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GMAP v. 32

GEOGRAPHIC MAPPING AND PALAEORECONSTRUCTION PACKAGE

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REPORT

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GMAP v. 32: GEOGRAPHIC MAPPING AND PALAEORECONSTRUCTION PACKAGE

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Summary:

GMAP is a state of the art computer program which performs all processing and plotting tasks usually associated with the storage and presentation of palaeomagnetic pole positions, and generation of palaeogeographic reconstructions. One of GMAP's special features, which places it ahead of other software of its type, is a built-in, statistically robust, method for fitting smooth curves to weighted palaeomagnetic pole positions. GMAP is menu-driven and very easy to use; the user is never far removed from the basic data from which palaeogeographic reconstructions are derived, and therefore has a sense of total control over the program's performance.

GMAP can generate reconstructions based on individual palaeomagnetic poles, averaged palaeomagnetic poles, and digitally derived smooth (APW) curves. The user is also free to simply move continents around on the screen, according to less tangible constraints. Palaeogeographic reconstructions can be saved to disk files, and later viewed in chronological order as `animations'.

GMAP is supplied with a full range of continental outlines. These continents may be edited, split or combined to suit the user's personal requirements. It is also possible to import new continents via simple ASCII files or to import continents from the Palaeomap project. An ATLAS of reconstructions (Torsvik & Eide 1998) is included in the system.

GMAP can also calculate plate-speeds (minimum), angular rotations and rates of APW based on APW paths. It also contains routines to estimate magnetic polarity bias and the most recent compilations of magnetic polarity data are included with the system.

GMAP is in use at leading institutions world-wide, and has been the `work horse' of EGT and EUROPROBE projects. GMAP also interfaces with the Global Palaeomagnetic Data Base.

Keywords: Software	Palaeomagnetism	Documentation
Palaeogeography	Windows 95/NT	Geodynamics
Tectonics	Hot Spots	Magnetic anomalies

CONTENT

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1. INTRODUCTION

Palaeogeographic reconstructions have been an integral part of global tectonic research since the discovery of sea-floor magnetic anomalies and the advent of the plate tectonic paradigm, and the display of reconstructions in sequential 'time slices' is a comprehensive method to view biogeographic, geologic and palaeogeographic information and is extremely useful to understand local and regional geologic relationships as well as the fundamental driving forces of the Earth's core and mantle.

In order to undertake reconstructions, the GMAP software system was originally designed between 1982-1985 at the University of Bergen. Several new versions have appeared since then, but this version is the first 32 bit edition of GMAP. This edition is designed to run under Windows 95 (Win95) or Windows NT (NT) operating systems. It will not function with older operating system.

GMAP is available in 2 editions, STANDARD or PROFESSIONAL. The Standard edition is free of charge and available on http://WWW.NGO.NO/GEOPHYSICS or http://WWW.DRAGON.NGU. The Professional edition can be purchased from the authors. A future ENTERPRISE edition will be restricted, and only be available for project partners. A comprehensive report demonstrating GMAP abilities are available by Torsvik & Eide (1998).

1.1 HARDWARE REQUIREMENTS

- IBM-compatible computer (Pentium recommended; will also run on MAC emulating Win95)
- A running copy of Microsoft Win95/NT operating systems
- Microsoft compatible mouse
- Any printer supported by Win95/NT

1.2 INSTALLATION

- Insert GMAP disk 1 in drive A (or drive B)
- In Program Manager select **Run**

- Type **a:\setup,** press OK, and follow instructions carefully.

1.3 MAIN PROGRAMS AND FILE-TYPES

Main programs

GM32-X.EXE	Palaeogeographic reconstruction program

Programs run from inside GMAP (only in Professional edition)

APW.EXE	APW Path-fitting routines (spherical splines)
VELWIN.EXE	Calculates drift and rotation rates from APWP's and polarity bias

Data file types

GMAPW.SET	GMAP configuration file
VELW.SET	VELWIN configuration file (only in Professional edition)
*.C97	Continent outlines (*.CON in earlier GMAP versions) *own-made *.CON files can be converted to new format*
*.VGP	Files containing virtual geomagnetic poles (VGP)
*.SDV	Finite rotation library files (only in Professional Edition) *(Replaces old *.FIN files)*
*.FIN	Files containing finite rotation poles (Euler-poles) *Not used in this version, but option to read these files is kept for those having their own-made files*
*.A97	Animation files (new type; *replaces *.ANI files*)
*.ANI	Animation files (old type)
*.WMF	Atlas maps (Windows metafile format)
*.POL	Magnetic polarity files (only in Professional edition)

Data file types which require other sources

*.LIS	Age, feature, ocean & plate (from National Data Centre)
Tracker.dat	PALMAP project continents
Tracker.txt	GMAP implemented list of PALMAP continents

Wmag.dat	Magnetic anomalies (from National Data Center)

1.4 ABBREVIATIONS

VGP	VIRTUAL GEOMAGNETIC POLE
APW	APPARENT POLAR WANDER
APWP	APW PATH
CONTINENT	A FILE CONTAINING LATITUDES AND LONGITUDES; THESE CAN BE COASTLINES, MAGNETIC ANOMALIES, TECTONIC LINEAMENTS OR TERRANE BOUNDARIES
α_{95}	95 PERCENT CONFIDENCE CIRCLE ON MEAN REMANENCE
A95	95 PERCENT CONFIDENCE CIRCLE ON MEAN POLES
k	FISHER (1953) PRECISION PARAMETER
dp,dm	SEMI-AXES OF THE OVAL OF 95% CONFIDENCE ABOUT THE VGP
DEC	MEAN REMANENCE DECLINATION
INC	MEAN REMANENCE INCLINATION
GLAT	LATITUDE OF SAMPLING SITE
GLON	LONGITUDE OF SAMPLING SITE
PLAT	VGP LATITUDE
PLON	VGP LONGITUDE

2. MAIN FEATURES OF THE EARTHS MAGNETIC FIELD

The magnetic field at any point on the Earth is a vector quantity described by its inclination (angle with the horizontal plane), declination (angle with respect to the Greenwich meridian) and field-strength or magnitude. The magnetic vector (Fig. 1) can be decomposed to Cartesian (orthogonal) magnetic elements X (N-S component), Y (E-W component) and Z (vertical component) as follows:

$X = F * \cos(\text{Declination}) * \cos(\text{Inclination})$

$Y = F * \sin(\text{Declination}) * \cos(\text{Inclination})$

$Z = F * \sin(\text{Inclination})$,

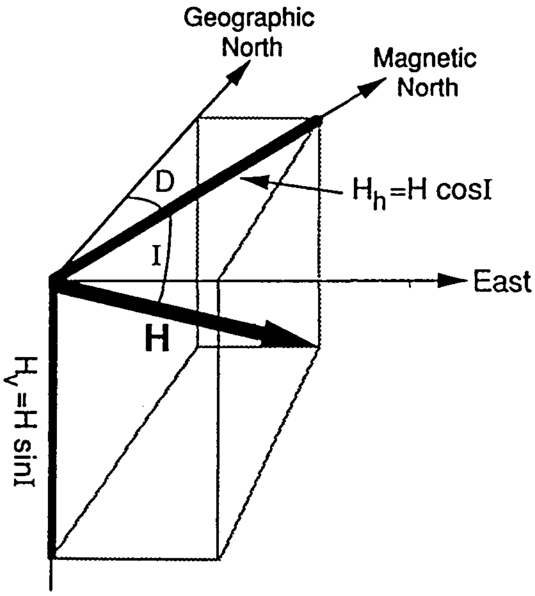
(where F = Magnetic Field strength)

The direction and strength of the magnetic field varies across the surface of Earth. The field-strength reaches a maximum at the magnetic poles (c. 70.000/60.000 nT at the south/north pole) and shows a minimum at the magnetic equator (c. 25.000 nT).

