"NODDY"- AN INTERACTIVE MAP CREATION PACKAGE

by Mark Jessell

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Department of Geology
Royal School of Mines
Imperial College of Science and Technology
London

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Chapter 1 Introduction

This package was assembled primarily so that structural geology problem maps could be made simply and efficiently. It can also be used in its interactive mode to demonstrate the development of structures in a model region, and with several reservations, it can be used to model the geology of an exsisting region, and thus be used as a predictive tool.

The need for a problem map package is twofold, first it takes on average two weeks to produce one advanced problem map by hand, whereas a series of related maps can be produced easily by this package within a day. Secondly, there is at present a limit to the complexity of problem maps equal to the the level of patience of the lecturer. With this package, once learned, it becomes easy to produce maps of considerable complexity, and the only limits are those imposed by a maximum of fifteen deformation events and, of course, the relative simplicity of the deformation models themselves.

Chapter 2 The Geometry of Geological Structures

This chapter is intended to provide a geological rather than mathematical view of the displacement equations used in this package. As well as this these equations are considered, where applicable, as models of existing structures.

2.1 Folds

The geometry of folds has long been a subject of study and over the past twenty years theories relating to the mechanisms of folding have become vastly more sophisticated. Given the large number of parameters which have been shown to effect the intiation and development of folds it is perhaps surprising how the geometry of naturally formed folds repeats itself in many different deformational environments. To date most fold studies have been based on fold profiles, which means they expressly or tacitly assume plane strain. Any study of naturally deformed rocks shows that far from the cylindricity implicit in this assumption, folds are not cylindrical, nor can they reasonably be expected to be. The geometries of folds in three dimensions, (which includes vertical variation in fold profile as well as non-cylindricity), are at present derived from two main sources. First by the traditional methods of mapping on the surface, and secondly and ever increasingly, by the use of seismic traverses. The majority of these traverses are at present being undertaken in oil fields consisting of strata with relatively open fold structures in them. To assist in the study of this type of environment it is useful to be able to condense the survey profiles into a form which allows the development of predictive models.

The simplest possible model asumes folds with a "similar" geometry and cylindrical fold hinges, such as those which can be generated by the "FOLD" routines in "NODDY". The actual defining profile can be as complex as desired, because a Fourier Series can be used as an accurate descriptor, as outlined by Huddleston (1971). For the local analysis of a structure this form of definition may be sufficient, however it cannot be said to be a very natural strain state. With the development of the theory of the buckling of anisotropic layers, Biot (1965), came the recognition of internal buckling in multilayers, and his displacement equations for sinusoidal internal buckling form the basis for routine "BIOT". This routine has the disadvantage that it can only produce regular wave trains, however it was included as it provided the only fold style which could produce a more realistic strain pattern around the fold. Incidentally "BIOT" can also be used to produce internal pinch and swells.

The cylindricity function, of the form:

$$Fe(v) = exp(-n.V^2)$$

has been included not so much to generate a useful non-cyclindrical fold style, but so that localised fold events could be generated using routines "FOLD", "SINE", "CHEVR" and "BIOT", thus making it possible to have a single stratigraphy undergoing two entirely independant geological histories.

Both for its neat dovetailing with the style of information being collected , (i.e.seismic profiles of folds), and for its ability to produce realistic fold geometries when used as a deformation model, the lofted surface stands out as the most versatile fold description. Lofted surfaces are curviplanar surfaces interpolated from a series of fold profiles, which can be at any orientation to one another, and the profile can be a description of any horizon in the stratigraphy. In its most complete form, all available fold profiles are used to generate a continuum of surfaces, which either represent the actual folded surfaces when used as a model of an exsisting structure, or as the defining displacement function when used as a deformation model. Routine "LOFT" uses just three profiles, two user supplied and a sine wave supplied by the program to produce non-cylindrical but similar folds. Lofted surfaces are very flexible because they can be adapted to use any profile information, whether complete or incomplete, and provide an accurate means of modelling complex fold surfaces. Furthermore, as only relatively few Fourier coefficients and the attitudes of the defining fold profiles need be retained, they represent a very efficient means of storing structural information. A more complete, but non-geological description of the use of lofted-surfaces may be found in Rogers and Adams (1976).

Often, when kink bands are discussed, they are thought of as centimeter to meter scale structures, and if they were only considered as being of this size, they would not be structures that affect the stratigraphy of a region, and certainly would not show up on a map. Their value in this case would be as relative age markers, and possibly as a palaeo-stress indicator. Nevertheless they have been included in this package, as parallel sided zones of homogeneous simple shear, so that polyclinal folds can be generated, and for this purpose they are very useful.

Of course all of these fold descriptions have drawbacks, not least their inability to cope with profiles that cannot be described by a linear function such as a fold with an elasticus, also, when large amplitude folds are generated it becomes apparent that "similar" folds are not sufficiently accurate , as the resulting limb attenuation is too great.

2.2 Faults

Even though it is becoming increasingly apparent that faults at depth represent a complex interaction of many different structures, some starting as anastamosing shear zones, and surfacing as sharp discontinuities, it may still be possible to model the fault zone as a discrete planar feature. Once outside the immediate influence of the fault zone the strain state may be modelled by using a simple slip function. Within the zone of contact strain, however, a much more detailed study of the strain states would be necessary to produce an accurate description. In some cases it may be feasible to use a flat fault superimposed on a shear zone as a model. The equations needed to model true faults zones are beyond the scope of this thesis, and in "NODDY", simple uniform slip and uniform rotation models are used. When a uniform slip is assumed it is possible to create curved fault traces, and routine "FAULT" does this. A useful halfway stage to producing a complete system of displacement equations for faults would be to use a system whereby unit displacements parallel to the gradient of a curved fault plane could be calculated and enacted so that, for example, ramps in thrusts could be approximated.

2.3 Shear Zones

The variation in strain states seen in and around shear zones has been comprehensively documented by Ramsay,(1980). Shear zones cover a wide range of scales, from the microscopic to the inter-continental , and one approach can be used to accurately model the resulting deformation patterns, as over most of the size range the strain states are inherently similar. This package is not really concerned with the smallest scale structures as these do not really interact with other structures. Similarly the internal strain states of medium-sized shear zones can be considered as black box zones of homogeneous simple shear, and it is only the large shear zone, with mappable internal structures such as sheath folds, which are considered in this package. Of course the information derived from smaller structures is important, however, it is not representable on such a large scale.

In routine "KINK" which as the name implies, also deals with kink-bands, the boundaries to the deformation bands are again considered to be flat planar, although more realistic shapes could be created by adding another function. Just as real faults are curved, so are real shear zones, and an analogous routine to

"FAULT", with its Fourier defined fault trace, would be nescessary to accurately synthesise a real shear zone. The shear zone is assumed to consist only of a zone of heterogeneous simple shear, so that there is no volume change. The actual distribution of shear strain across the zone is defined by the profile of a continuous planar feature perpendicular to the shear zone boundary. This is stored as a series of Fourier Coefficients, not so much because it is the best method of storing the information, but so that a single data storage method could be provided for all curved features.

2.4 Unconformities

In the real world all unconformities, whether marine or sub-ariel are of only one type, the buried landscape. For modelling purposes it may be possible to regard some unconformities as being planar so that the amount of data needed to synthesise the structure is minimised. Routine "BURY" represents the former type, where the erosional surface is defined by a contour map, and routine "UNC" the latter where the equation of a plane is used. In both routines the geology above the unconfomity is assumed to be untilted and ignores the nature of the unconformity. Since the area of study in the final map may not coincide at any point with the area of definition of a non-planar unconformity, the described area is initially set to cover four times the area of the default map, and the geometry of the unconformity is reflected by the boundaries of the defined area, so that it represents an infinite erosional surface.

2.5 Igneous Events

The geometry of an igneous body need follow no set pattern, nevertheless in general terms it is useful to distinguish between planar dykes and sills, and the irregular plugs. For the purposes of this package, plugs are defined by their sectional shape, stored as the Polar Coordinate Fourier Coefficients of the contact. This section can be projected into three dimensions in one of three ways: prismatically, to produce a cylinder of rock; with a linear function of distance, so that a cone shaped body results; or finally with a parabolic distance function, so that the apex of the cone is blunt. Since these three types only give rise to fairly limited plug shapes, the option is also provided of defining successive igneous events as a single intrusion, and this points the way to a more complete method of modelling irregular bodies, using a number of "standard" shapes to build up a complete description.

Most dykes can be modelled as a single surface, with the thickness of the dyke , and possibly the amount of displacement across the dyke being included as seperate functions. The question of whether dykes and plugs are intruded dilationally in response to a tensile stress field, or by the assimilation of the country rock into the magma chamber must be considered as very different strain states near the contacts will result . With plugs it has been assumed that only stoping takes place so that the country rock is unstrained, in contrast both possibilities are available when modelling dykes in this package so that a simple translation is possible in the country rock to one side of the dyke wall. This distiction does not arise with sills, as these are modelled simply by including them within a defined stratigraphy.

Igneous bodies often posses a metamorphic aureole, and the position of the isograds will be a function of the heat flow from the magma and the conductivity of the various rocks involved. Since no assumptions can really be made as to the values of the parameters involved, it is best to avoid the issue altogether. To this end the position of the isograds around igneous bodies is defined by a metamorphic stratigraphy which in the case of plugs radiates outward from its central axis, maintaining the shape of the plug section, and in the case of dykes simply extends outward in planes parallel to the dyke walls. As it is only possible to define one metamorphic event, if two or more igneous bodies are merged, only the first will be associated with a metamorphic aureole.

