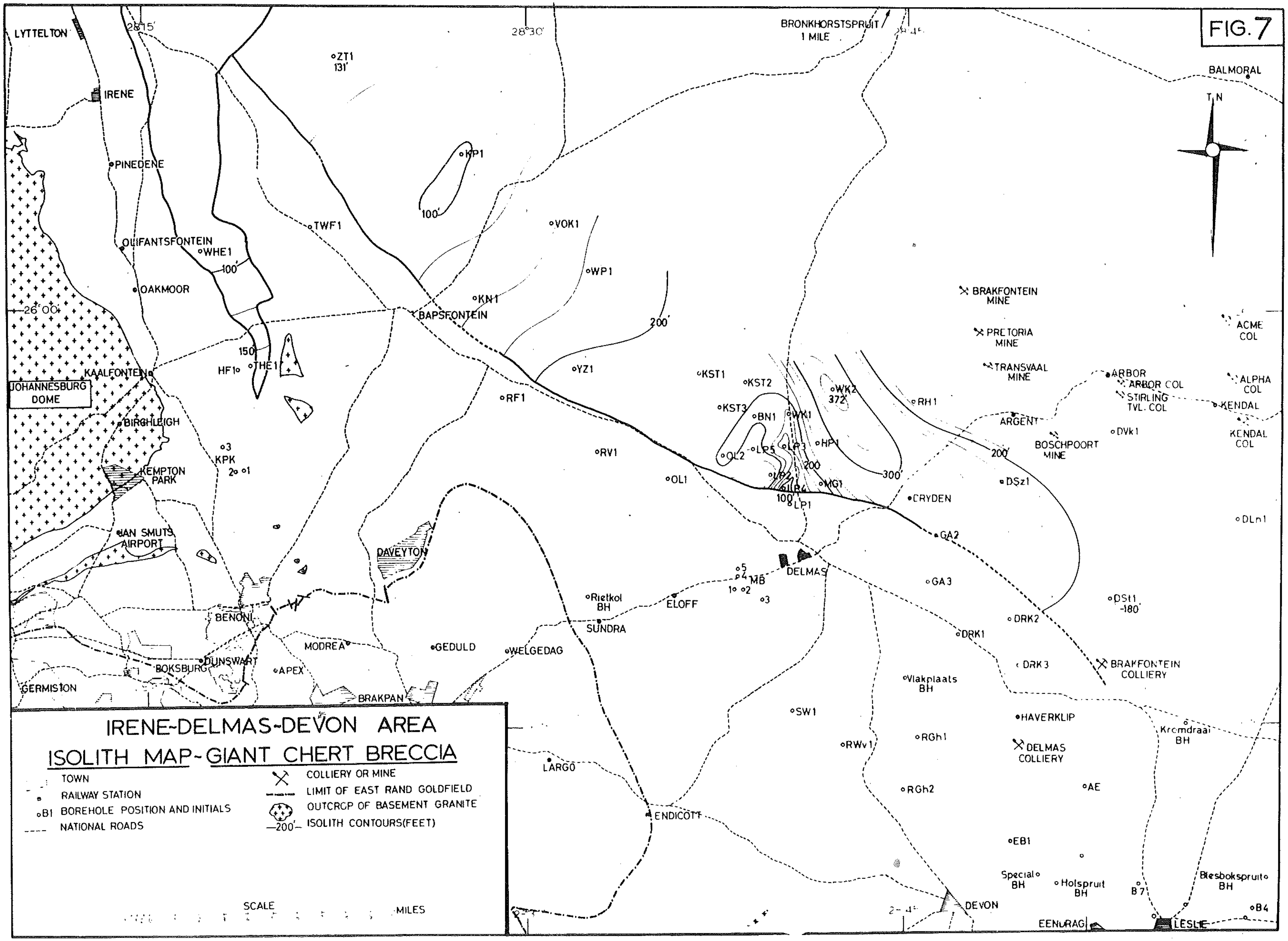


FIG. 7

IRENE-DELMAS-DEVON AREA

ISOLITH MAP-GIANT CHERT BRECCIA

TOWN
RAILWAY STATION
B1 BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
-200'- ISOLITH CONTOURS (FEET)