The magnetic inclination defines the angle between the total magnetic field vector (H) and the horizontal plane. Inclinations are described as positive (downward pointing) or negative (upward pointing). The inclination varies with latitude (Fig. 2), a feature which we take advantage of in palaeomagnetic palaeo-reconstructions (see later). At the magnetic north-pole, which does not coincide with the geographic north-pole, the inclination is said to be +90, at equator the inclination is zero and at the magnetic south-pole the inclination is -90 (Fig. 3).

The magnetic north and south poles differ from the geographic north and south poles, and the magnetic axis differs approximately 11.5° from the geographic axis (Fig. 3). The magnetic axis, however, is slowly rotating / precessing around the geographic axis, and over a period of c. 4-5000 years, we can state that averaged magnetic poles correspond to a reasonable estimate of the geographic pole.

FIG 1 Decomposition of the Earth's magnetic field-vector



There are a number of ways in which a rock can acquire a long-lived magnetization (remanence). In the most simplistic case, we can consider remanence acquisition of a basaltic lava flow during cooling. The most important magnetic mineral in basaltic rocks is titano-magnetite (TM) which has a characteristic blocking-temperature according to the amount of titanium present. Low-titanium phases (e.g. pure magnetite) have blocking-temperatures close to 580°C, whereas the presence of titanium will lower the blocking temperature. When a lava-flow cools below the blocking temperature of the TM phase (Fig. 4) the Earth's magnetic field is recorded within the lava-flow, and the declination/inclination and magnetization intensity can subsequently be measured in the laboratory using a conventional spinner magnetometer or a superconducting magnetometer (SQUID).

FIG 2 The relationship between inclination and latitude

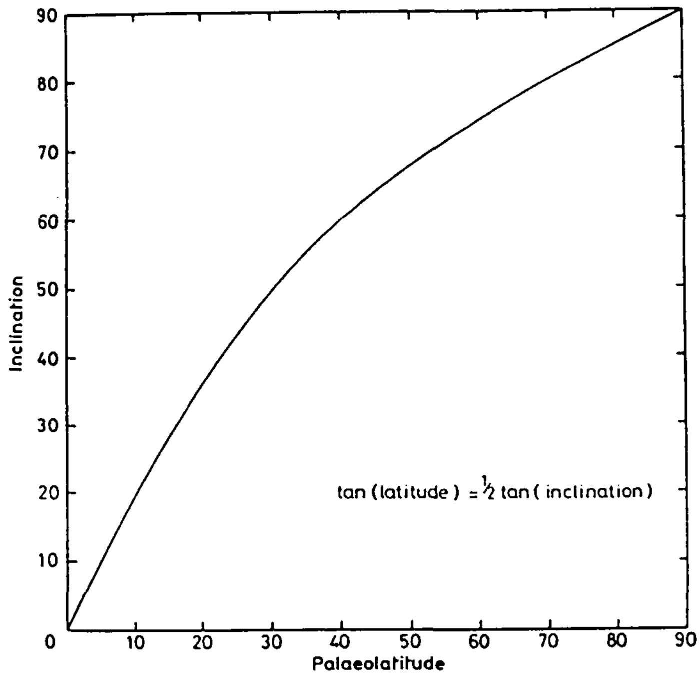


FIG 3 The geometrical relationship between the geomagnetic and the geographic axes (inclined geocentric dipole model; after McElhinny, 1973).

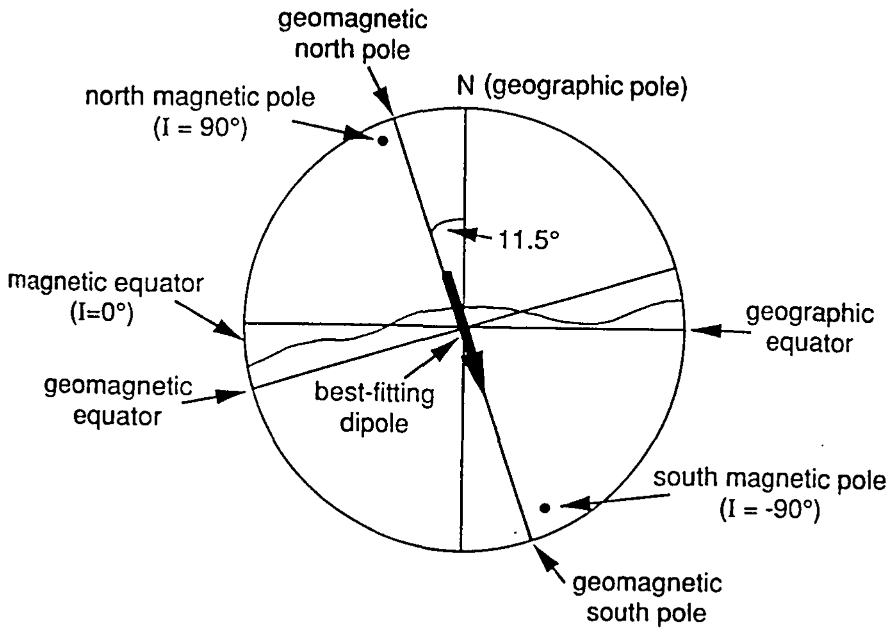
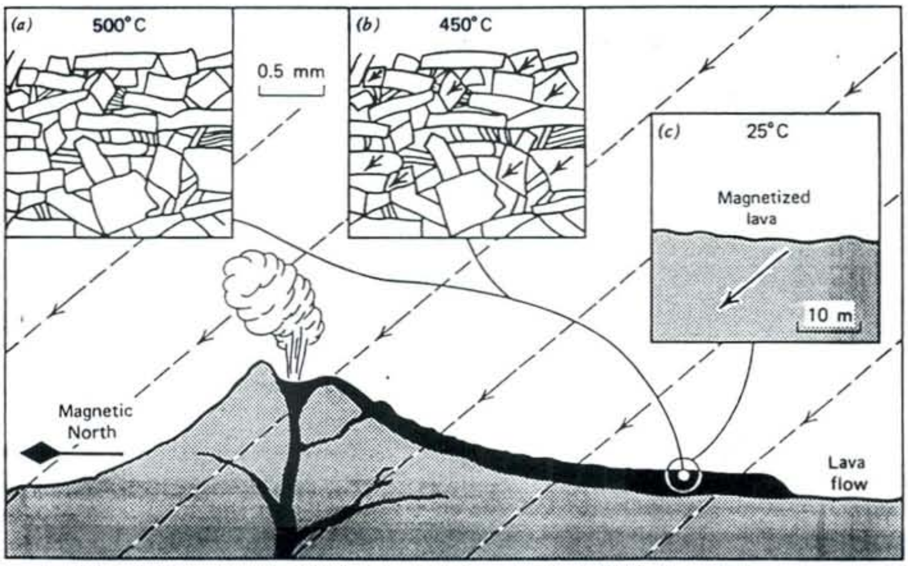