2.6 Homogeneous Strain Deformations

If all deformations were the result of homogeneous strain, life would be very boring indeed. As it is, homogeneity of strain can only be used for the desciption of deformations on a scale smaller than that of the structures, for example within the limb of a fold, or much larger, so that the structures can be considered insignificant. It is with these limitations in mind that the strain matrices should be used in routines "PURE" and "ROT" . The former uses directly the coefficients of the the Lagrangian strain matrix, which may, of course include components of pure shear, simple shear and rotation. The latter generates a rotation matrix from the orientation data supplied by the user. No routine for translation was included as it is possible to view the geology at any locality anyway.

2.7 Penetrative Strain Markers

Routines "PLANE" and "LINE" were included so that penetrative strain markers could be incorporated independantly of any particular deformation event. Although in the block diagrams they are invisible, in the final section of the program their orientation may be determined. The orientation of all linear and planar features is calculated by enacting the Lagrangian displacements on a three by three regular grid of coplanar points of the correct pre-deformational orientaion and position. Once these displacements have been calculated the final orientation is calculated by finding the mean of the eight planes defined by the center point of the grid and any two adjacent perimeter points. Lineation orientations are in fact calculated in an identical manner, except that the grid lies in the normal plane to the undeformed lineation. Unfortunately because the strain patterns displayed by real folds have only been rather crudely approximated, the resulting orientation data is similarly crude, even though it is internally self— consistant with the deformations calculated by the program. It may prove possible to use strain equations of the form found in Ramsay,(1967) to simulate the results of various folding mechanisms, although these would have to take into account the positions of the layer boundaries, and would thus pose a more complex problem than that solved in this package. The grid has dimensions of two by two and it may be found that by increasing this somewhat a more precise dip calcultion may be derived, as the high frequency fluctions produced by using Fourier coefficients may be more important than the less localised deformations suffered by the grid as a whole.

Chapter 3 The Deformation Models Used in "NODDY"

This chapter lists all the dispacement equations used by this package to model geological structures, and the definitions of the parameters needed to vary one structure's geometry during a program run. The relevance of most of the parameters should be apparent to anyone with a basic knowledge of structural geology, although the precise definitions, (the wavelength of a fold train for example), need to be stated. The section titles in this chapter refer not to the subroutine names, but to the event labels which identify each deformation type within the program. The figures in this section are unreferenced and are positioned with the relevant displacement equations. The orientation of the resulting displacement vector or vectors is displayed on these figures, with the magnitude of the vectors being that for the position shown, and not nescessarily the maximum displacement possible.

3.1 Principles of the Displacement Equations Used in "NODDY"

The curious world inhabited by "NODDY" consists of an infinite volume of rock and the displacements are defined implicitly or by inference with respect to flat planes, thus the curvature of the Earth has not been considered in producing these deformations. The displacement equations in "NODDY" are all unary, that is there is a one to one mapping of all points before and after each deformation. These equations are calculated in both their natural form, i.e. Lagrangian, and their inverse form, i.e. Eulerian. The Lagrangian form is calculated in routines with deformation names without prefixes, for example "FOLD", and are used to calculate the coordinates of a small grid to determine orientation information. These equations are enacted successively in normal chronological order, whereas the Eulerian equations are enacted in the reverse order. The Eulerian form is contained in routines prefixed with either "UN" or "LN" such as "UNFOLD" and "LNFOLD", and in fact these two sets of routines are identical except that the dimensions of the arrays containing the grid points are different.

Since it doesn't matter whether the space occupied by the geology is deformed by complex equations which include terms for the orientation and position of the deformation, or by transforming the space into a standard orientation, calculating relatively simple displacement equations, and then transforming the space back, the latter method was chosen as it made it much easier to create new displacement equations, and to modify exsisting ones. To this end routine "CONVERT" calculates the direction cosines of the pole to the defining plane of the deformation, and of the defining pitch direction within that plane. "ROTSET" then calculates the concatenated rotation matrices necessary to rotate the plane pole into parallel with the X-axis and the pitch line into parallel with the Y-axis, and it also calculates the inverse matrices which rotate these axes back into their normal orientation.

At each point in the program where a block diagram or map is requested, routines "DOTMAP" and "LDOTMAP" calculate the coordinates of the surface points and then enacts in reverse order the Eulerian displacement equations. Since all stratigraphies in "NODDY" start off as horizontal, the Z coordinate of the point's final position defines its position within that stratigraphy. If during the enactment of the displacement equations a point is found to be within an igneous body no further calculations need be carried out. Similarly any point which is found to lie above an unconformity during one of the routines need not be further displaced as the Z coordinate will give its position within the new stratigraphy.

Information about the deformation history is stored for each point as the fourth variable with the coordinates of the point. After all the deformations have been enacted, this code provides information on the rock type the point represents, and if it is not from the base stratigraphy, the age of the erosional or igneous event that removed that stratigraphy. This information is then used to place the point in the right stratigraphic column or igneous body.

Once these transformations have been carried out for every point on the surface of the map, it is possible to define the stratigraphic boundaries by contouring the Z values. Each sub-area, which is bounded by discontinuities in the form of faults, igneous bodies, unconformities and the edges of the map, is contoured as a single unit, and different sub-areas, which must have undergone different displacement histories, must be contoured seperately. The levels of the contours are defined by the heights of the contacts in the originally defined stratigraphies. The boundary between continuous sub-areas is contoured by setting each point within the sub area to +1.0, and setting each point outside it to -1.0, and contouring the Z = 0.0 level. As this is a much more crude description than that used within a sub-area, the contours have a more jagged appearence, however the only way to improve on this would be to recalculate the entire set of displacement equations for each boundary, and this would be prohibitively expensive in terms of computer time. GCONTR, the contouring routine used in this package is, as yet, not generally available from the Computer Center, and thus at some future date it may become nescessary to alter the procedure files which call this routine.

In the following equations, (U,V,W) represents the coordinates of a point in the deformation reference frame into which the (X,Y,Z) space is rotated prior to the calculation of the displacements, and (U′,V′,W′) represents the coordinates of a point after a Lagrangian deformation has taken place. When the pitch of a line is called for, such as a slip vector, zero results in a plunge direction of the dip direction of the plane minus 90 degrees, with positive amplitudes resulting in displacements in the direction of the pitch, and negative ones resulting in displacements which are in the opposite direction to the pitch plunge. The parameters which define the geological history are stored in array "HISTORY", and the storage location associated with each parameter for a given event label are shown in Fig.1.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Inherent Planar / Linear Features
Fold	θ	Ø	ϒ	X	Y	Z	A	λ_T			Cyln. index				1S	Four Label	Foun code		Matno	Axial Plane Cleavage Hinge Line Lineation
Sine	θ	Ø	ϒ	X	Y	Z	A	λ			Cyln. index				1S		Four Code		Matno	Axial Plane Cleavage Hinge Line Lineation
Chevr	θ	Ø	ϒ	X	Y	Z	A	λ			Cyln. index				1S		Four code		Matno	Axial Plane Cleavage Hinge Line Lineation
Biot	θ	Ø	ϒ	X	Y	Z	A	λ_z			Cyln. index	Ξ			1S				Matno	Axial Plane Cleavage Hinge Line Lineation
Lofte	θ	Ø	ϒ	X	Y	Z	A_1	λ_{T1}	A_2	λ_{T2}	Sepn.	Four $Label_1$	Four $Code_1$		1S	Four $Label_2$	Four $Code_2$		Matno	Axial Plane Cleavage
Kink	θ	Ø	ϒ	X	Y	Z	W					S			1S				Matno	None
S-Z	θ	Ø	ϒ	X	Y	Z	W					S			1S	Four Label	Four Code		Matno	Stretching Lineation
Ideal	θ	Ø	ϒ	X	Y	Z	W					S			1S		Four Code		Matno	Stretching Lineation
Fault	θ	Ø	ϒ	X	Y	Z	A	λ_T				S			1S	Four Label	Four Code		Matno	None
Flat	θ	Ø	ϒ	X	Y	Z	Rotn. Ang.	A	B	C	D	S	ROT or TRANS		1S	α	β	γ		Fault Plane, Slip Vector
U/C	θ	Ø	zero	X	Y	Z		A	B	C	D				1S					Plane of Unconformity
Burie															1S					None
Plug	θ	Ø	Zero	X	Y	Z		Rad or Ap.Ang or Ap.Br	Met?	Rock NAME	Merge?		Merge Base No cyl, cone, or para		1S	Four Label	Four Code	Igno	Matno	None
Dyke	θ	Ø	ϒ	X	Y	Z	W	Dil or Slope	Met?	Rock NAME	Merge?	S	Merge Base No		1S			Igno	Matno	Dip of Boundary (but use bed dip function)
Rotat	P	PD		X	Y	Z	Rotn. Ang.								1S				Matno	None
Pure + Simpl	a	b	c	d	e	f	g	h	i						1S				Matno	None
Line	P	PD													1S				Matno	Lineation
Plane	θ	Ø	zero												1S				Matno	Planar Feature

Fig.1. Table of storage locations of geological history information within array "HISTORY", and the inherent penetrative planar and linear features whose orientation may be determined in the third part of "NODDY".

3.2 "FOLD", "SINE", and "CHEVRON"

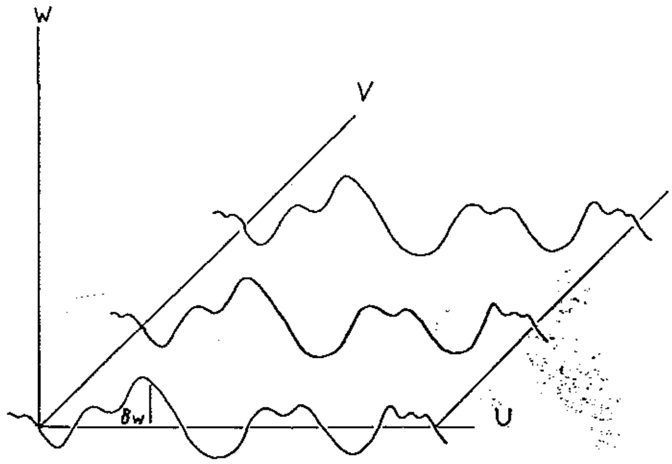

Fig.2. Three sections showing the post-deformational geometry of the W=0 plane using "FOLD" with cylindrical hinges. The V=0 plane is the plane of maximum amplitude for non-cylindrical folds.