SCALE MILES

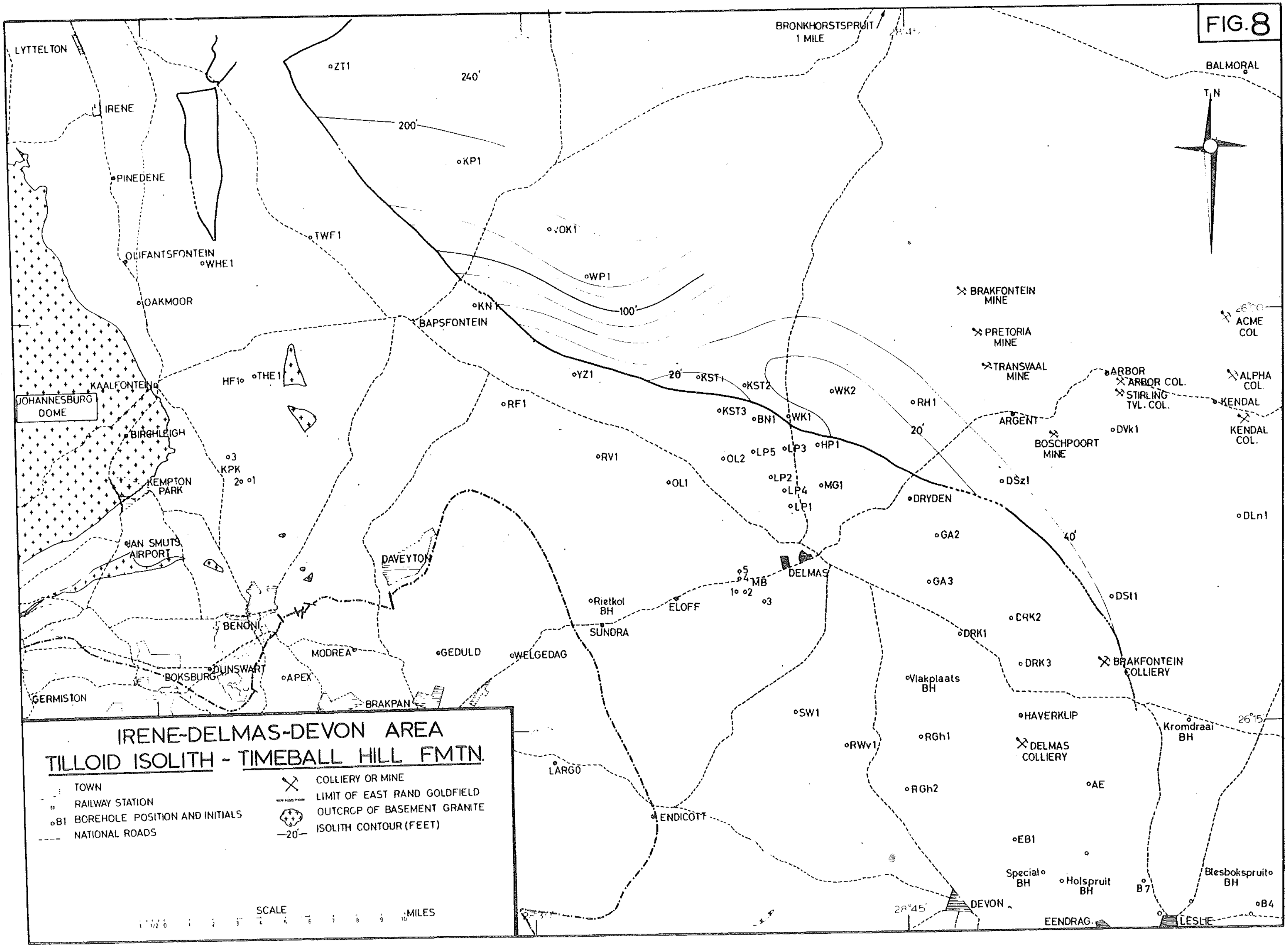


FIG. 8
IRENE-DELMAS-DEVON AREA
TILLOID ISOLITH - TIMEBALL HILL FMTN.
TOWN
RAILWAY STATION
B1 BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
-20- ISOLITH CONTOUR (FEET)
SCALE
MILES
T.N
BRONKHORSTSPRUIT 1 MILE
BALMORAL
LYTTELTON
IRENE
PINEDENE
OLIFANTSFONTEIN
WHE1
OAKMOOR
KAALFONTEIN
JOHANNESBURG DOME
BIRCHLEIGH
KEMPTON PARK
JAN SMUTS AIRPORT
BENONI
BOKSBURG
DUNSWART
GERMISTON
APEX
MODREA
BRAKPAN
DAVEYTON
GEDULD
WELGEDAG
LARGO
ENDICOTT
SUNDRA
Rietkol BH
ELOFF
MB
DELMAS
ZT1
240'
200'
KP1
TWF1
OK1
WP1
100'
KN1
BAPSFONTEIN
HF1
THE1
KPK
RF1
YZ1
RV1
OL1
OL2
20'
KST1
KST2
KST3
BN1
WK1
WK2
LP1
LP2
LP3
LP4
LP5
HP1
MG1
RH1
DRYDEN
GA2
GA3
DSz1
DSt1
40'
DLn1
BRAKFONTEIN MINE
PRETORIA MINE
TRANSVAAL MINE
ARGENT
BOSCHPOORT MINE
ARBOR
ARBOR COL.
STIRLING TVL. COL.
DVk1
ACME COL
ALPHA COL.
KENDAL
KENDAL COL.
CRK2
DRK1
DRK3
BRAKFONTEIN COLLIERY
Vlakplaats BH
SW1
RWv1
RGh1
RGh2
HAVERKLIP
DELMAS COLLIERY
AE
EB1
Special BH
Holspruit BH
B7
Kromdraai BH
Blesbokspruit BH
B4
26°15'
28°45'
DEVON
EENDRAG.
LESLIE

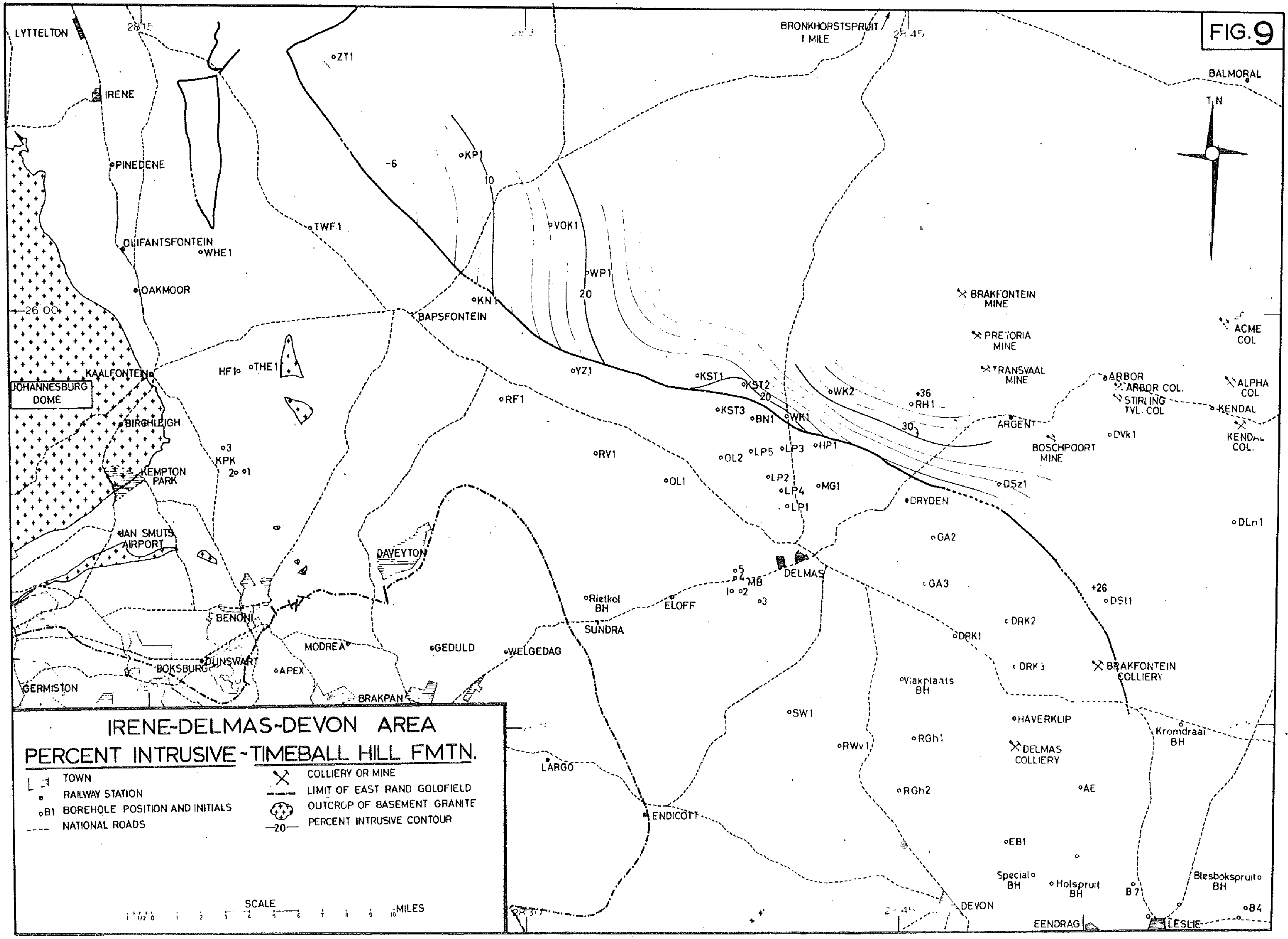
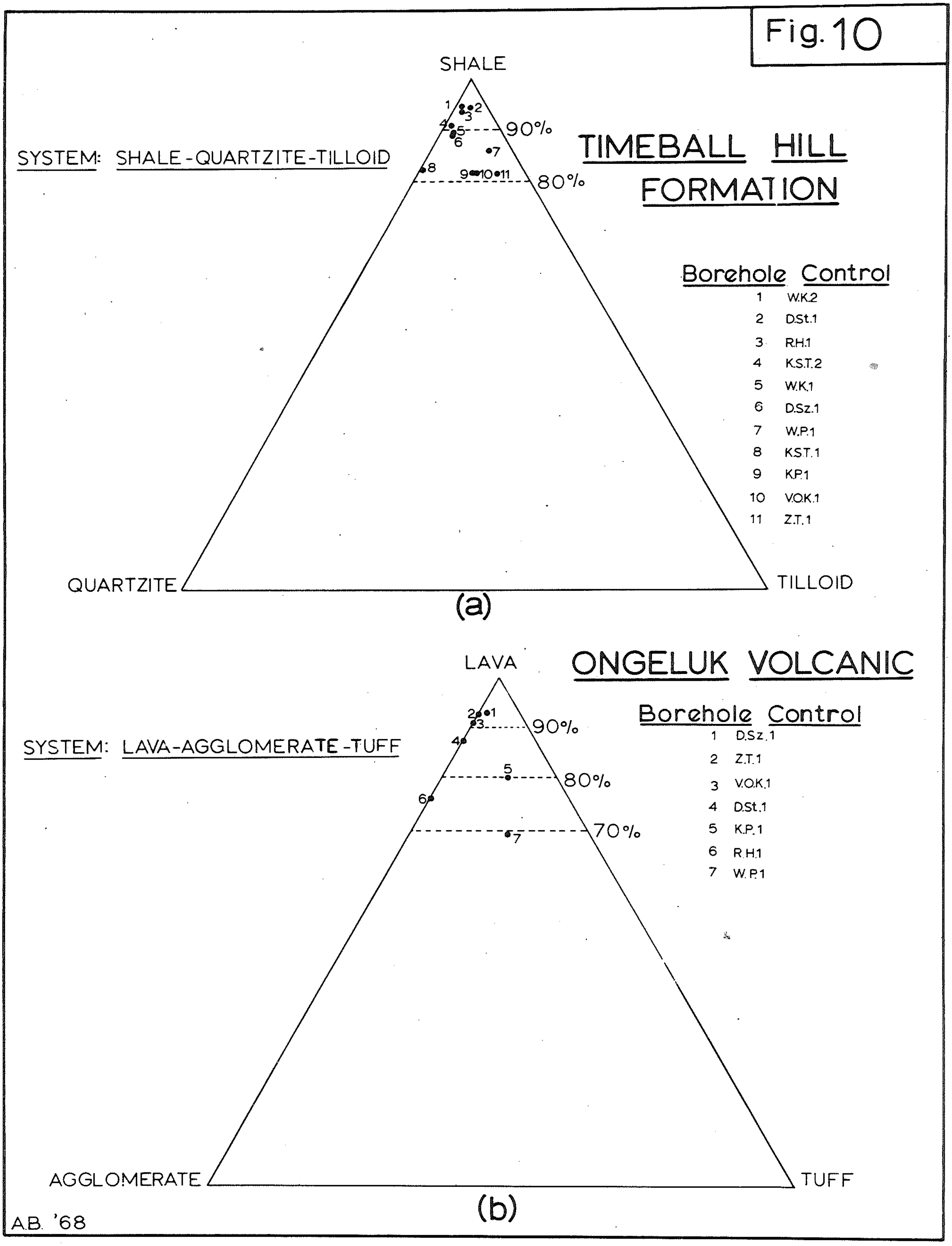