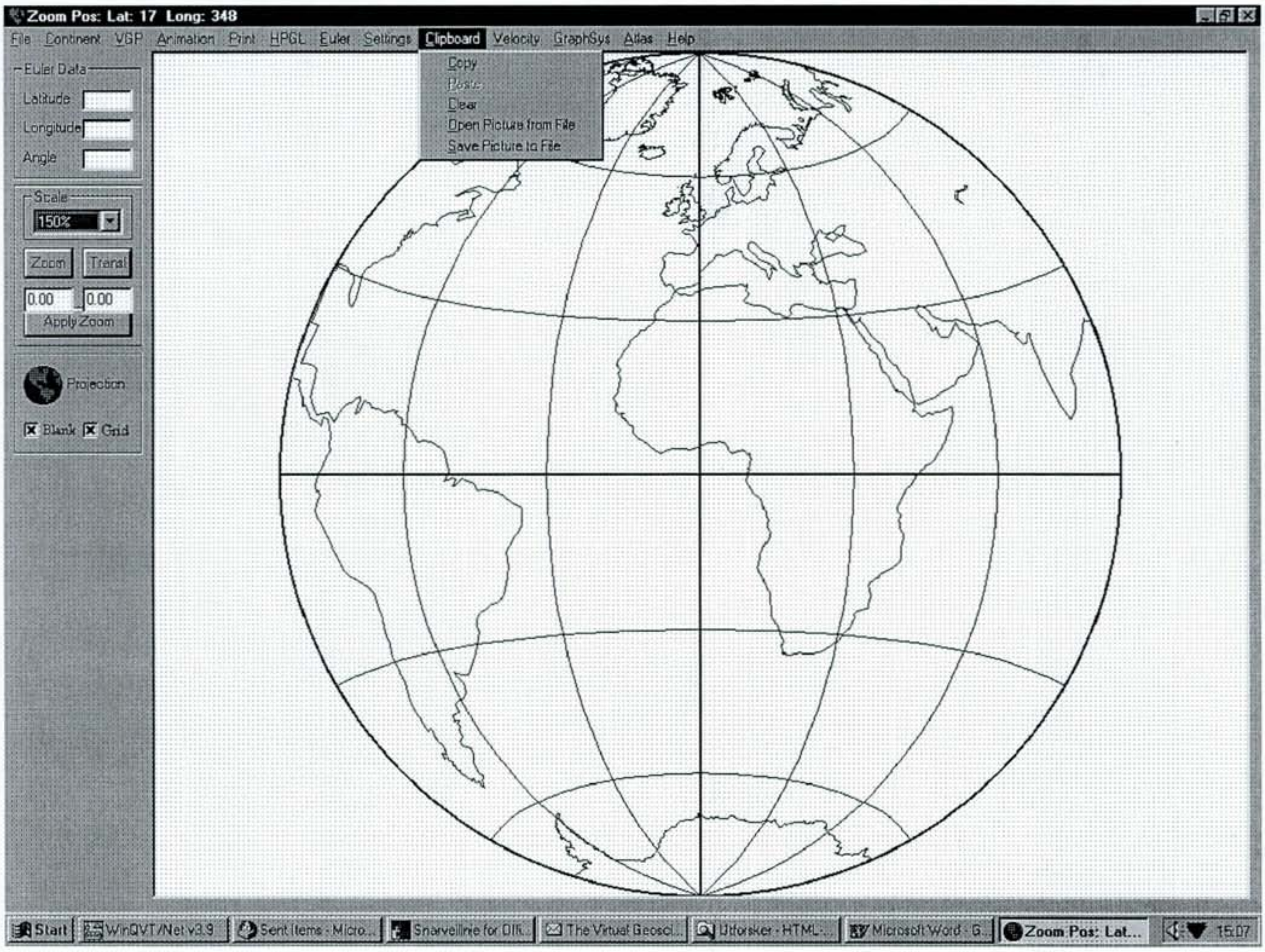
FIG 4 Basic principle for remanence acquisition for a basaltic lava (after Wyllie 1976).



3. DESCRIPTION OF GMAP

Select **GMAP** from the Program Manager. After start-up the main menu is displayed (Fig. 5). An **option** in the menu may be selected through the use of the mouse and executed by clicking the mouse.

FIG 5 Main menu GMAP



Main options in GMAP include:

OPTION	Suboption	EFFECT
File	Import	
	Ascii	IMPORT ASCII CONTINENTAL FILES
	Palmap	IMPORT CONTINENTS FROM PALMAP PROJECT
	NGDC	IMPORT MAGNETIC ANOMALIES
	NorMaps	IMPORT NORWEGAIN MAPS (high resolution)
	Ascii Export	EXPORT CONTINENTAL FILES
	Convert old CON files	CONVERT OLD CONTINENT FILES TO NEW FORMAT (*.CON to *.C97 format)
	Text Editor	ACTIVATE AN TEXT EDITOR
	Exit	END/QUIT GMAP
Continent	Open	LOAD A CONTINENT FILE
	Save As	SAVE A CONTINENT FILE
	Merge	MERGE CONTINENTS FILES
	Library	DISPLAY CONTINENTAL LIBRARY FILES
	Table	REMOVE/DELETE DATA-POINTS
	Draw	SCREEN DISPLAY OF CONTINENT
	Rotate	ROTATE CONTINENT ACCORDING TO A PRE-DEFINED EULER-POLE
	Calculate distance	CALCULATE DISTANCE BETWEEN TWO GEOGRAPHIC POINTS (AND SPEED)
VGP	Open	LOAD A VGP DATA FILE
	Save As	SAVE A VGP DATA FILE
	Merge	MERGE VGP FILES
	Draw	SCREEN DISPLAY OF VGP DATA
	Library	LOAD A VGP LIBRARY FILE (Professional Edition)
	Table	SHOW/EDIT/MANIPULATE VGP IN TABLE FORM
	Rotate	ROTATE VGP ACCORDING TO A PRE-DEFINED EULER POLE
	Vgp reconstruct	MAKE A RECONSTRUCTION BASED ON A VGP
Animation	Open	LOAD AN ANIMATION FILE
	Save As	SAVE AN ANIMATION FILE TO DISK
	Library	LOAD AN ANIMATION LIBRARY FILE (Professional Edition)
	Draw	SCREEN DISPLAY OF ANIMATION FILE
	Table	SHOW/EDIT ANIMATION FILE IN TABLE FORM
Print	Send to printer	A COPY OF THE LAST SCREEN OPERATION IS SENT TO THE PRINTER BUFFER. THE OPERATOR CAN BUILD UP COMPLEX PICTURES ON A SINGLE PAGE USING THIS OPTION FOLLOWED BY OPTION 'End printing'
	End printing	THIS OPTION EMPTIES THE PRINTER BUFFER, I.E.