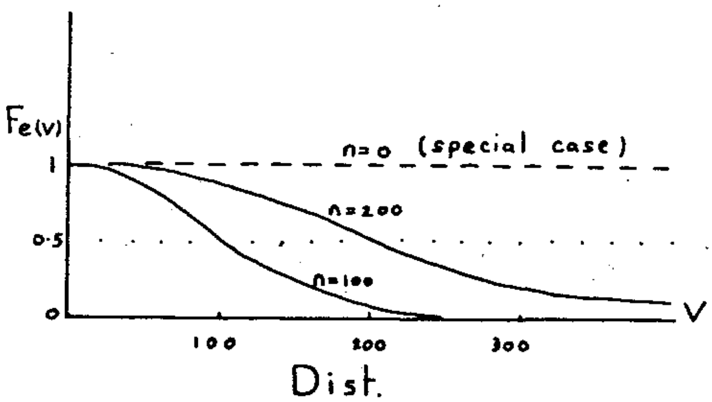

Fig.3. The effect of the non-cylindricity function Fe(V) on the hinge line profile of a fold.

Lagrangian Form:

$$U' = U$$

$$V' = V$$

$$W' = W + A.Fr(U).Fe(V)$$

Eulerian Form:

$$U = U'$$

$$V = V'$$

$$W = W' - A.Fr(U').Fe(V')$$

Where A is the amplitude of the fold and the wavelength of the fold profile, or fold train profile, is normalised to 2.Pi, so that a wavelength function does not actually appear in the equations. The local origin of the fold defines the phase of the fold profile and the plane of maximum amplitude for non-cylindrical folds. For these, and all following equations, Fr and Fe are defined as:

$$Fr(U) = 1/2\ a_0 + \quad A_m COS\ m.x \quad + \quad B_m SIN\ m.x$$

$$Fe(V) = EXP(-n.V^2)$$

A_m and B_m are the Fourier Coefficients of the design as calculated by "SYNMAP". The Fe function is so normalised that if a value of n is input, then the function will have a value of 0.5 at a distance V=n from the plane of maximum amplitude. The amplitude of a fold train is defined as the largest positive digitised amplitude, and the wavelength is the length of the digitised fold profile, rather than the wavelength of an individual waveform.

3.3 "BIOT"

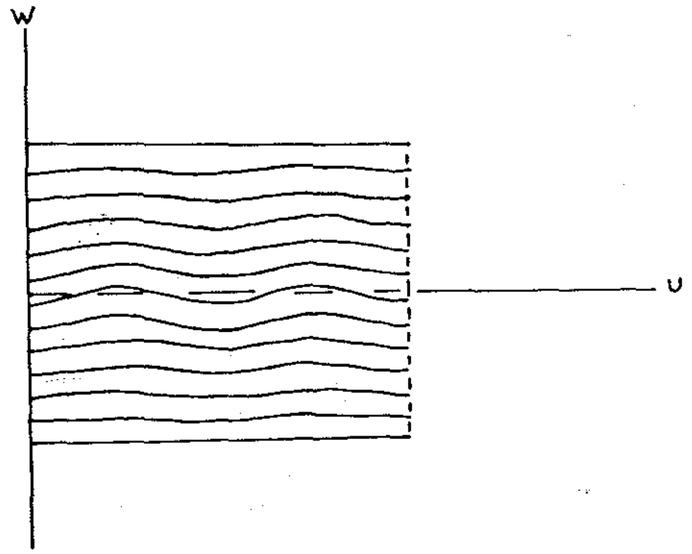

Fig.4. The displacement pattern demonstrated by the W=n family of planes using "BIOT".

Lagrangian Form:

U′ = U - C.L.Xi.COS(L.U).SIN(Xi.L.W).Fe(V)

V′ = V

W′ = W + C.L.SIN(L.U).COS(Xi.L.W).Fe(V)

L = 2.Pi/Fold Wavelength

Xi = Ratio of Fold Wavelength to Wavelength of Internal Buckling

C = Amplitude of Fold

Eulerian Form:

The Eulerian form of these displacement equations involves the use of an iterative non-linear root finding technique, and the one chosen is descibed in Atkinson,(1978). This scheme requires a routine for solving simultaneous equations, and routine F04ATF from the NAG program library was used. As this is a complicated solution compared to the other displacemnt equations, it uses considerably more computer time, and this should be kept in mind if only a simple map is desired.

The local origin defines the phase of the fold profile and the position of the plane of maximum amplitude non-cylindrical folds.

3.4 "LOFT"

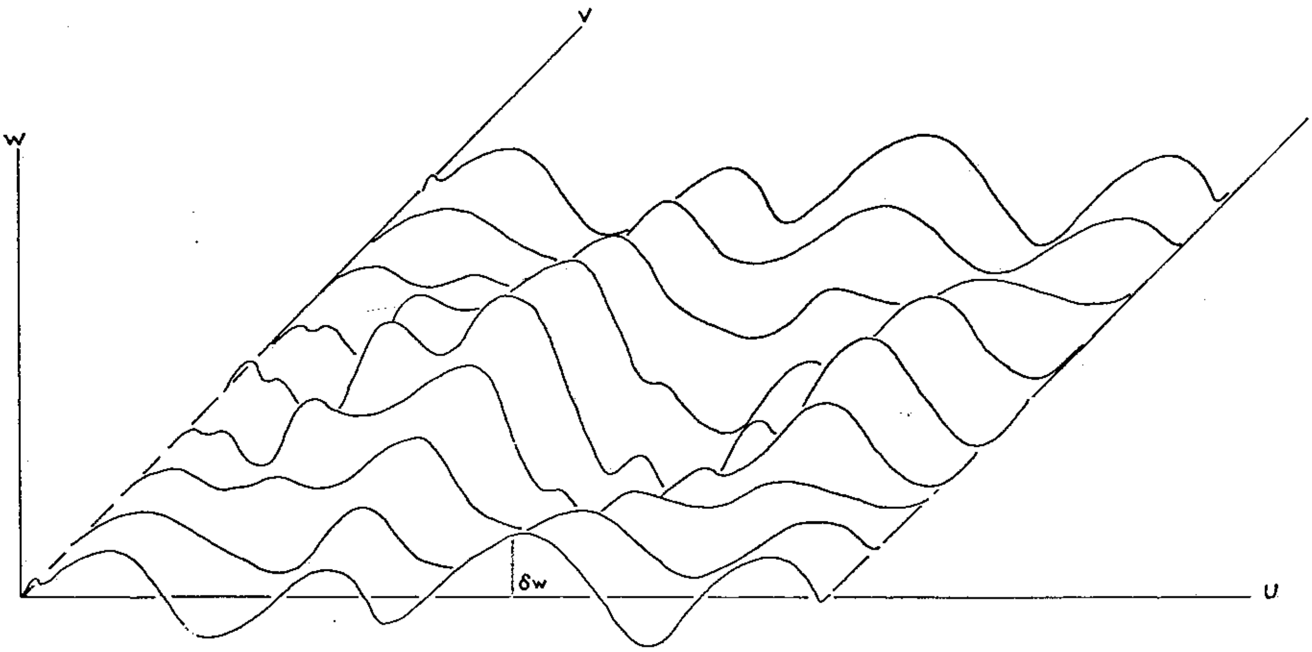

Fig.5. Nine sections showing the post-deformational geometry of the W=0 plane using "LOFTED". The V=0 plane is the plane containing the first defined fold profile and this sequence represents a complete cycle from the first profile, through the second, and back again.

Lagrangian Form:

$$U' = U$$

$$V' = V$$

$$W' = Fr_1(U).D + Fr_2(U).(1-D)$$

$$D = 1+(SIN(Fa(Sep,V).Pi)- Pi/2)/2$$

Fa(sep,V) calculates the position of a coordinate relative to the defining planes or reflections of the defining planes in each other. The wavelength and amplitude terms are as defined in

"FOLD".

Eulerian Form:

$$U = U'$$

$$V = V'$$

$$W = W' - Fr_1(U').D - Fr_2(U').(1-D)$$

The local origin defines the position of the plane containing the first defined fold profile. The fold hinge profile for all lofted folds is a sine wave with amplitude varying according to the values of the two interpolating values.

3.5 "FAULT"

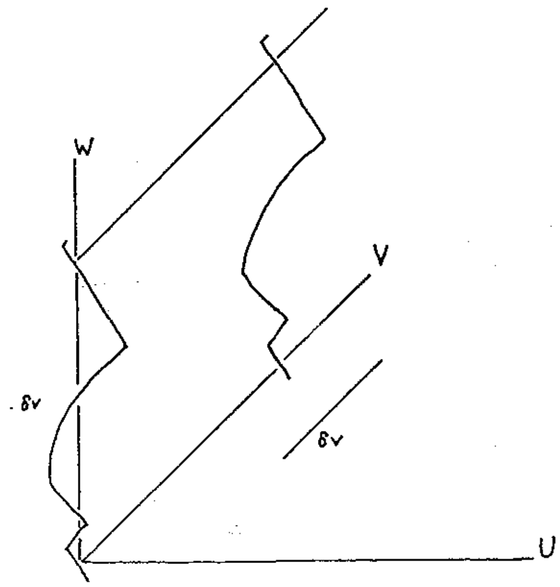

Fig.6. Two sections through the fault plane as defined by "FAULT". The U=0 plane is the mean fault position.