FIG. 9
T.N
LYTTELTON
IRENE
PINEDENE
OLIFANTSFONTEIN
WHE1
OAKMOOR
JOHANNESBURG DOME
KAALFONTEIN
BIRCHLEIGH
KEMPTON PARK
JAN SMUTS AIRPORT
BENONI
BOKSBURG
DUNSWART
GERMISTON
APEX
MODREA
BRAKPAN
GEDULD
WELGEDAG
DAVEYTON
ZT1
TWF1
KP1
KN1
BAPSFONTEIN
HF1
THE1
KPK
VOK1
WP1
YZ1
RF1
RV1
OL1
OL2
KST1
KST2
KST3
BN1
WK1
WK2
LP1
LP2
LP3
LP4
LP5
HP1
MG1
RH1
DSz1
DRYDEN
GA2
GA3
DELMAS
MB
Rietkol BH
ELOFF
SUNDRA
LARGO
ENDICOTT
SW1
RWv1
RGh1
RGh2
Viakplaats BH
DRK1
DRK2
DRK3
DS11
DLn1
HAVERKLIP
DELMAS COLLIERY
BRAKFONTEIN COLLIERY
Kromdraai BH
AE
EB1
Special BH
Holspruit BH
B7
Blesbokspruit BH
B4
DEVON
EENDRAG
LESLIE
BRONKHORSTSPRUIT 1 MILE
BALMORAL
BRAKFONTEIN MINE
PRETORIA MINE
TRANSVAAL MINE
ARBOR
ARBOR COL.
STIRLING TVL. COL.
ARGENT
BOSCHPOORT MINE
DVk1
ACME COL
ALPHA COL
KENDAL
KENDAL COL.
-6
10
20
30
+36
+26
IRENE-DELMAS-DEVON AREA
PERCENT INTRUSIVE - TIMEBALL HILL FMTN.
TOWN
RAILWAY STATION
B1 BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
PERCENT INTRUSIVE CONTOUR
SCALE
MILES



SHALE
SYSTEM: SHALE-QUARTZITE-TILLOID
90%
80%
TIMEBALL HILL FORMATION
Borehole Control
1 W.K.2
2 D.St.1
3 R.H.1
4 K.S.T.2
5 W.K.1
6 D.Sz.1
7 W.P.1
8 K.S.T.1
9 K.P.1
10 V.O.K.1
11 Z.T.1
QUARTZITE
TILLOID
(a)
LAVA
ONGELUK VOLCANIC
Borehole Control
1 D.Sz.1
2 Z.T.1
3 V.O.K.1
4 D.St.1
5 K.P.1
6 R.H.1
7 W.P.1
SYSTEM: LAVA-AGGLOMERATE-TUFF
90%
80%
70%
AGGLOMERATE
TUFF
(b)
A.B. '68