		STARTSPRINTING AND PERFORM FORM-FEED. THE DEFAULT PRINTER IS SET WITH OPTION 'Printer Setup'.
HPGL	Continent	WRITE CONTINENT TO A HPGL FILE
	VGP	WRITE VGP FILE TO A HPGL FILE
	Animation	WRITE ANIMATION FILE TO A HPGL FILE
	Net	WRITE NET TO A HPGL FILE (this is done automatically when writing ANIMATION files; see 3.7)
Euler	Open	LOAD EULER INFORMATION STORED IN A FILE
	Keyboard input	SET AN EULER POLE AND ROTATION ANGLE
	Euler rotation	PERFORM AN EULER ROTATION
	Calculate E.P.	CALCULATE AN EULER POLE
	Add Euler poles	CALCULATE AN EULER POLE BASED ON TWO SEPARATE EULER POLES
	Euler Fit	CALCULATE BEST FIT EULER POLE (4 POINTS FIT)
	Library	SELECT EULER DATA FROM FINITE ROTATION LIBRARY (Professional Edition)
Settings	Colours	
	Backcolor	ADJUST BACKCOLOR SETTINGS
	Continent	ADJUST CONTINENT COLOR SETTINGS
	Net	ADJUST NET COLOR SETTINGS
	VGP	ADJUST VGP COLOR SETTINGS
	BW Palette	USE BLACK & WHITE PALETTE
	Vgp defaults	ADJUST VGP SCREEN/HARDCOPY SETTINGS
	Printer setup	ADJUST DEFAULT PRINTER SETTINGS
Clipboard	Copy	COPY CURRENT SCREEN TO THE CLIPBOARD
	Paste	PASTE CLIPBOARD CONTENT TO SCREEN
	Open Picture	OPEN A BITMAP PICTURE FILE
	Save Picture	SAVE TO BITMAP PICTURE FILE
Velocity		CALCULATE LATITUDINAL DRIFT-RATES, ROTATIONS & POLARITY BIAS (Professional Edition)
GraphSys	Aldus	RUN ALDUS FREEHAND
	Freelance	RUN LOTUS FREELANCE
	Corel Draw	RUN COREL DRAW
Atlas		DISPLAY AN ATLAS OF RECONSTRUCTIONS (described in Torsvik & Eide 1998)

Options displayed in the main menu (left part of the screen) include:

OPTIONS	EFFECT
Zoom	After entering this option a 'pencil arrow' is displayed on the screen, and the pencil is moved around the screen using the *cursor* arrows. During this operation LATITUDE & LONGITUDE are displayed at the top of the menu. Click mouse at <EXIT> to finish. A new plot, centred on the new zoom-centre, is now displayed.
Translate	Interactive translation & rotation of continent or adding lines/points /characters to the existing continent. After entering this option a 'pencil arrow' is displayed on the screen, and the 'pencil' is moved around the screen using the *cursor* arrows.
Translate	Move pencil arrow to any position on the continent: Type **1** to record position Move pencil arrow to a new LAT-LONG on the globe and, Type **2** to record the new position Click with mouse at <EXIT> to finish A new plot showing the continent translated by an amount that takes point 1 to point 2 will now be displayed
Point	Type **P** to draw lines between consecutive points Click with mouse at <EXIT> to finish Save continent in the main menu using a different file name
Annotate	Move pencil arrow to any position on the continent Type **A** to record position Type a single character in the input edit box which will appear, e.g. T for Tillite, E for evaporites etc. Click with mouse at <OK> to register character Click with mouse at <EXIT> to finish Save continent in the main menu using a different file name
Scale	Select scale (magnification) centred around zoom-centre. Click with mouse at the appropriate scale value (50-2000%)
Blank	Change between BLANK ON and BLANK OFF BLANK ON is default, and to preserve a picture during successive loading of continents ('OPEN CONTINENT)' this option must be set to OFF. Click with mouse for the appropriate state
Grid	Set automatic drawing of NET to ON/OFF Click with mouse for the appropriate state
Projection	Set projection type (Fig. 8)

3.1. IMPORT

3.1.1 ASCII IMPORT

This option allows import of ASCII continental files which are stored as longitude, latitude (1000,100 is pen-up command). A list of CONTINENT (file extension *.*) file-names are displayed in alphabetic order. Select the appropriate directory, drive and file name followed by <OK>.

Example of ASCII input format:		
	-39.37,33.7	**(longitude, latitude)**
	-38.95,33.62	
	-40.48,31.88	
	-40.57,31.79	
	-41.53,30.86	
	1000,100	**(pen up command)**

GMAP uses a BINARY RANDOM ACCESS format for continental files. NOTE that in this version of GMAP we have changed the data-format and individual records now consist of latitude and longitude, 4 bytes each (total 8 bytes pr. record). Latitudes and longitudes are stored as single precision values. Example of a Microsoft Visual basic than reads data (longitude, latitude) from and ASCII file and converts them to a GMAP compatible file is given below:

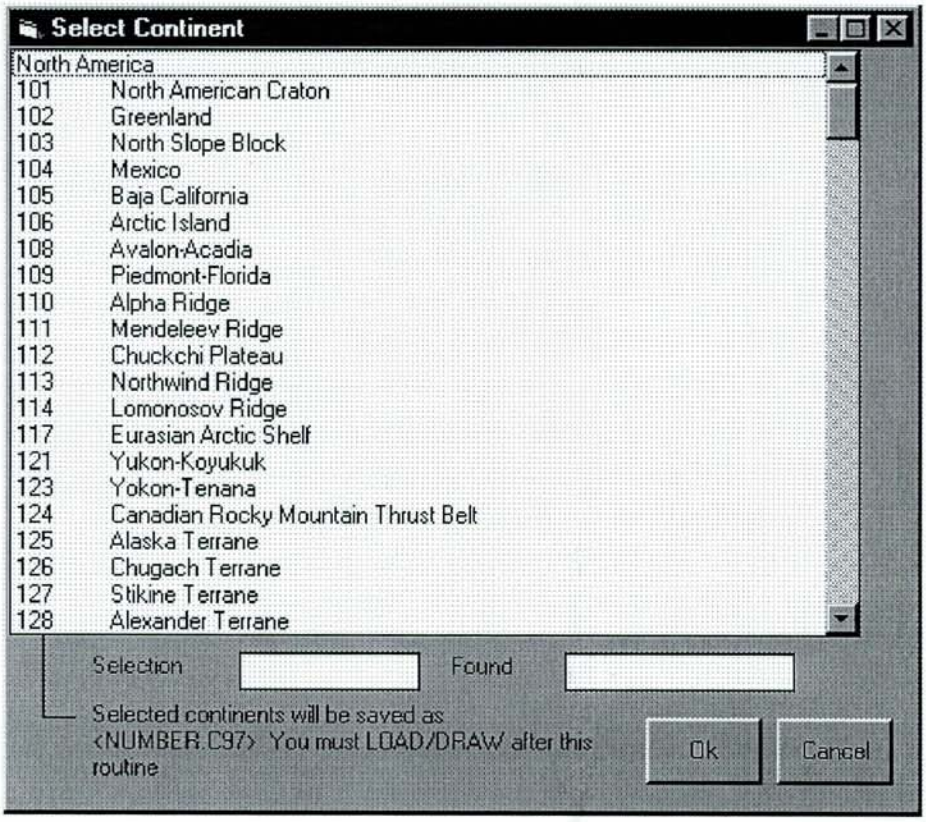
```
'Put this code as global declation:

Type CONNEW
    CNLONG As Single
    CNLAT AS Single
End Type
Global RECCON As CONNEW
```

```
'Make subroutine with the following code:

ch1=Freefile                                'input ASCII channel
ch2=Freefile                                'output BINARY channel
infile$="????"                              'input ASCII file
outfile$="???.c97"                          'output GMAP compatible file

Open infile$ For Input as #ch1              'open ASCII file for input
Open outfile$ For Random as #ch2 Len=8      'open binary (length=8 byte)
    i%=1                                    'record counter
    While Not Eof (ch1)                     'loop until input file is empty
            Input #ch1, asclong, asclat     'get longitude and latitude
            RECCON.CNLONG=asclong
            RECCON.CNLAT=asclat
            PUT#ch2, i%, RECCON             'put data in record i%
            i%=i%+1                         'advance one record
    Wend
Close ch1                                   'close channels
close ch2
```