Lagrangian Form, $(U > Fr(W).A)$:

$$U' = U$$

$$V' = V + S$$

$$W' = W$$

Eulerian Form, $(U > Fr(W).A)$:

$$U = U'$$

$$V = V' - S$$

$$W = W'$$

S is the magnitude of the slip vector, and the fault plane and the translated volume of rock are defined by:

U > Fr(W).A

The local origin defines the position of the mean fault plar and the phase of the fault trace, A is the amplitude of the trac and W is normalised to 2.Pi .

3.6 "FLAT "

Lagrangian Form, ((X,Y,Z) > plane):

$$X' = X + \alpha . S$$

$$Y' = Y + \beta . S$$

$$Z' = Z + \gamma . S$$

Eulerian Form, ((X,Y,Z) > plane):

$$X = X' - \alpha . S$$

$$Y = Y' - \beta . S$$

$$Z = Z' - \gamma . S$$

Where α , β and γ are the direction cosines of the slip vector and S is its magnitude. The local origin defines the position of the fault plane, and when a rotational fault is called for, the centre of rotation.

3.7 "S-Z", "IDEAL" and "KINK"

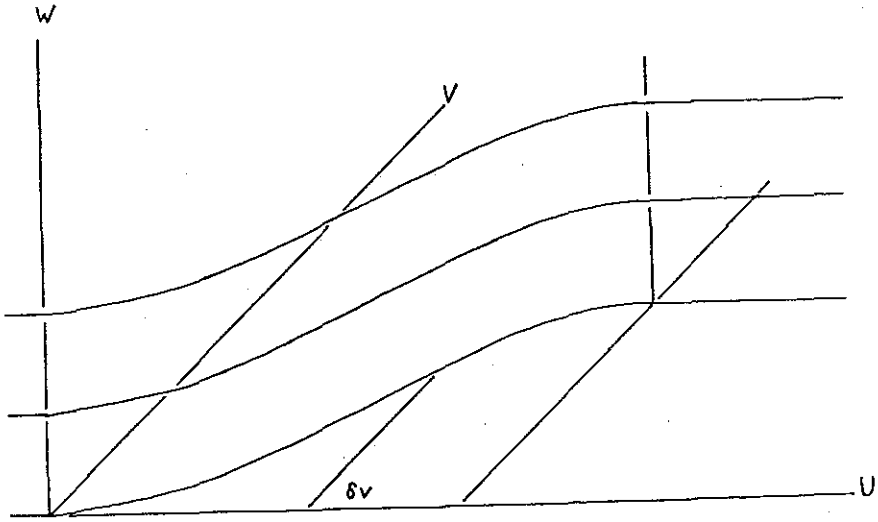

Fig.7. The post-deformation geometry of the V=0 plane using "IDEAL".

Lagrangian Form, (shear zones):

$U' = U$

$V' = V + Fr_1(U).S$

$W' = W$

Eulerian Form, (shear zones):

$U = U'$

$V = V' - Fr_1(U).S$

$W = W'$

Lagrangian Form, (kinks):

$U' = U$

$V' = V + Fk$

$W' = W$

Eulerian Form, (kinks):

$$U = U'$$

$$V = V' - Fk$$

$$W = W'$$

where, for $(U < 0)$:

$$Fr_1(U) = 0$$

$$Fk = 0$$

for $(0 < U < Width)$:

$$Fr_1(U) = Fr(U)$$

$$Fk = (U/Width).S$$

and for $(U > Width)$:

$$Fr_1(U) = S$$

$$Fk = S$$

S is the magnitude of the slip vector, Width is the width of the deformation band and the local origin defines the position of the boundary between the static body of rock and the deformation band.

3.8 "U/C"

This routine determines whether a point in (X,Y,Z) space is above the defined plane, and if it is, the rock is placed in the new stratigraphy. The local origin defines the position of the plane of unconformity.

3.9 "BURIED"

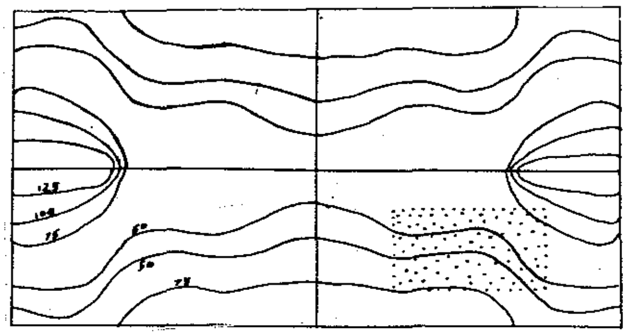

Fig.8. The form of the pre-defined buried landscape with respect to the default map, (shaded).

This routine determines whether a point in (X,Y,Z) space lies above the plane of unconformity as interpolated from the four surrounding defined grid points. The point is first normalised with respect to the area of contoured surface using the Fa function. The scaling factor enables you to vary the amplitude of the ridges and valleys, and even to invert them. The absolute value of the zero level is a constant term which is added to each point on the surface to raise or lower it.

3.10 "PLUG "

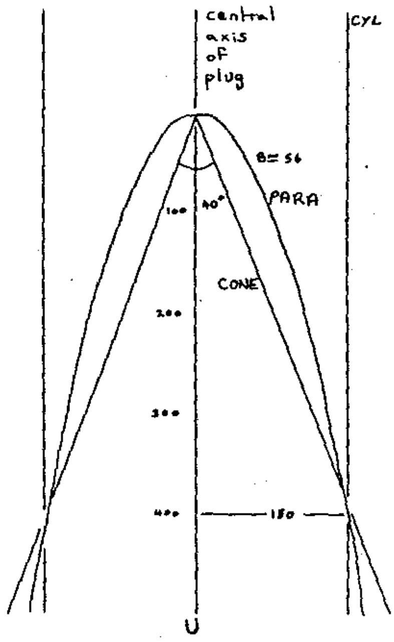

Fig.9. The co-axial plane profiles defined by "PLUG".

The sectional shape of the plug in the plane perpendicular to its axis is defined by:

$$C = R.Fr(\emptyset)$$

and the shape of the plug in a plane including the plug axis is defined in one of three ways:

CYL indrical:

$$R = \text{Radius}$$

PARA bolic:

$$R = \text{Radius}.(B.U)^{1/2}$$

CONE shaped:

$$R = Radius.TAN(Q/2).U$$

where Radius is the defined mean radius of the plug, Ø is the angle between the positional vector and the positive V-axis, B is the parabola shape value and Q is the apical angle of the cone. A plug is only present for (U > 0) for PARA and CONE. The local origin defines the apex of parabolic and cone plugs, and just the central axis for cylindrical plugs.

3.11 "DYKE"

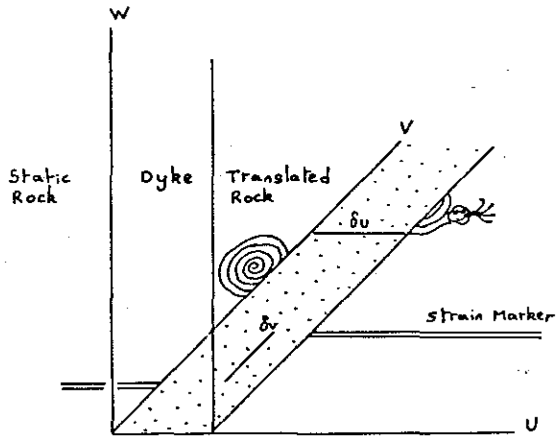

Fig.10. The post-deformation geometry of a dilational dyke intruded parallel to the U=0 plane.

Lagrangian Form, (dilated, (U > Width)):

$U' = U + Width$

$V' = V + S$

$W' = W$

Eulerian Form, (dilated, (U > Width)):

$U = U' - Width$

$V = V' - S$

$W = W'$

Lagrangian Form, (stoped, $(U > Width)$, or $(U < 0)$; or dilated, $(U < 0)$):

$$U' = U$$

$$V' = V$$

$$W' = W$$

Eulerian Form, (stoped, $(U > Width)$ or $(U < 0)$; or dilated, $(U < 0)$:

$$U = U'$$

$$V = V'$$

$$W = W'$$

Where Width is the width of the dyke and S is the magnitude of the slip vector for the translated rock projected onto the plane of the dyke. The local origin defines the position of the boundary between the static lower rock group and the dyke.

3.12 "PURE" and "SIMPLE"

Lagrangian Form:

$$(X',Y',Z') = (X,Y,Z)(S)$$

$$(S) = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}$$

Eulerian Form:

$$(X,Y,Z) = (X',Y',Z')(S)'$$

(S)′ is the inverse of matrix (S), and to solve this inversion the NAG library routine F01AAF is used.

3.13 "ROTATE"

Lagrangian Form:

$$(X',Y',Z') = (X,Y,Z)(R)$$

Eulerian Form:

$$(X,Y,Z) = (X',Y',Z')(R)'$$

Where (R) is the rotation matrix defined by the direction cosines of the rotation axis and the amount of rotation.

Chapter 4 Creating a data set for "NODDY"

Although it is not essential to create new data sets for "NODDY" or even to use an ancilliary data set at all, it is useful when modelling the variety and irregularity of real geology, even if only a topography is included. The example data sets "RAW" and "SYN" show the formats of the digitised and synthesised data sets. If it is felt that an alternative system of data synthesis is prefered, for example using a more sophisticated regularising routine for contour data, then assuming that the format of the synthesised data set is adhered to, this should not present any problems.