Fig. 10

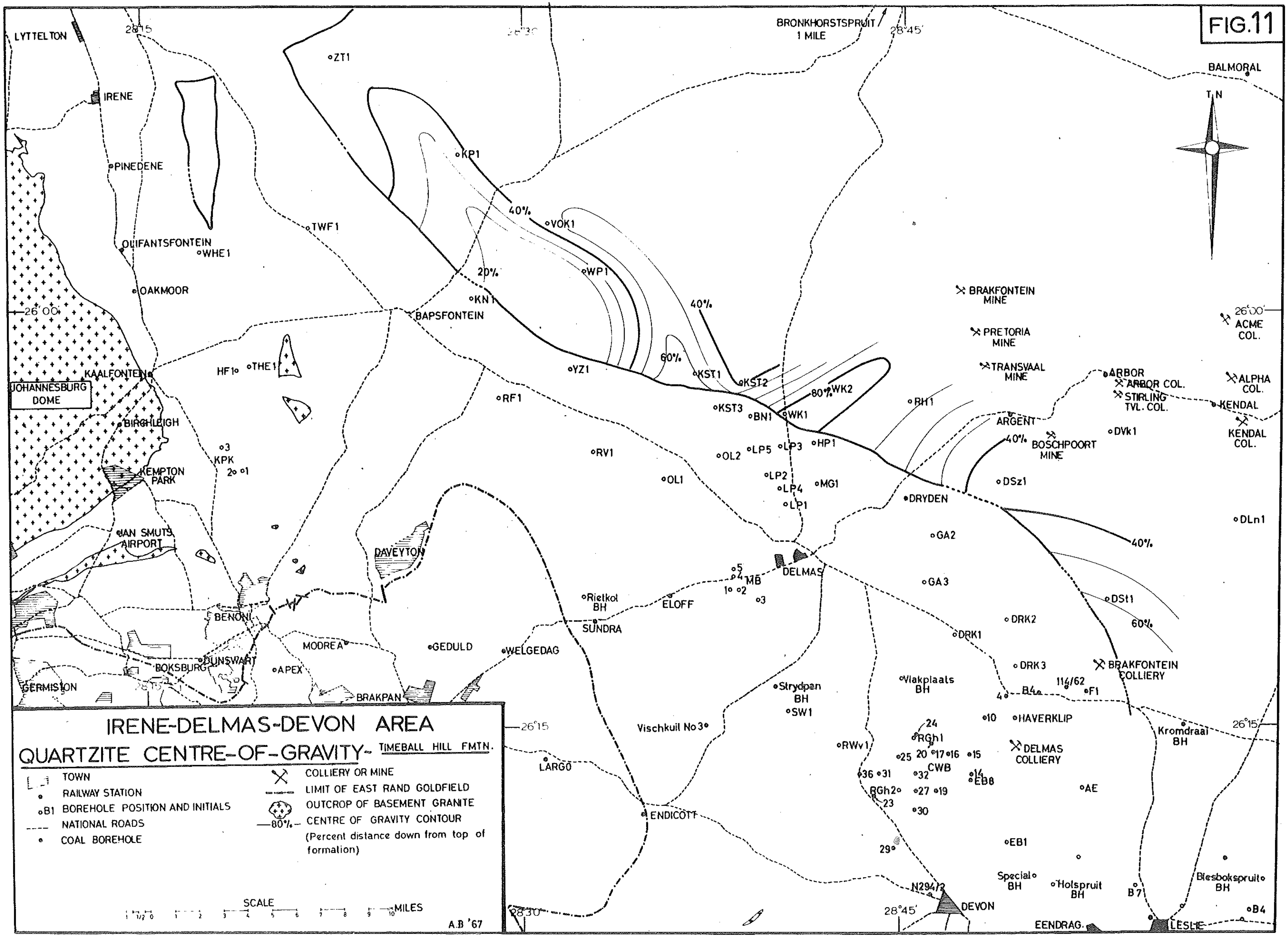


FIG.11
IRENE-DELMAS-DEVON AREA
QUARTZITE CENTRE-OF-GRAVITY- TIMEBALL HILL FMTN.
TOWN
RAILWAY STATION
B1 BOREHOLE POSITION AND INITIALS
NATIONAL ROADS
COAL BOREHOLE
COLLIERY OR MINE
LIMIT OF EAST RAND GOLDFIELD
OUTCROP OF BASEMENT GRANITE
CENTRE OF GRAVITY CONTOUR
(Percent distance down from top of formation)
SCALE
MILES
A.B '67
LYTTELTON
IRENE
PINEDENE
OLIFANTSFONTEIN
WHE1
OAKMOOR
JOHANNESBURG DOME
KAALFONTEIN
BIRCHLEIGH
KEMPTON PARK
JAN SMUTS AIRPORT
GERMISTON
BOKSBURG
DUNSWART
BENONI
APEX
MODREA
BRAKPAN
DAVEYTON
GEDULD
WELGEDAG
ZT1
TWF1
THE1
HF1
KPK
KP1
VOK1
WP1
KN1
BAPSFONTEIN
RF1
YZ1
RV1
OL1
OL2
KST1
KST2
KST3
BN1
WK1
WK2
LP1
LP2
LP3
LP4
LP5
HP1
MG1
BH1
DRYDEN
DSz1
GA2
GA3
DELMAS
MB
ELOFF
Rietkol BH
SUNDRA
LARGO
ENDICOTT
Vischkuil No3
Strydpan BH
SW1
RWv1
Vlakplaats BH
RGh1
RGh2
CWB
DRK1
DRK2
DRK3
HAVERKLIP
DELMAS COLLIERY
BRAKFONTEIN COLLIERY
EB8
EB1
AE
Special BH
Holspruit BH
N294/2
DEVON
EENDRAG.
LESLIE
B7
B4
Blesbokspruit BH
Kromdraai BH
DSt1
DLn1
BRAKFONTEIN MINE
PRETORIA MINE
TRANSVAAL MINE
ARGENT
BOSCHPOORT MINE
DVk1
ARBOR
ARBOR COL.
STIRLING TVL. COL.
KENDAL
KENDAL COL.
ALPHA COL.
ACME COL.
BALMORAL
BRONKHORSTSPRUIT 1 MILE
T.N
28°15'
28°30'
28°45'
26°00'
26°15'
20%
40%
60%
80%