3.1.2 PALMAP IMPORT

This option imports continents developed during the Paleomap Project (Chris Scotese and co-workers). This option, however, requires a registered licence for the Plate Tracker system (Walsh 1994). The authors of GMAP use a data-file originally named *PLATE12G.DAT* (1994 version of Plate Tracker Ver. 1.1). This file or updated files should be renamed *TRACK.DAT* and copied to the GMAP sub-directory before this option can be used.

Upon entering this routine a list of terranes/continents are displayed. Select the terrane/continent by clicking the appropriate line in the list - GMAP formatted continent files are created using the terrane number identity (e.g. 101.C07). Use option 'OPEN CONTINENT' and 'DRAW CONTINENT' to inspect the imported terrane/continent.



3.2 TEXT EDITOR

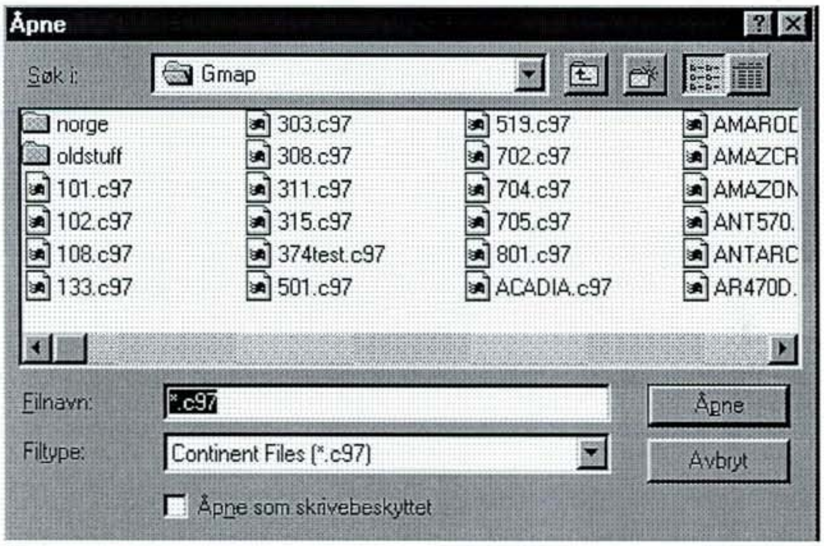
In order to recall earlier reconstructions, choice of reconstruction pole etc., a basic text editor has been implemented. The following options have been implemented:

OPTION/SUBOPTION	EFFECT
File	
New	Initiate a new text file
Open	Open a text file
Save As	Save a text file to disk
Close	Close a text file
Exit	Exit Text Editor
Edit	
Cut	Cut a highlighted text area
Copy	Copy a highlighted text area
Paste	Insert text which has been 'CUT' or 'COPIED'

3.3 OPEN (CONTINENT, VGP, ANIMATION or EULER files)

A list of CONTINENT (file extension .C97), VGP (file extension .VGP), ANIMATION (file extensions .A97 or .ANI) or EULER (file extension .FIN) file-names are displayed in alphabetic order (Fig. 6). Select the appropriate directory, drive and file name followed by <OK>.

FIG 6 Sorted list of CONTINENT files in option OPEN CONTINENT



3.4 MERGE (CONTINENT or VGP)

This option is identical to that described above (3.3), but the selected file will be merged with an existing CONTINENT/VGP file in memory. These combined data can later be saved to a disk-file using option `SAVE AS' (CONTINENT or VGP). Note, however, that the maximum permitted number of co-ordinates in a single continent outline is 25.000 (could be less dependent on memory size) and 300 data-points in a VGP file.

3.5 SAVE AS (CONTINENT, VGP or ANIMATION)

The purpose of this routine is to save modified CONTINENT, VGP or ANIMATION data to disk files. Merged CONTINENT files (3.4), EDITED CONTINENTS or rotated CONTINENT data (3.6) can be saved under a new file name. The latter is useful for constructing ancient terranes or storing palaeogeographic maps. In option `DRAW CONTINENT' (3.9) one can also add points/lines to the existing CONTINENT file which can later be saved under this option.

3.6 ROTATE (CONTINENT or VGP)

Define euler-data before selecting this option, either manually using the `KEYBOARD INPUT' option (3.14) in the Euler-menu or from a file using the `OPEN' option (3.13). When rotating VGP's one can also rotate the sampling site latitude and longitude, to permit the generation of proper error ovals on data in their rotated positions.

Note that the CONTINENT outline/VGP's in memory are changed during rotation. To later perform a rotation on the original data-set the original continent file must first be re-loaded. Compound rotations can be performed using `KEYBOARD INPUT' (3.14) and `ROTATE CONTINENT/VGP' repeatedly.

Example of compound rotation:

Problem:
You wish to rotate North America to its Devonian palaeo-position according to palaeomagnetic data from BALTICA.