4.1 The GRAF/PEN Digitiser, a Primer

The GRAF/PEN sonic digitiser, which is used to create acilliary data files for "NODDY", can work in several different modes. The mode used primarily by this package consists of generating Cartesian Coordinates of points. The coordinates of a point on the Perspex tablet are calculated by the digitiser from the arrival times of the sound waves produced by a spark generator, as measured by two orthogonal strip microphones. There are two different spark generators, one is situated at the tip of a pen, so that a record of the actual points digitised may be kept. With the pen, a point or line is digitised when the tip of the pen is pressed down. The alternative spark source is a cursor system whereby the coordinates of a point are digitised by placing the cursor cross wires over the desired locality and pressing the white button on the center of the cursor. To generate a valid data file for synthesis by program "SYNMAP" it is necessary to use the digitiser in four different modes, not only digitising plot coordinates, but also digitising menu choices, inputing data from the linked terminal keyboard and controlling the digitiser by means of the controls on the front of the GRAF/PEN processor.

The digitiser works by receiving sound waves, so it is important that nothing should obstruct the microphones, as otherwise spurious plot coordinates will be generated. The digitiser coordinate system is such that the user looks along the Y-axis,and to ensure that this is the coordinate system you actually digitise it is best to stick the piece of paper with the information to be digitised down onto the Perspex. When digitising in line mode the spark source automatically emits a click at regular intervals. The rate of information down the telex line is faster than the speed at which the terminal works, so that random data is displayed on the screen as you are digitising a line, however do not be alarmed, the data file itself is normal.

4.2 Generating a Data File

Since there are so many small important steps that have to be followed in order to generate a data file for "SYNMAP" and "NODDY", the best guide to its creation is a step by step account of what has to be done. In the following guide, (T) refers to input by terminal keyboard, (D) refers to digitised input, (either a plot coordinate or a menu choice), and (G/P) indicates that a control on the front of the GRAF/PEN processor needs to be altered. Comments refering to each step are enclosed in double brackets, and are not to be input.

Starting a new data file

Enter Digitiser Room ((Room 403, RSM))
Turn On Wall Plug To GRAF/PEN Processor
Press "Power" Button on Processor ((Red Light Comes On))
Turn On Terminal
Turn Rate Knob Fully Clockwise (G/P)
Log On To ICCC System via TAC (T)
enter:new,mydata (T)
text (T)

The system will then respond with "ENTER TEXT MODE", and you are now ready to input data to the file "MYDATA". All data requiring a Fourier Synthesis must be digitised before any buried topography contours, and the surface topography must be digitised last of all. Within the first group, however, there is no order of priority between plugs,folds,shear zones or faults, and data can be totally intermingled within the data group. Where the word "namel" is used in the guide it refers to a five letter label by which the data will be retrieved when used in "NODDY", therefore names should be chosen that cannot be confused, further the names "CHEVR", "SINE " and "IDEAL" are forbidden as these are names supplied by "NODDY". It does not matter what scale drawing is used to generate Cartesian Fourier coefficients, as these are normalised anyway. However all contour information must be drawn to fill an A4 sheet of paper , with the East-West or X-axis parallel to the long edge of the paper, and all plugs must be drawn with a base circle of 4cm radius, although this base itself does not have to be drawn. The transformation carried out in "SYNMAP" for plugs is shown in Fig.11.

4.3 Digitising Plug Shapes

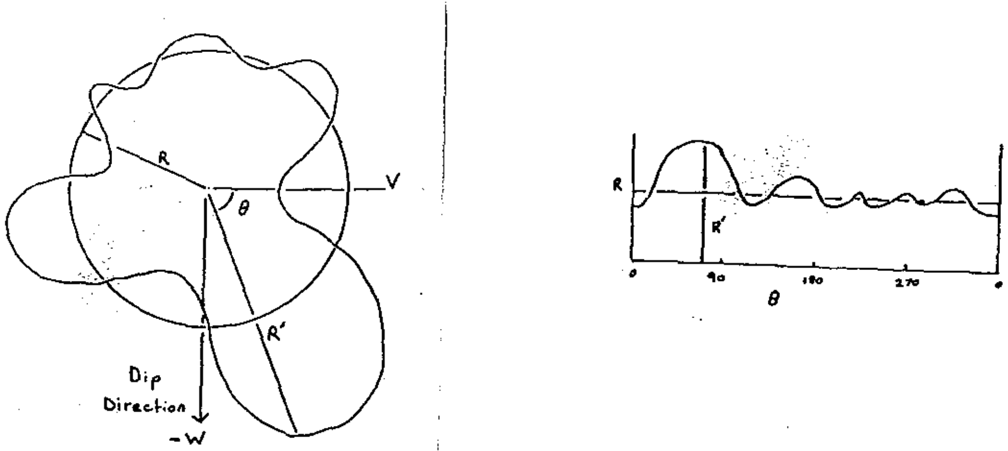

Fig.11. The form of a plug boundary in Polar and Cartesian coordinates, the former as it would be digitised, the latter ready for Fourier Synthesis.

A/ enter:PLUG ,name1 (T)
T or F ((depending on whether you digitise clockwise (T) or anticlockwise (F))) (T)
Clear,Start,Point,Menu (G/P)
Digitise "OUTPUT" box in lower R/H corner of perspex (D)
Digitise Central Point of Plug (D)
Origin,Line (D)
Digitise Plug Shape (D)
1 ((1 is end flag)) (T)

4.4 Digitising Faults,Folds and Shear-Zones

B/ enter:{FAULT,name1 or (T)
{FOLD ,name1 or (T)
{S-Z ,name1 (T)
Clear,Start,Point,Menu (G/P)
Digitise "OUTPUT" box (D)
Digitise Origin of Fault/Fold/S-Z ((i.e. The left hand side of the line)) (D)
Origin (G/P)
Digitise Upper Limit of X values (D)

Line (G/P)
Digitise Fault/Fold/S-Z Profile from left to right (D)
1 ((1 is end flag)) (T)

Once all the desired profiles have been digitised, enter "END" via the terminal after the last endflag of "1", and go on to the next section.

4.5 Digitising Contours

If no buried landscape is wanted, enter "END" once again, however if it is, follow command list "C".

```
c/ enter:BURY ,namel          (t)
       Clear,Start,Point,Menu    (T)
       Digitise "OUTPUT" box     (T)
       Digitise origin of map, i.e. The bottom L/H corner    (D)
       Origin,Line               (G/P)
       123.0 ((first contour level)) (T)
       Digitise 123.0 Contours    (D)
       1          ((end of height flag))    (T)
       240.0 ((next contour level))    (T)
       Digitise 240.0 Contours    (D)
       1          ((end of height flag))    (T)
       200.0        ((next contour level))     (t)
       .
       .
       .
       .
       .
       Etc.  Until
       .
       .
       .
       .
       575.0     ((last contour height))    (T)
       Digitise Last Contour                (D)
       9            ((end of map flag))    (T)
```

"SYNMAP" creates a regular grid of topographic data from the contour information you have digitised. To this end it searches though the data set to find points within a given radius of each grid point and calculates a weighting function for each data point, which is inversely proportional to the distance between it and the grid point. The interpolation scheme used is dscribed in Davis and McCullagh, (1975). Since this results in a smoothing of the topography it is best to exaggerate all features of interest. It is also advisable to enter spot heights along the crests of ridges and valley bottoms as otherwise these features become very diluted. Even though an A4 sheet defines the boundaries of the grid it helps to continue digitising the contours some distance beyond this boundary as this will greatly reduce any possible edge effects.

If no surface topography is wanted, a final entry of "END" via the terminal will complete the data set, otherwise proceed with command list "C" again, replacing "BURY " by "TOPO " in the first line.

To complete the command sequence enter "control" C and the system will respond with "EXIT TEXT MODE". Then enter "pack" and the system will respond with "PACK COMPLETE". You may then save data file "MYDATA" or you may add it to a preexisting data set, always bearing in mind that the order of the data types must be preserved and that you are only allowed to create twelve Fourier Synthesised data sets, and two contoured data sets, one BURY and one TOPO.

4.6 Synthesising the Digitised Data Set

Once the data set , for example "MYDATA" has been created and saved, to synthesise the data you need access to procedure file "SYNDAT" and program "NODDY". The calling command is:

CALL,SYNDAT(RAW=mydata).

The name of the file containing the processed data is "SYN". It is possible to check for errors in the datafile "MYDATA" by getting a listing of "SYN". If there are no errors, the terminal will output "NO WORRIES SPORT", however if you have made some mistakes it will tell you how many errors you have made, and interspersed with the correctly synthesised data in file "SYN" will be a series of basic error messages, giving a rough guide to the location and nature of the error. Once these errors have been located and corrected, it is then possible to use this data set from within program "NODDY".

Chapter 5 Using "NODDY"

When using "NODDY" for the first time it is advisable to have access to this chapter and to have already looked over the example program run in Appendix II. It is also desirable to produce an example block diagram of each structure available, so that a feel for the meaning of the parameters involved may be acquired. Even if this is done, in practical terms, the only realistic method of understanding the details of this package is to use it.

5.1 The Tektronix Terminal , a Primer

"NODDY" was written to interface with the Tektronix graphics terminals, and these differ in several important ways from a standard VDU . The most significant difference is, obviously, their ability to display graphic information. Every part of the program can be classified as either being hardware character display, which resembles the normal output from a VDU, or graphics display, which consists entirely of the display of lines. All graphics display, apart from the error messages and graphics surrounding the final line maps, may be saved either in the Quick-Look pool, which redisplays any given picture and then queues it for microfilm output; or in the Kingmatic pool which produces a paper plot on the Kingmatic flat bed plotter. If during a run of "NODDY" a lower quality, photo-copy style representation of the screen contents (including hardware characters) is desired, this can be achieved by pressing to the right the "Auto Copy" key in the top right hand corner of the keyboard, but this will only work in conjunction with a screen copier , and if used otherwise will clear the screen. During the program, after each new display of graphic information, the program asks whether a hard copy of the screen contents is desired. This refers to the post processing, however it also provides a break in the program where a screen copy of the display may be made.