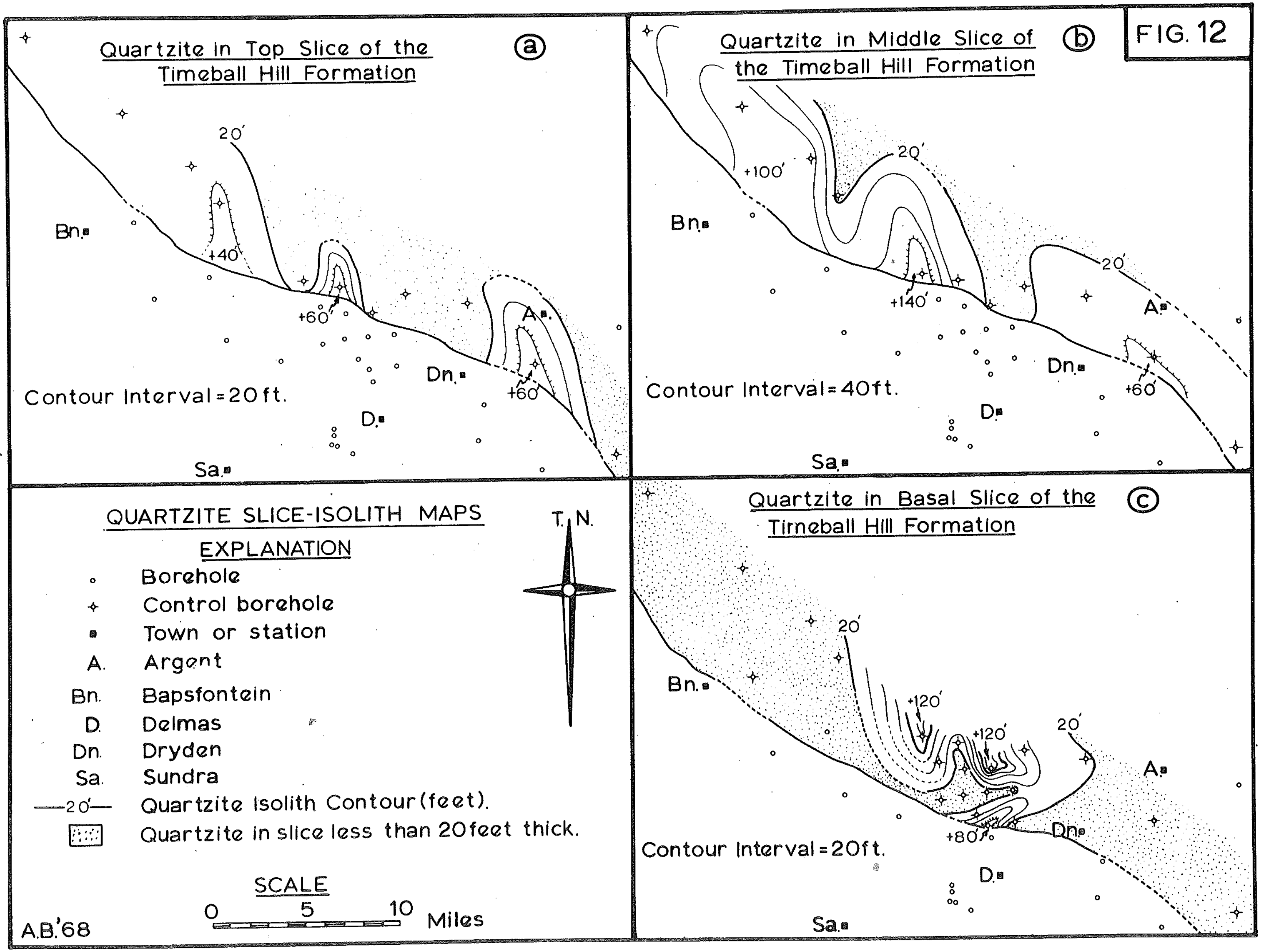
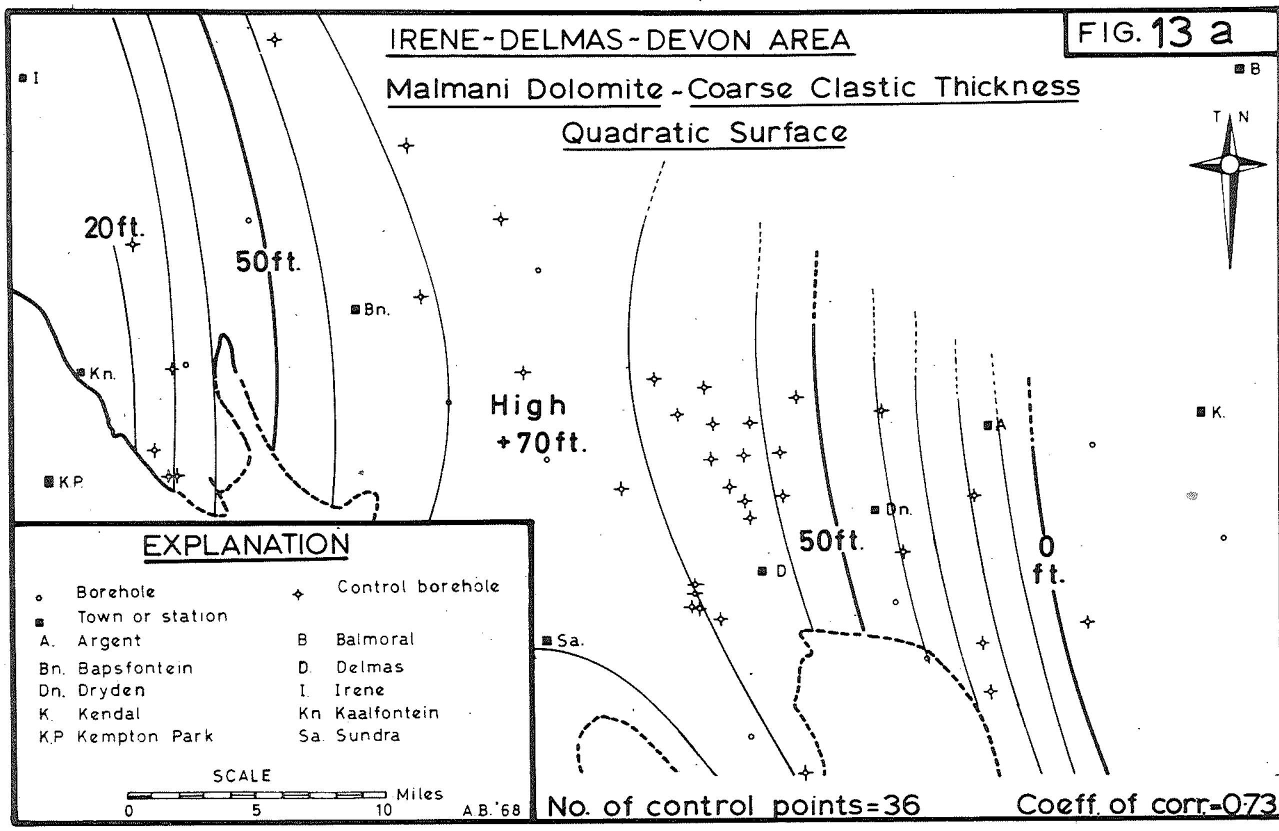
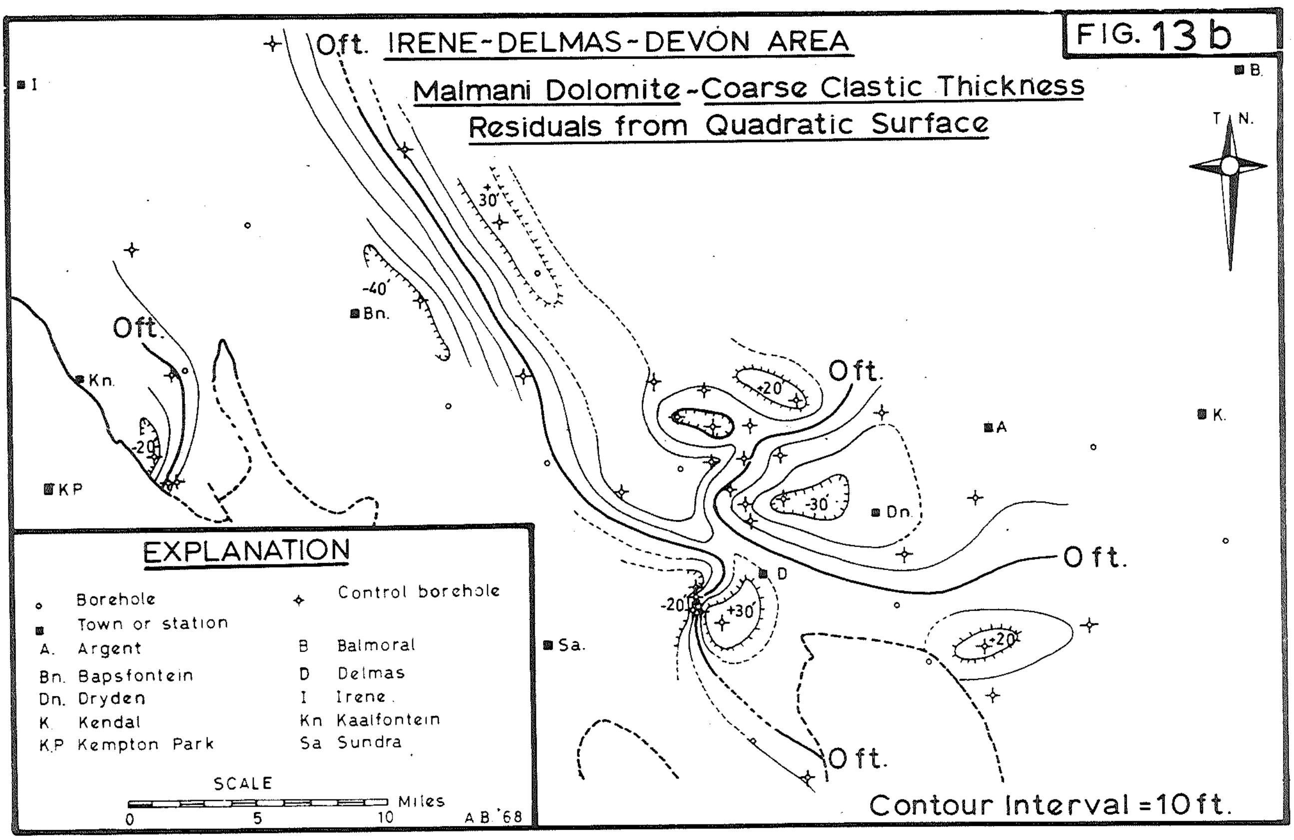