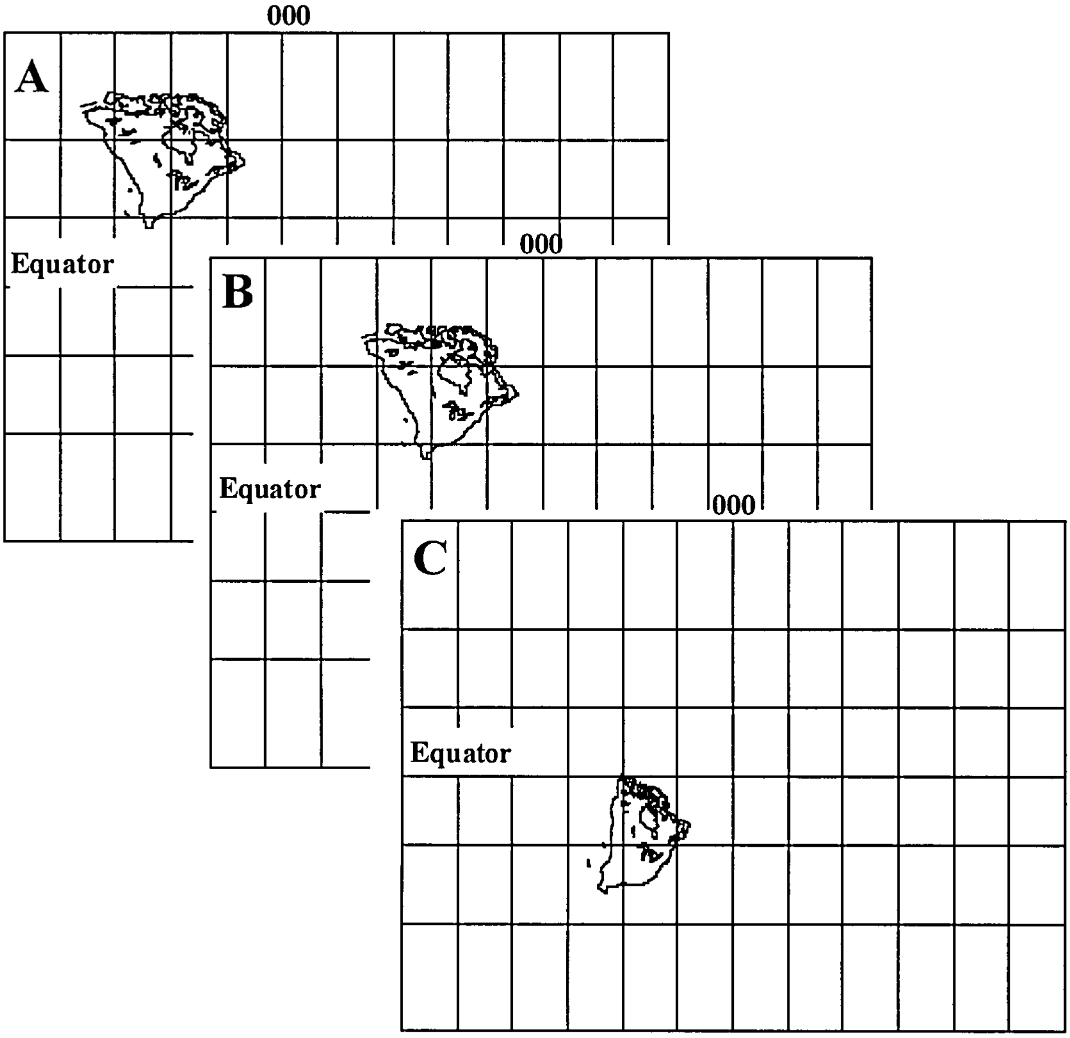
- Select option 'OPEN CONTINENT'
- Open North America (file=NAMPAL.C97)
  (If you now use option `DRAW CONTINENT', a map like Fig. 7A will appear on the screen)
- Use option `KEYBOARD INPUT' in the Euler-menu to register the rotation pole and angle which corrects for the Mesozoic/Cenozoic opening of the North Atlantic (e.g. use a Bullard et al. (1965) fit: c. 88 (latitude), 27 (longitude) and 38 (euler-angle).
- Select option 'ROTATE CONTINENT'. The continent outline will then be adjusted for the opening of the North Atlantic (If you then use option `DRAW CONTINENT', a map like Fig. 7B appears on the screen).
- Select option `OPEN VGP'.
- Open the fitted APW path for BALTICA (e.g. file B95200 supplied with the GMAP package).
- Select option 'TABLE VGP' in the VGP menu.
- Select sub-option 'RECONSTRUCT'.
- Select reference pole (e.g. pole **20** corresponding to an age of 375 Ma) by clicking the appropriate line at the line-number column.
- Select south-pole and click the <OK> option.

Result:

Continent data, already corrected for the opening of the N. Atlantic is rotated by an amount which brings the selected reference VGP to the South pole. Note that the Euler Rotation Pole required to do this will become the current Euler Pole setting which is displayed below the main menu, and can be used by option `ROTATE CONTINENT' to position other continents in a Devonian reconstructed position. North America will be displayed on the screen in a Devonian (375 Ma) configuration in 'European' co-ordinates (Fig. 7C).

FIG 7

Example of compound rotation. (A) North-America (CONTINENT File=NAMPAL; Appendix 2) displayed in present position. (B) NAM rotated into a Bullard et al. fit (lat=88, long=27, angle=38) with Europe, taking account of the opening of the North Atlantic.(C) The 'corrected' NAM positioned according to pole **20** in VGP file **B95200** (Appendix 1).



3.7 HPGL (CONTINENT, VGP, ANIMATION or NET)

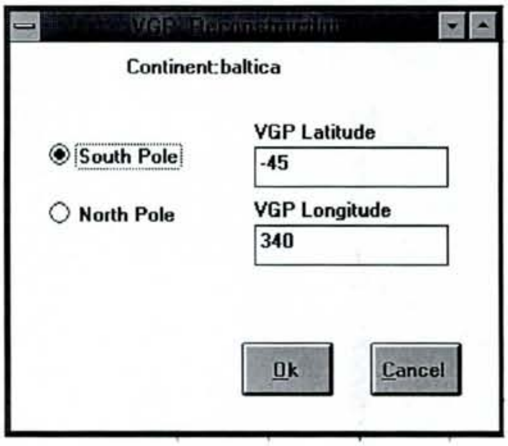
Write CONTINENT, VGP or ANIMATION data to HPGL compatible file. Data are appended to a file-name hence a complicated picture can be constructed by accessing this routine over and over again, without changing the file-name. The HPGL coded file can subsequently be imported and modified in drawing-packing systems such as Aldus Freehand, Lotus Freelance or Corel Draw (Cf. section 6). When writing ANIMATION files to HPGL format, the NET is automatically written as well.

3.8 VGP RECONSTRUCT

This option performs a reconstruction based on a VGP inputted from the keyboard. Enter VGP latitude and longitude and state whether it is a SOUTH or NORTH pole.

Example of how to produce a display for a map of the 'Permian' paleoposition for Baltica:

- Load BALTICA using `OPEN CONTINENT'
- Select option `VGP RECONSTRUCT' and enter -45 (VGP latitude) and 340 (VGP Longitude)
- Select SOUTH POLE and click on <OK>.
- BALTICA will now be displayed in its PERMIAN position.



3.9 PROJECTION

This option allows the operator to choose projection typea CONTINENT, VGP or ANIMATION file is displayed on the screen using the pre-defined projection. Use option `PROJECTION' to alter projection type. The plot is centred on a `zoom-centre', which by default is 0,0 (LAT,LONG). Blanking is **ON** by default.