The contents of a graphics display are in effect stored physically, rather than in a memory and the screen is analogous to a line printer terminal in that it will superimpose any overlapping information displayed on the screen, rather than erasing the old information if it coincides, as with a normal VDU. If at any stage you wish to clear the screen, you can press the "Reset Page" key found in the upper left corner of the keyboard. There is only one point in the program where you are actually advised to do this, and that is in between the displaying of the contour map and the geology map, as if superimposed they can create problems in understanding the geology.

In the third section of the program, which begins after the display of the mapping area, interaction is carried out by means of two crossing lines which appear on the screen. The position of these two lines, and hence the coordinates of their intersection, can be altered by moving the thumb wheels found to the right of the keyboard. When the cross-wires are lined up so that they intersect within the box which represents the desired command input, the information is retrieved by the terminal shortly after any key on the keyboard is pressed, (except carriage return). This system was chosen so that the screen did not become cluttered with questions and answers, as this would cover the map and create confusion.

5.2 Gaining Access to "NODDY"

Once the data from synmap has been accepted, to run "NODDY" you need a copy of the compiled program in binary form called "JOKE" and procedure file "FAST", which carries out all the necessary job control commands, both before and after the running of the program. If a compiled binary copy of the program is not available, this can be generated by using procedure file "EASY". "NODDY" must be run at a graphics terminal, and to use the package most flexibly a screen copier is essential. (these facilities may be found in room 406 in the Mechanical Engineering Building.) After logging onto the time-sharing system, and ensuring that the upper case shift lock is on, "NODDY" can be run simply by issuing the following command:

-FAST

the terminal then responds with :

**COUPLER ASSIGNED.

and it then will ask for the number of the terminal, which is found in the lower right hand corner of the keyboard. If using a 4014 terminal it will also give a choice of character set sizes, however this is overriden by "NODDY" so that any answer may be entered.

5.3 "NODDY" Preamble

The first response "NODDY" makes is to display an introductory page which describes the program structure and types of input formats allowed. Typing in "GO" will then let the program know that you are ready to define the base stratigraphy for the geology. It does not really matter what height range is specified in your base stratigraphy as the block diagrams and final map can be of any scale and position, however for the unmodified block diagram, (with local origin equal to absolute origin and scaling factor equal to one), a stratigraphic column that spans from about +600 to -100 is well placed to show up the deformation history as it develops.

5.4 Defining the Geological History

Having input the stratigraphy, the main interactive definition section of the program comes into operation. As an introducion a one line description of each deformation event and its associated label is displayed. A fuller definition of each type of deformation and the meaning of the parameters needed to define them can be found in Chapter Three of this thesis. After each definition cycle you have the choice of viewing block diagrams of the structure defined to date. These blocks are nominally 1000 units East-West, 700 units North-South and 500 units deep, with the origin of the block coordinates defined as the lower South-West corner of the block. By redefining the coordinates of this local origin and the scale of the block it is possible to generate block diagrams of any part of the structure, and at any scale. It is important to remember the scale of the geology you are interested in as otherwise the coarseness of the grid of sampled points on the block surface may mean that the structure does not show up at all. If this is the case, or for any other reason, after you have seen all the block diagrams you want to , you can retrace your steps back to any part of the geological history and restart it from there. When you have generated a geological history to suit your purpose, and have located the block diagram which is positioned so as to best display the resulting geology, you can exit from the defining stage of the program by using event label "END". The program then asks once more if a block diagram is required so that you can check your results, and then no further block diagrams may be generated. If the program is being used simply to generate block diagrams, and specific orientation information or the detail and clarity that a line map provides is not wanted, then answering in the negative to all remaining questions will terminate the run after a key to the stratigraphy has been displayed.

5.5 Interactive Dip Data Production

If, however, a line map or dip data is wanted, then there are two alternatives, after a contour map of the topography is displayed, one option is to have a full outcrop map of the geology for a given local origin and scale displayed. If instead the uncertainty of real mapping is prefered, this map can be suppressed so that only the topographic map will be shown. If a linemap is chosen it may be best to follow the advice given from within the program to clear the screen between the display of the topography map and the geology map. This is achieved by pressing the "Reset Page" key on the top-left of the keyboard, and it has the effect of simplifying the resultant map, as no distinguishing variations in line thickness or colour are available on a Tektronix screen. On subsequent Kingmaticic or Microfilm copies of this map, however, the two will be superimposed. Of course, if desired, the two plots can be superimposed simply by neglecting to press this key.

Once the program is ready for interaction it will print "START OF INTERACTION" in the error messages box, the top left of the four boxes surrounding the map area. To achieve anything in this part of the program, apart from a page full of error messages, it is nescessary to have a copy of the tree diagrams which represent the allowable sequences of commands. All interaction is carried out by means of the crosswires that are displayed on the screen whenever a response is required by the program. A valid response is input by lining up the crosswires, (using the thumb wheels on the right hand side of the terminal), so that they intersect within one of the boxes in the age choices or menu area, or if a location on the map is wanted, within the map boundaries. The position of the crosswires is only actually calculted after one of the alphanumeric keys is pressed so there is no hurry. If an error is made, either due to not following the relevant tree diagram or simply by missing all of the boxes, then after three bleeps a short error message is printed and the program returns you to the beginning of the cycle. This section is best, and possibly only understood by following the example program run. Exiting from this phase is achieved by choosing the box labeled "END" at the start of a cycle. This clears the screen, so if an immediate copy is wanted it should be made prior to this. Neither screen copies nor real hardcopies can detect the crosswires.

The program will then display stereographic or equal area plots of all the orientation data which was accepted in the previous stage, one plot for each symbol used and one larger plot which displays all the data generated. The accepted data is stored in data pools according to the mapping symbol cuurently associated with each menu box, thus a call to New Symbol will change the destination of that and all future data points from the same box, until another symbol is chosen to replace it. The default symbols are displayed beneath each box. You then have the option of restarting the third section of the program so that you can have a map of a different locality of the same defined geology, however it will utilise the same topographic data, if available, so that it is not possible to build up endless line maps of the geology unless the flat plane topography option is chosen. When no more maps are wanted, after the final set of stereograms is produced the end option in the next question will terminate the program run and those pages which have been accepted for hardcopy generation will be placed in the relevant Quick-Look or Kingmatic data pools. The materials generated can be collected from the reception area in the Computer Center. Unfortunately there is a lag of three to four days before this is produced, so the only copies available for immediate use are those generated on the screen copier. To rerun the program enter:

-AGAIN

or re-call "FAST". Any files saved in the Quick-Look pool may be viewed immediately by typing in '-QL' and following the instructions provided.

5.6 Tree Diagrams for Interactive Labelling

Rock Name:

```
1--21
```

Metamorphic Grade:

```
2--21
```

Bed Plane Dip:

```
        15
       /
      /
3--21--16--8
      \
       \
        17
```

Planar Feature Dip:

```
            15
           /
          /
4--30--21--16--8
          \
           \
            17
```

Linear Feature Plunge:

```
            15
           /
          /
5--30--21--16--8
          \
           \
            17
```

Bedding/Cleavage Lineation:

```
            15
           /
          /
6--30--21--16--8
          \
           \
            17
```

Cleavage/Cleavage Lineation:

```
                        15
                       /
                      /
        7--30--30--21--16--8
                      \
                       \
                        17
```

```
-- = "followed by"

/
- =  "choice of three"
\
```

Fig.12. The Box Numbering System used in the Tree Diagrams.

When using a tree, such as Planar Feature Dip, where an Age Choice is required, the box chosen defines the age of the penetrative strain marker. For example, choosing "PLANE" will give the orientation of the special planar feature defined in routine "DEFPLAN", and choosing "FOLD" will give the orientation of the inherent axial plane cleavage associated with the folding event chosen. Fig.1. Gives a full list of all the inherent planar and linear features which may be used.

5.7 Correcting Input Errors

It is notoriously difficult to use other people's packages, especially when there is a lot of interactive data input. For this reason it has been made relatively easy to correct input errors. During all stages of keyboard interaction the program will only accept the correct answers to verbal questions, such as "YES" or "NO", any other input resulting in a restatement of the question. When numerical data is wanted such as the dip of a plane, only numerical answers will be accepted, any other resonse, such as +*%(" or seven, will result in the response of "ERROR IN INPUT LINE, PLEASE RETYPE". Incomplete numerical input, for example only giving two numbers for a coordinate set, results in another question mark, and the remaining data should then be typed in. Unfortunately the latter two errors result in a computer system response, so that the retyped line is overprinted by the next question. Numbers may be either integer or decimal, and lists of numbers need only be seperated by commas. With some deformation parameters, it may be possible to enter completely meaningless values, and where these would result in a program failure, such as having a fold with a wavelength of zero, you are returned to the start of the definition cycle. Negative wavelengths, in contrast, are admissable, as these simply reverse the waveform.

Within a particular cycle of questions, such as a set which defines stratigraphy or a deformation event, it is possible to restart the cycle by inputing a carriage return without first typing in any data, this is useful both when you change your mind and when a question is overwritten by an error message. At the end of each cycle of definition during the generation of the geological history, it is possible to retrace any number of events.

In the third phase of the program, when using the cross wires it is possible to abort from any one cycle simply by choosing an intersection outside any of the valid box choices. Orientation data is initially displayed only as a point on the Test Plot stereogram, and only if the point is accepted by choosing the Accept box, or the New Symbol box, does the program display the mapping symbol and the point become stored for replotting on the stereograms which are dispalayed after the "END" option is chosen.