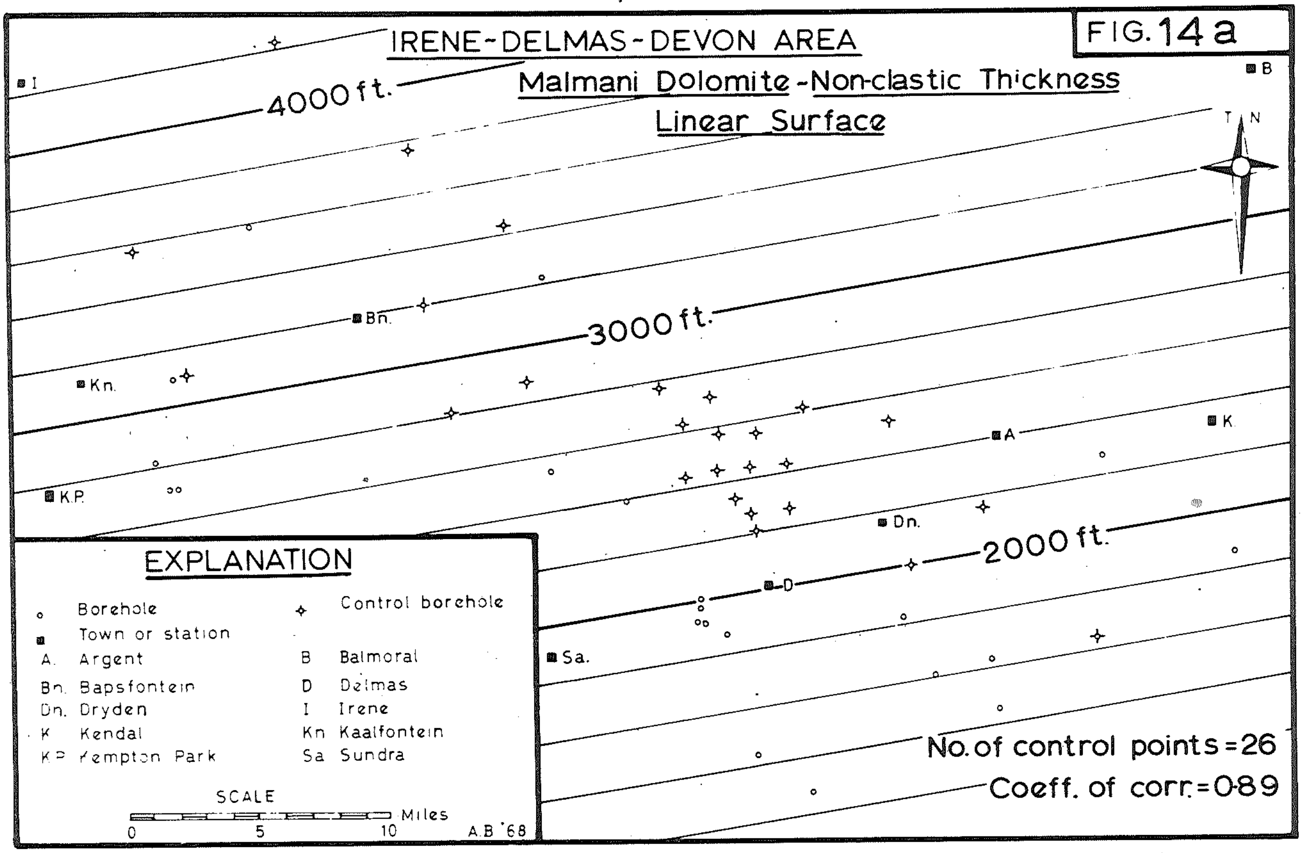
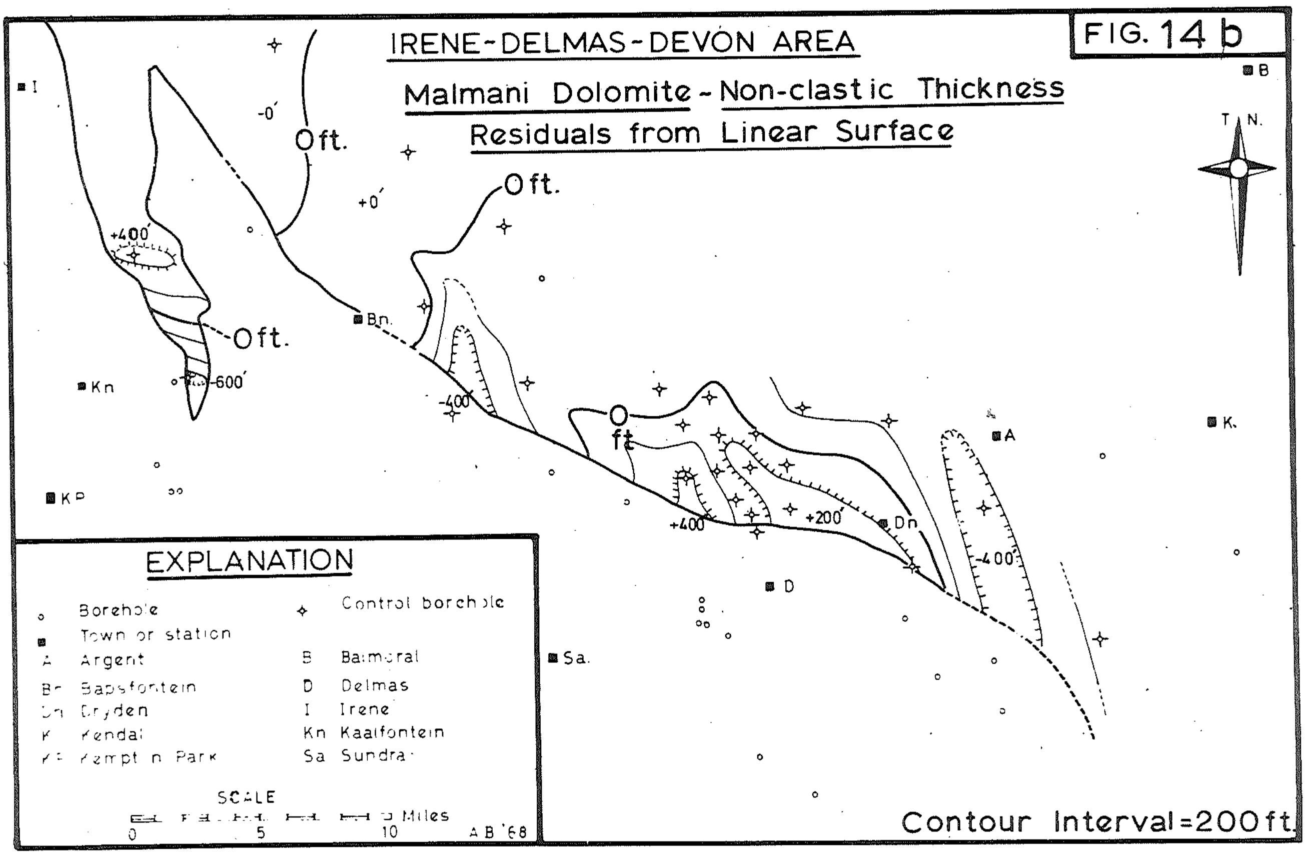