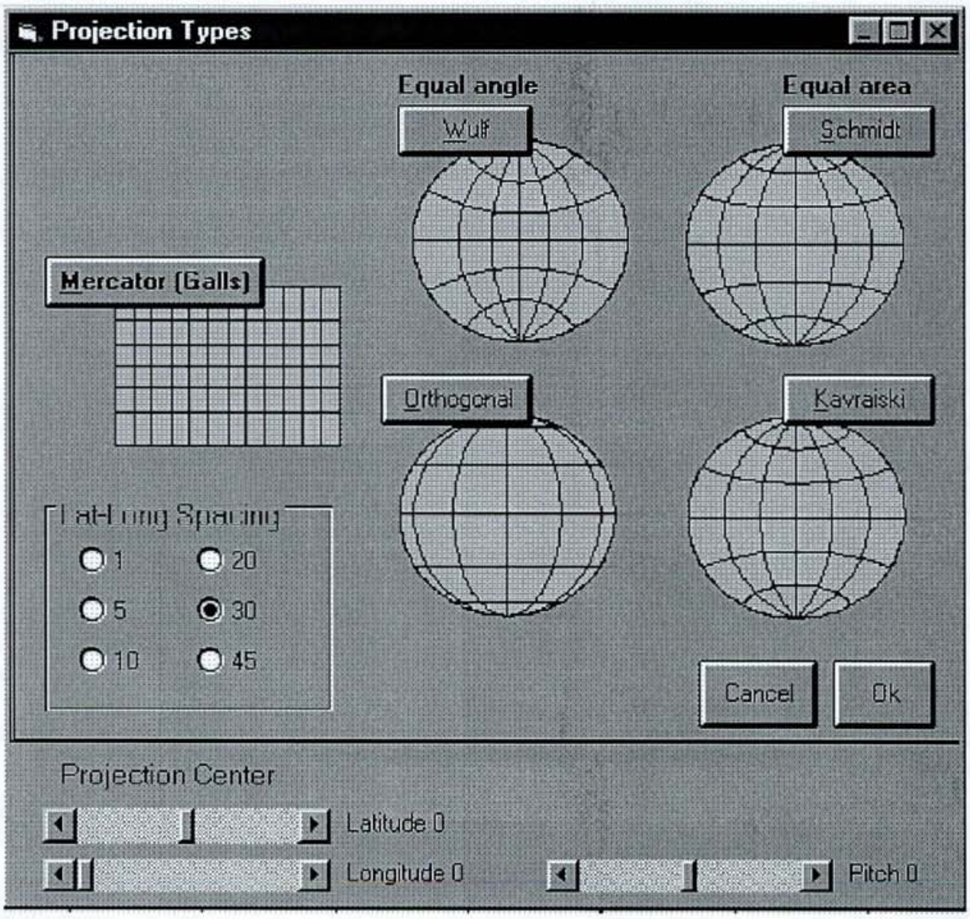
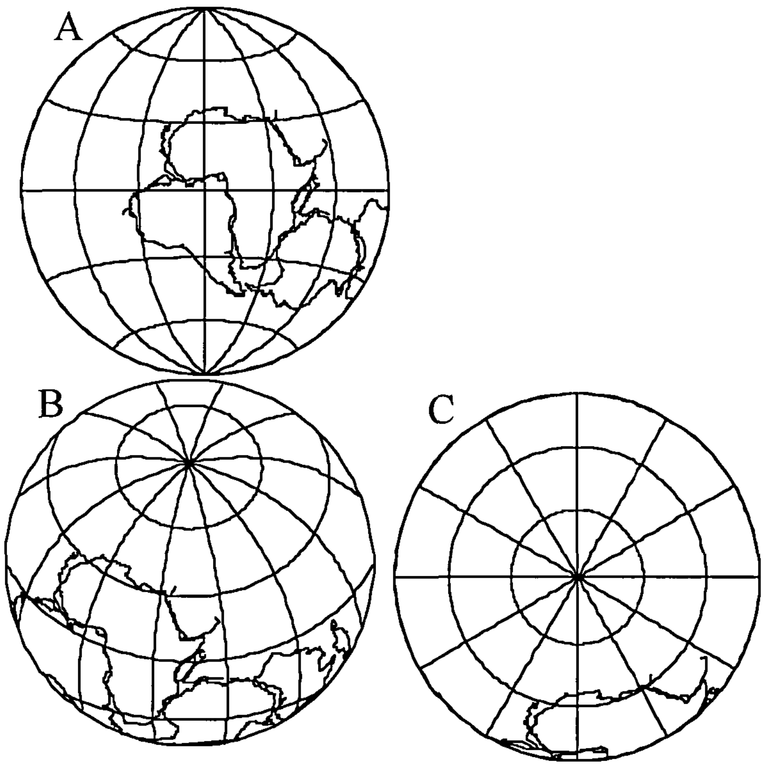


FIG 8
Examples of Schmidt (equal area) projections. (A) projection centre 0°E, 0°N, pitch=0. (B) projection centre 45°E, 45°N, pitch=0. (C) projection centre 0°E, 90°N, pitch=0.



3.10 TABLE CONTINENT

This option displays a listing of CONTINENT grid data in memory, i.e. latitude and longitude data. Note, however, that only the first 2000 data-points can be viewed in this function. During listing of continental data the following options are available:

OPTION	EFFECT
DELETE	Click on a single line or drag the mouse to include several lines to delete
EDIT	Select a line by clicking the mouse at the appropriate line and edit latitude and longitude
EXIT	Return to main menu

Note that any longitude exceeding 500 will be interpreted as a code to lift pen during screen and hard-copy plotting. Also note that changes in the data are not be stored on disk unless the 'SAVE AS CONTINENT' option has been performed in the main menu.

3.11 TABLE VGP

This is a frequently used options in GMAP. Upon selecting this option the following table is displayed (Fig. 9):

Column#	Content
1- Nr.	Pole number
2- CLPOL CODE	Combined character string of Van der Voo classification/grading (1-7) and palaeomagnetic polarity (n,r,m). This string is important and controls plotting symbols (3.11) and weighting in the fitting of smooth APW paths. For example a pole with `Q' factor = 7 and normal polarity are entered as `7n' Name of rock-formation or other information
3- DEC	Remanence Declination
4- INC	Remanence Inclination
5- a_{95}	95 % confidence circle on mean remanence direction
6- GLAT	Latitude of sampling site
7- GLON	Longitude of sampling site
8- PLAT	Latitude of VGP
9- PLON	Longitude of VGP
10- dp	half-angle of the confidence on the VGP in the direction of the palaeomeridian.
11- dm	half-angle of the confidence on the VGP perpendicular to the palaeomeridian.
12- AGE	VGP age. All poles must be assigned an age if a smooth path is to be fitted to them (see 3.11.3). During hard-copying the age will be printed next to the pole.

Note:
Column #12 (Age) for VGP files created from the DRAGON Web-site (from the Global Palaeomagnetic Database) will write a mean of Low and High magnetic age given in the database.