Chapter 6 Conclusions

For a package of this kind conclusions should only really be drawn after it has been put to use. Nevertheless it has been shown to supply sufficiently varied structures that there is not a strong sense of artificiallity, which might have been present using such idealised deformations. Given the simplicity of the the deformation models, and the complexity of the resulting geology, it is not surprising that the interpretation of real structures is so open to discusion. Although it would not have been a problem to have included more sophisticated deformation models, the package is not presented as a model of the real world, and a package which was designed to do this would have to be so much more complex that it would become cumbersome to use it simply to generate teaching maps.

I would like to thank Erica for making the thesis work, Frank for making the program work and Rob for putting up with all three of us.

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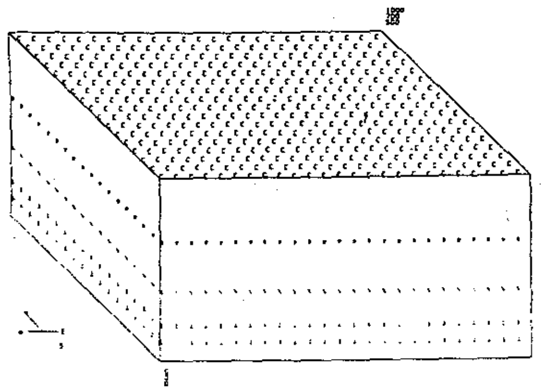
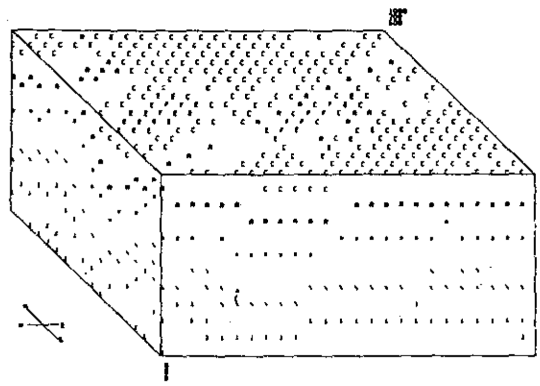
Appendix II Example Program Run

```
FOR THE BASE STRATIGRAPHY:
HOW MANY LAYERS ARE THERE IN THE
STRATIGRAPHY (INCLUDING TOP AND
BOTTOM LAYERS, NOT MORE THAN 16 ?
NOW, STARTING WITH THE HIGHEST RO
UNIT, INPUT THE ROCK NAME AFTER
THE FIRST PROMPT, AND THE HEIGHT
OF THE LOWER CONTACT AFTER THE
SECOND PROMPT
ROCK NAME ? SST.
CONTACT HEIGHT ? 575
ROCK NAME ? MARL
CONTACT HEIGHT ? 540
ROCK NAME ? SBALE
CONTACT HEIGHT ? 524
ROCK NAME ? LIMESTONE
CONTACT HEIGHT ? 464
ROCK NAME ? MUDSTONE
CONTACT HEIGHT ? 405
ROCK NAME ? SILTSTONE
CONTACT HEIGHT ? 366
ROCK NAME ? ZONE C
CONTACT HEIGHT ? 322
ROCK NAME ? ZONE B
CONTACT HEIGHT ? 280
ROCK NAME ? ZONE A
CONTACT HEIGHT ? 195
ROCK NAME ? JURASSIC
CONTACT HEIGHT ? 140
ROCK NAME ? PERMIAB
CONTACT HEIGHT ? 994
THAT'S MORE THAN THE LAST HEIGHT.
ROCK NAME ? PERMIAN
CONTACT HEIGHT ? 94
ROCK NAME ? CARB. LST.
CONTACT HEIGHT ? 45
ROCK NAME ? LLANVIRN
CONTACT HEIGHT ? -50
NOW FINALLY GIVE THE NAME OF THE
ROCK TYPE ? SAXOPHONE

     THIS PAGE LISTS THE  POSSIBLE GEOLOGICAL EVENT CODES
     (IN INVERTED COMMAS), AND GIVES A BRIEF DESCRIPTION OF THEIR MEANING.
          'CHEVR'ON........PROGRAM DESIGNED CHEVRON SHEAR FOLD
          'SINE '..........PROGRAM DESIGNED SINUSOIDAL SHEAR FOLD
          'FOLD '..........DIGITISED SHEAR FOLD PROFILE
          'BIOT '..........PROGRAM DESIGNED SINUSOIDAL INTERNAL BUCKLES
          'KINK '..........PROGRAM DESIGNED KINK BANDS
          'LOFTE'D.........LOFTED SURFACE FOLD DESCRIPTION
          'PLANE'..........USER DEFINED PENETRATIVE PLANAR FEATURE
          'FLAT 'FAULT.....PROGRAM DESIGNED FLAT PLANAR FAULT
          'FAULT'..........DIGITISED FAULT TRACE
          'U/C  '..........PROGRAM DESIGNED PLANAR UNCONFORMITY
          'BURIE'D.........DIGITISED BURIED TOPOGRAPHY
          'S-Z  '..........DIGITISED SHEAR ZONE STYLE
          'IDEAL'..........PROGRAM DESIGNED SHEAR ZONE
          'DYKE '..........PLANAR IGNEOUS BODY
          'PLUG '..........DIGITISED IGNEOUS BODY SHAPE
          'ROTAT'E.........HOMOGENEOUS ROTATION
          'PURE '..........HOMOGENEOUS PURE SHEAR
          'SIMPL'E.........HOMOGENEOUS SIMPLE SHEAR
          'LINE '..........USER DEFINED PENETRATIVE LINEAR FEATURE
          'HELP '..........REDISPLAYS THIS PAGE
          'END  '..........END OF GEOLOGICAL HISTORY
          'START'..........DUMMY ROUTINE ENABLING VIEW OF UNDEFORMED STRATA

NOW PLEASE CHOOSE A LABEL FROM THIS LIST ? PLANE

WHAT IS THE DIP AND DIP DIRECTION OF THE PLANE ? 75,30

DO YOU WANT A VIEW OF THE
STRATIGRAPHIC COLUMN
('YES' OR 'NO') ? NO
DO YOU WANT A BLOCK DIAGRAM OF
THE GEOLOGY TO DATE ?
('YES' OR 'NO') ? YES
```

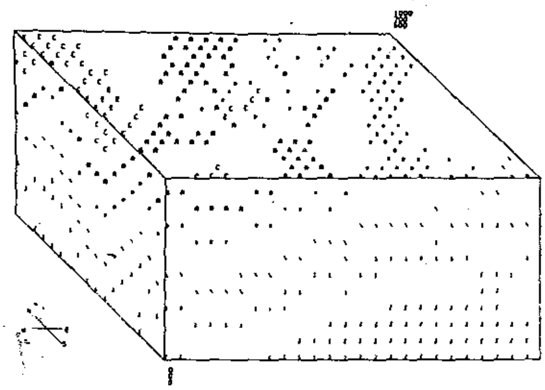


```
YOU NOW HAVE THREE CHOICES:
TO ACCEPT THE NEWLY DEFINED EVENT AS
PART OF THE HISTORY ('OK')
IF YOU DON'T LIKE WHAT YOU HAVE JUST
DONE, YOU CAN ('ERASE') IT
OR FINALLY, IF YOU'VE MESSED IT UP
COMPLETELY, YOU CAN GO BACK TO
ANY POINT IN THE GEOLOGICAL HISTORY
AND ('REDEFINE') IT FROM THERE ? OK

NOW TYPE IN THE LABEL FOR THE NEXT
GEOLOGICAL EVENT FROM THE LIST BELOW
CHEVRON..SINE..FOLD..BIOT..KINK..
LOFTED..FLAT FAULT..FAULT..
U/C..BURIED..S-Z..IDEAL  S-Z..
DYKE..PLUG..ROTATE..PURE..SIMPLE..
LINE..PLANE..HELP..END..START ? LOFTED
```

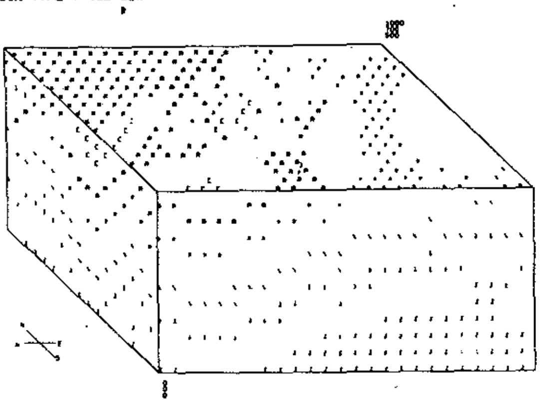
```
WHAT IS THE SEPERATION OF THE DEFINING PLANES ? 1000
TYPE IN THE DIP AND DIP DIRECTION
OF THE MEAN AXIAL PLANE ? 80,330
INPUT THE PITCH OF THE FOLD HINGE ? 0
NOW INPUT THE LOCAL (X,Y,Z) ORIGIN COORDINATES ? 1400,400#400
WHAT ARE THE RECURRENCE WAVELENGTHS
AND AMPLITUDES OF THE FOLD TRAINS
FOLD TRAIN ONE ? 600,150
FOLD TRAIN TWO ? 2000,100
FOR FOLD TRAIN ONE
*****
SINE
CHEVR
RANDM
PULSE
CUSP
***** P
FROM THE ABOVE LIST WHICH DESIGN
DO YOU WANT ? PULSE
FOR FOLD TRAIN TWO
*****
SINE
CHEVR
RANDM
PULSE
CUSP
*****
FROM THE ABOVE LIST WHICH DESIGN
DO YOU WANT ? RANDM
DONEDB WANT A VIEW OF THE
STRATIGRAPHIC COLUMN
('YES' OR 'NO')
('YES' OR 'NO') ? NO
DO YOU WANT A BLOCK DIAGRAM OF
THE GEOLOGY TO DATE ?
('YES' OR 'NO') ? YES
DO YOU WANT: '1' TOP FACE ONLY
             '2' TOP AND FRONT,OR
             '3' COMPLETE BLOCK ? 3
WHAT ARE THE ABSOLUTE COORDINATES
OF THE BLOCK ORIGIN ? 0,0,0
WHAT SCALING FACTOR DO YOU WANT
1 = 1000 BY 700 ? 1
```