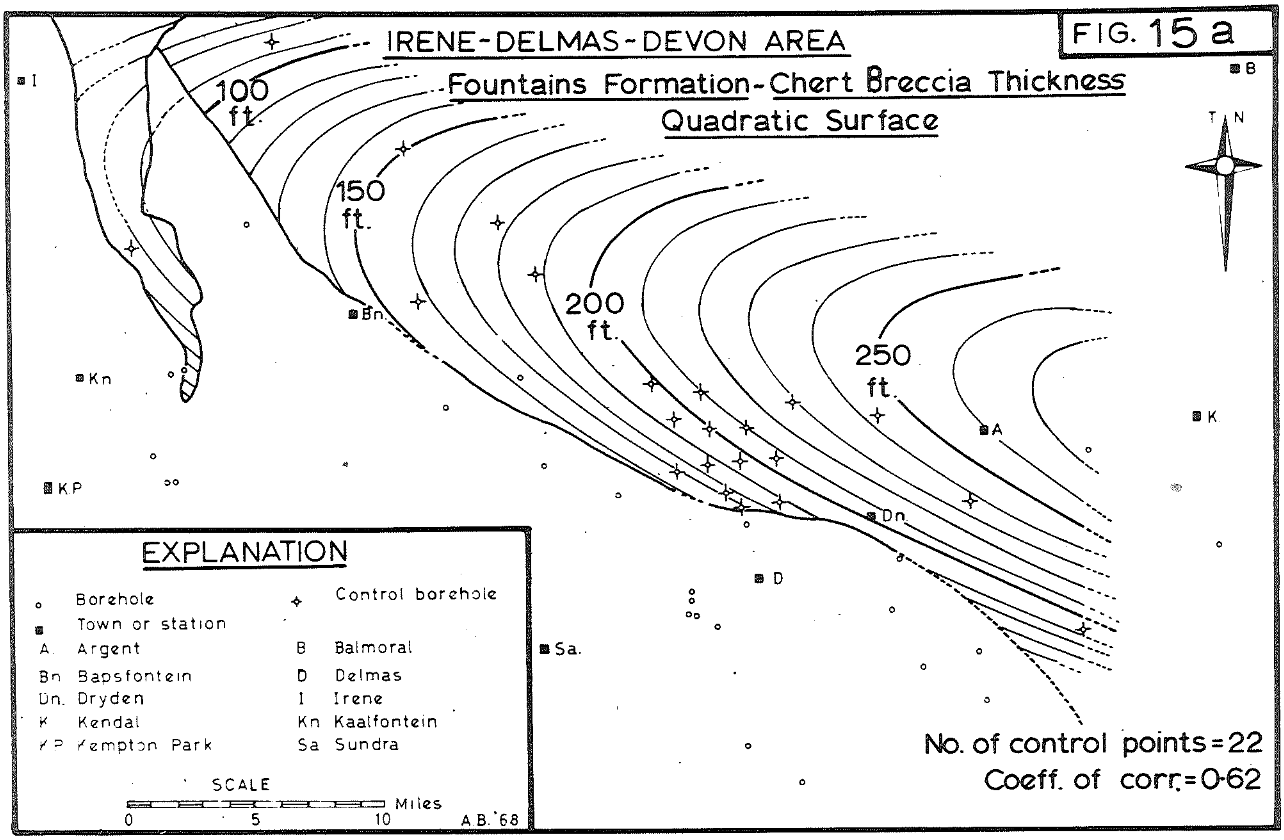
FIG. 12
Quartzite in Top Slice of the Timeball Hill Formation
(a)
20'
+40'
+60'
+60
Bn.
Dn.
A.
D.
Sa.
Contour Interval=20 ft.
Quartzite in Middle Slice of the Timeball Hill Formation
(b)
20'
+100'
+140'
20'
+60
Bn.
Dn.
A.
D.
Sa.
Contour Interval=40 ft.
Quartzite in Basal Slice of the Timeball Hill Formation
(c)
20'
+120'
+120'
20'
+80'
Bn.
Dn.
A.
D.
Sa.
Contour Interval=20 ft.
QUARTZITE SLICE-ISOLITH MAPS
EXPLANATION
Borehole
Control borehole
Town or station
A. Argent
Bn. Bapsfontein
D. Delmas
Dn. Dryden
Sa. Sundra
—20'— Quartzite Isolith Contour (feet).
Quartzite in slice less than 20 feet thick.
T.N.
SCALE
0 5 10 Miles
A.B.'68