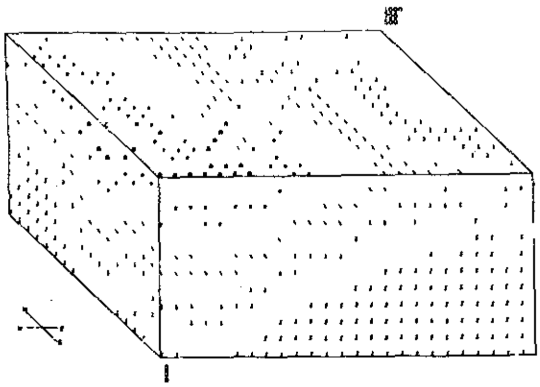
```
WHAT IS THE PLUNGE AND PLUNGE DIRECTION
OF THE ROTATION AXIS ? 20,10
NOW TYPE IN THE (X,Y,Z) COORDINATES
OF ONE POINT ON THE AXIS ? 0,0,0
FINALLY INPUT THE AMOUNT OF ANTI-CLOCKWISE
ROTATION LOOKING DOWN THE AXIS ? 15
DO YOU WANT A VIEW OF THE
STRATIGRAPHIC COLUMN
('YES' OR 'NO') ? NO
DO YOU WANT A BLOCK DIAGRAM OF
THE GEOLOGY TO DATE ?
('YES' OR 'NO') ? NO
```

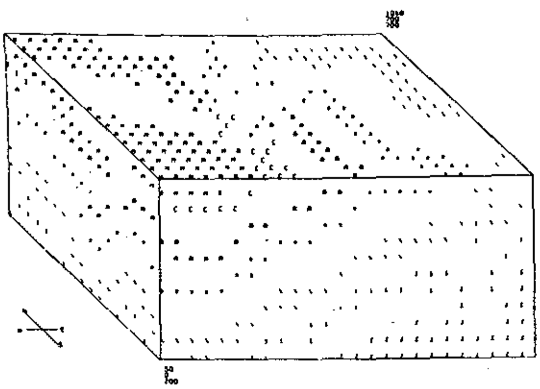


```
WHAT IS THE DIP AND DIP DIRECTION OF THE
PLANE OF UNCONFORMITY ? 20,315
PLEASE GIVE THE (X,Y,Z) COORDINATES OF ONE
POINT ON THE UNCONFORMITY ? 0,250,500
HOW MANY LAYERS ARE THERE IN THE
STRATIGRAPHY (INCLUDING TOP AND
BOTTOM LAYERS, NOT MORE THAN 16 ? 8
NOW, STARTING WITH THE HIGHEST ROCK
UNIT, INPUT THE ROCK NAME AFTER
THE FIRST PROMPT, AND THE HEIGHT
OF THE LOWER CONTACT AFTER THE
SECOND PROMPT
ROCK NAME ? ROSE BED
CONTACT HEIGHT ? 660
ROCK NAME ? BATER BED
CONTACT HEIGHT ? 580
ROCK NAME ? RED BED
CONTACT HEIGHT ? 522
ROCK NAME ? RD UNDRRDD
CONTACT HEIGHT ? 450
ROCK NAME ? ROBBED
CONTACT HEIGHT ? 422
ROCK NAME ? RIBBED
CONTACT HEIGHT ? 362
ROCK NAME ? RUBBED
CONTACT HEIGHT ? 240
NOW FINALLY GIVE THE NAME OF THE LOWEST
ROCK TYPE ? GEE GEE
```

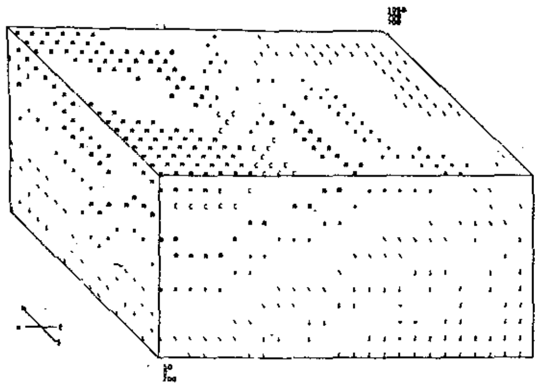


```
WHAT IS THE PLUNGE AND PLUNGE DIRECTION
OF THE ROTATION AXIS ? 10,300
NOW TYPE IN THE (X,Y,Z) COORDINATES
OF ONE POINT ON THE AXIS ? 0,0,0
FINALLY INPUT THE AMOUNT OF ANTI-CLOCKWISE
ROTATION LOOKING DOWN THE AXIS ? 17
DO YOU WANT A VIEW OF THE
STRATIGRAPHIC COLUMN
('YES' OR 'NO') ? NO
DO YOU WANT A BLOCK DIAGRAM OF
THE GEOLOGY TO DATE ?
('YES' OR 'NO') ?
```

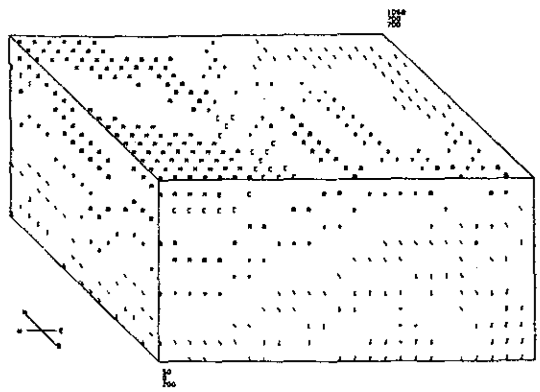




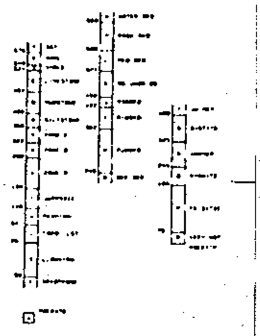
```
WHAT IS THE DIP AND DIP DIRECTION
OF THE DEFINING PLANE ? 45,0
WHAT ARE THE (X,Y,Z) COORDINATES
OF THE LOCAL PLUG ORIGIN ? 700,400,500
DO YOU WANT A CYLINDRICAL, CONE
SHAPED OR PARABOLA SHAPED PLUG
'CYL', 'CONE', OR 'PARA' ? CYL
WHAT RADIUS PLUG DO YOU WANT ? 50
*****
HANDY
EYE
CONE
SINE
CHEVR
*****
FROM THE ABOVE LIST WHICH DESIGN
DO YOU WANT ? CHEVR
PLEASE TYPE IN THE NAME OF THE PLUG ROCK
NOT MORE THAN TEN LETTERS ? ROCKITE
IS THERE A METAMORPHIC AUREOLE AROUND
THIS INTRUSION ('YES' OR 'NO') ? YES
IN THE FOLLOWING QUESTIONS
STRATIGRAPHY REFERS TO METAMORPHIC
STRATIGRAPHY AND CONTACT HEIGHT
REFERS TO DISTANCE FROM IGNEOUS CONTACT
HOW MANY LAYERS ARE THERE IN THE
STRATIGRAPHY (INCLUDING TOP AND
BOTTOM LAYERS, NOT MORE THAN 16 ? 6
NOW, STARTING WITH THE HIGHEST ROCK
UNIT, INPUT THE ROCK NAME AFTER
THE FIRST PROMPT, AND THE HEIGHT
OF THE LOWER CONTACT AFTER THE
SECOND PROMPT
ROCK NAME ? UN-MET
CONTACT HEIGHT ? 400
ROCK NAME ? BIOTITE
CONTACT HEIGHT ? 325
ROCK NAME ? WARMER
CONTACT HEIGHT ? 255
ROCK NAME ? KYANITE
CONTACT HEIGHT ? 205
ROCK NAME ? FELSITIC
CONTACT HEIGHT ? 75
NOW FINALLY GIVE THE NAME OF THE LOWEST
ROCK TYPE ? VERY HOT
```



```
WHAT IS THE DIP AND DIP DIRECTION OF
THE FAULT PLANE 80/135
DO YOU WANT A ROTATIONAL OR TRANSLATIONAL
FAULT, ('ROT' OR 'TRANS') ? TRANS
WHAT IS THE PITCH AND MAGNITUDE OF THE
SLIP VECTOR ? 0,200
PLEASE INPUT THE (X,Y,Z) COORDINATES OF ONE
POINT ON THE FAULT ? 750,0,700
```



```
DO YOU WANT A VIEW OF THE
STRATIGRAPHIC COLUMN
('YES' OR 'NO') ? NO
DO YOU WANT A BLOCK DIAGRAM OF
THE GEOLOGY TO DATE ?
('YES' OR 'NO') ? O
PLEASE TYPE IN 'YES' OR 'NO' ? NO
DO YOU REQUIRE A GEOLOGY ('LINE') MAP
JUST THE BLANK AREA TO MAP WITH ('NOMAP')
OR ('END') ? LINE
DO YOU WANT 'EQU'AL AREA OR
'STE'REOGRAPHIC PROJECTIONS ? STE
WHAT ARE THE ABSOLUTE COORDINATES OF THE
SOUTH-WEST CORNER OF THE MAP ? 50,0,500
WHAT SCALING FACTOR DO YOU WANT
1 = 1000 BY 700 ? 1
```



WILL YOU NOW DO THREE THINGS
MAKE A COPY OF THIS PAGE
PRESS THE NEWPAGE BUTTON
AND FINALLY TYPE IN (GO) TO CONTINUE ?