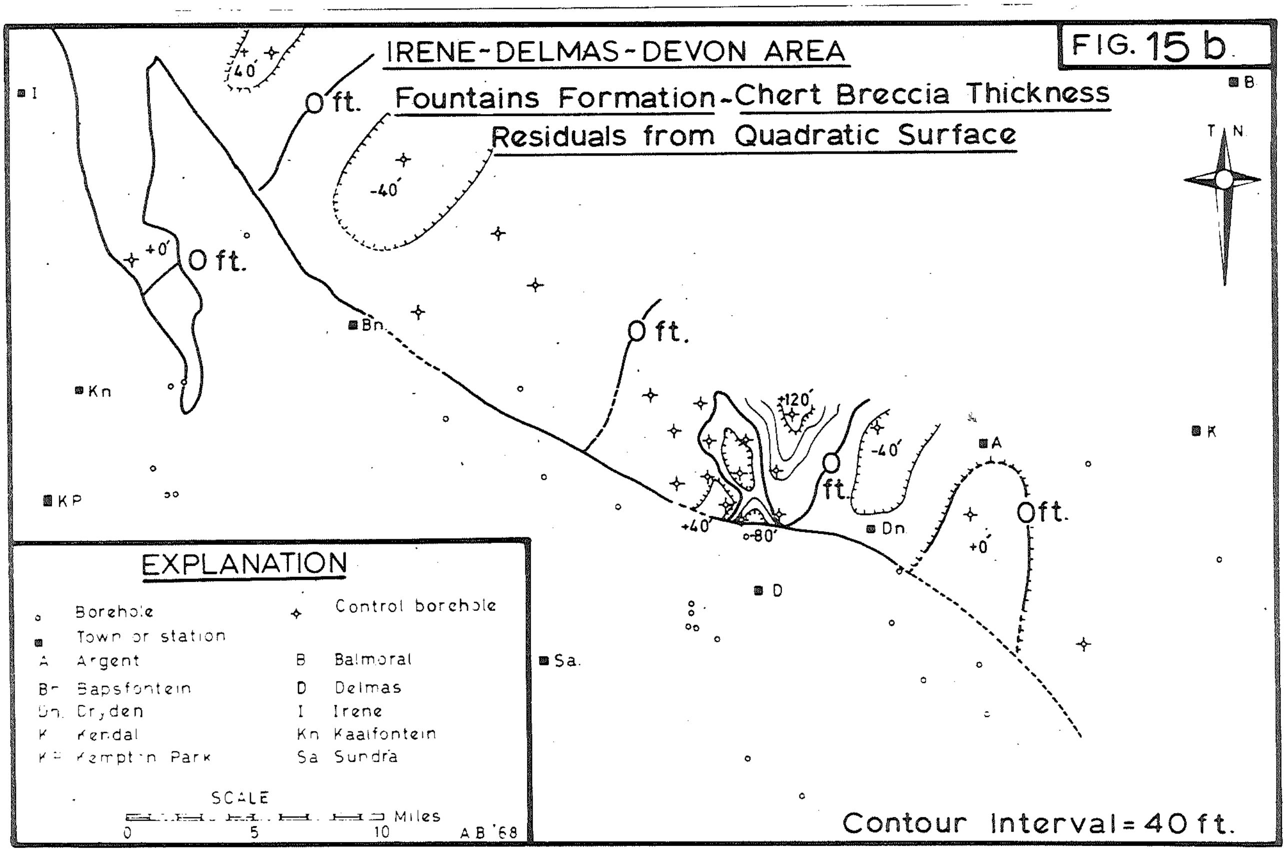

IRENE-DELMAS-DEVON AREA
Malmani Dolomite-Coarse Clastic Thickness
Quadratic Surface
FIG. 13 a
20ft.
50ft.
High
+70ft.
50ft.
0
ft.
I
B
T N
Bn.
Kn.
K.P.
A
K.
Dn.
D
Sa.
EXPLANATION
Borehole
Town or station
Control borehole
A. Argent
B Balmoral
Bn. Bapsfontein
D. Delmas
Dn. Dryden
I. Irene
K. Kendal
Kn Kaalfontein
K.P Kempton Park
Sa. Sundra
SCALE
0
5
10
Miles
A.B.'68
No. of control points=36
Coeff. of corr.=0.73


IRENE-DELMAS-DEVON AREA
Malmani Dolomite-Coarse Clastic Thickness
Residuals from Quadratic Surface
FIG. 13 b
0ft.
30
-40
-20
0ft.
+20
0ft.
-30
0 ft.
-20
+30
-20
0 ft.
I
B.
T N.
Bn.
Kn.
KP
A
K.
Dn.
D
Sa.
EXPLANATION
Borehole
Town or station
Control borehole
A. Argent
B Balmoral
Bn. Bapsfontein
D Delmas
Dn. Dryden
I Irene
K Kendal
Kn Kaalfontein
K.P Kempton Park
Sa Sundra
SCALE
0
5
10
Miles
A.B.'68
Contour Interval =10ft.


IRENE-DELMAS-DEVON AREA
FIG. 14 a
Malmani Dolomite-Non-clastic Thickness
Linear Surface
4000 ft.
3000 ft.
2000 ft.
T N
EXPLANATION
Borehole
Control borehole
Town or station
A. Argent
B Balmoral
Bn. Bapsfontein
D Delmas
Dn. Dryden
I Irene
K Kendal
Kn Kaalfontein
KP Kempton Park
Sa Sundra
SCALE
0 5 10 Miles
A.B '68
No. of control points = 26
Coeff. of corr. = 0.89


IRENE-DELMAS-DEVON AREA
FIG. 14 b
Malmani Dolomite-Non-clastic Thickness
Residuals from Linear Surface
T N.
0 ft.
-0'
+0'
+400'
-600'
-400'
+200'
-400'
EXPLANATION
Borehole
Control borehole
Town or station
A Argent
B Balmoral
Bn Bapsfontein
D Delmas
Dn Dryden
I Irene
K Kendal
Kn Kaalfontein
KP Kempton Park
Sa Sundra
SCALE
0 5 10 Miles
A B '68
Contour Interval = 200 ft.


IRENE-DELMAS-DEVON AREA
Fountains Formation-Chert Breccia Thickness
Quadratic Surface
FIG. 15 a
100 ft.
150 ft.
200 ft.
250 ft.
I
B
Bn
Kn
KP
A
K
Dn
D
Sa.
T N
EXPLANATION
Borehole
Control borehole
Town or station
A Argent
B Balmoral
Bn Bapsfontein
D Delmas
Dn. Dryden
I Irene
K Kendal
Kn Kaalfontein
KP Kempton Park
Sa Sundra
SCALE
0 5 10 Miles
A.B.'68
No. of control points = 22
Coeff. of corr. = 0·62


IRENE-DELMAS-DEVON AREA
Fountains Formation-Chert Breccia Thickness
Residuals from Quadratic Surface
FIG. 15 b
-40'
0 ft.
-40'
+40'
0 ft.
0 ft.
+120'
-40'
0 ft.
+40'
-80'
0 ft.
+0'
I
B
Bn
Kn
KP
A
K
Dn
D
Sa.
T N
EXPLANATION
Borehole
Control borehole
Town or station
A Argent
B Balmoral
Bn Bapsfontein
D Delmas
Dn. Dryden
I Irene
K Kendal
Kn Kaalfontein
KP Kempton Park
Sa Sundra
SCALE
0 5 10 Miles
A.B.'68
Contour Interval = 40 ft.