FIG. 9 TABLE VGP menu

File Reconstruct Gen. APWP Calculate Invert Delete Sort Edit Add

	CLPOL	CODE	DEC	INC	α95	GLAT	GLON	PLAT	PLON	Dp	Dm	AGE
1	4R	Arendal Diabase (A)	200.2	-27.5	5.2	58.4	8.8	-43.6	341.3	3.1	5.7	260.0
2	5R	Arendal Diabase (C)	207.9	-22.1	3.7	58.4	8.8	-38.5	332.9	2.1	3.9	260.0
3	5R	Arendal Diabase (B)	213.9	-39.5	8.9	58.4	8.8	-46.6	320.2	6.4	10.7	260.0
4	5R	Arendal Diabase (D1+D2)	215.0	-42.0	5.7	58.4	8.8	-47.8	317.6	4.3	7.0	260.0
5	5R	Bohuslen dolerite (D)	198.0	-45.0	29.1	58.6	11.3	-55.6	341.9	23.2	36.7	260.0
6	4R	Bohuslen Dykes (RPM)	196.0	-27.9	8.8	58.6	11.3	-44.7	349.2	5.2	9.5	260.0
7	5R	Bohuslen Dykes (RPC)	198.0	-32.7	3.6	58.6	11.3	-47.2	345.6	2.3	4.1	260.0
8	5R	Bohuslen porphyry dykes (PD)	190.0	-44.9	20.8	58.6	11.3	-57.1	354.6	16.6	26.3	260.0
9	5R	Ny-Hellesund Dykes	201.3	-18.4	2.9	58.0	7.8	-38.7	340.7	1.6	3.0	265.0
10	5R	Oslo Graben Lavas (HB)	204.0	-33.0	13.4	60.0	10.0	-44.6	337.1	8.6	15.2	270.0
11	5R	Oslo Igneous Rocks (B)	203.5	-24.3	8.8	59.7	10.4	-39.9	339.9	5.0	9.4	270.0
12	5R	Oslo Igneous Rocks (I)	203.6	-36.2	3.0	59.7	10.4	-47.0	337.0	2.0	3.5	270.0
13	4R	Scania Melaphyres	193.5	-38.0	11.0	55.5	13.5	-54.0	351.5	7.7	13.0	270.0
14	4R	Sarna Body	200.0	-22.4	11.0	61.7	12.9	-38.0	348.0	6.0	12.0	281.0
15	4R	Sarna Body (2)	202.3	-24.4	8.8	61.7	12.9	-38.5	345.0	5.0	9.0	281.0
16	5R	W-Vastergotland sill	202.0	-17.0	6.3	58.6	12.5	-38.0	346.0	3.4	6.5	284.0
17	5R	Scania Dolerites (A)	190.0	-11.0	11.0	55.5	13.5	-39.0	360.0	5.7	11.2	290.0
18	5R	Scania Dolerites (B)	199.5	-15.0	6.5	55.5	13.5	-38.5	348.5	3.4	6.7	290.0
19	5R	Stabben Sill (HB)	192.0	-12.0	2.4	63.3	8.5	-32.1	354.4	1.0	2.0	291.0
20	5R	E-Vastergotland Sill	197.0	-2.0	4.0	58.5	14.0	-31.0	354.0	2.0	4.0	293.0
21	5R	Billefjorden Group (R)	210.0	-30.0	24.9	78.5	16.5	-26.0	344.0	15.3	27.6	350.0
22	5N	Billefjorden Group (N)	46.0	27.0	12.6	78.5	16.5	-22.0	327.0	7.4	13.7	350.0
23	6M	ORS W. Ukraine	248.8	37.4	7.1	48.6	26.0	2.6	325.4	5.0	8.0	400.0
24	5M	Dicksonfjorden ORS	238.0	-12.0	10.0	79.0	15.5	-10.0	315.0	5.0	10.0	400.0
25	4N	Seiland Igneous Complex (A)	50.0	-33.0	7.7	70.5	22.3	5.0	335.0	5.0	9.0	410.0
26	5m	Honningsvåg Igneous Complex	45.0	-38.0	8.4	71.0	26.0	7.0	344.0	6.0	10.0	411.0
27	3N	Gotland Medby Limestone	25.0	-14.0	8.0	57.5	18.5	-23.0	351.0	4.2	8.2	420.0
28	7M	Ringerike Sandstone (HB)	26.0	-16.0	9.1	60.0	10.0	-19.0	344.0	4.8	9.3	420.0
29	4N	Gotland Dacker Limestone	28.0	-18.0	2.0	57.5	18.5	-19.0	349.0	1.1	2.1	425.0
30	3N	Gotland Follingbo Limestone	32.0	-13.0	6.0	57.5	18.5	-21.0	344.0	3.1	6.1	425.0
31	5N	Gotland Visby Limestone (HB)	25.0	-19.0	5.1	57.5	18.5	-19.0	352.0	3.0	5.0	428.0
32	5M	Oslo Limestone	4.2	-41.9	5.4	60.5	10.4	-5.3	6.5	4.0	6.6	440.0

Sub-options include:

OPTION	SUBOPTION	EFFECT
File	Save	Save Table as VGP file (same as in main menu)
	New	Create a new VGP file. Use option 'EDIT' to input data
	Print	Print table to default printer
	Stereoplot	Display declination and inclination in a stereoplot
	Export to ASCII	Write VGP table to a regular ASCII file for later manupilation
	Export to Excel	Write VGP table to EXCEL format file
	Exit	Return to main menu
Reconstruct		Perform a reconstruction based on a VGP in the table *Note - Load a continent prior to this operation* -Select pole by clicking on numerical row code at the first column -Select North or South pole -Resulting reconstruction will be displayed
Generate APWP		Fit a smooth APW path to the data in the Table (see 3.11.3) (only in Professional Edition)
Calculate	Pole Statistics	Calculate mean of the listed VGP's (A95)

	Calculate poles	Determine the palaeomagnetic pole-position for all data in the Table. Based on declination, inclination and sampling position.
	Pole Reference	Calculate amount of rotation and flattening Enter Reference Pole and A95 (see 3.11.1)
	Calculate Dec/Inc	Calculate declination and inclination Based on VGP latitude & longitude and sampling position
	Plat Reference	Enter latitude & longitude (optional) for which palaeolatitudes are to be determined. Note that latitude & longitude will replace original sampling co-ordinates in the Table. This enables the operator to calculate 'local' declination and inclinations at the selected reference locality.
	Calculate location	Calculate sampling sampling co-ordinates. Based on declination inclination and VGP.
Edit	Edit a row	Edit a pole. Select pole by clicking on numerical row code at the first column
	Delete row(s)	Delete one or several entries in the Table. Select pole by clicking on numerical row code at the first column or drag the mouse to include several poles
	Add a row	Add a pole to the table
	Invert	Invert VGP polarity of one or several poles. Select pole by clicking on numerical row code at the first column or drag the mouse to include several poles
	Sort a column	Sort data based on any column. Select column by clicking at the first row

Note:

All alterations to data in the Table will only affect the dataset in memory, and not on the disk. To save alterations made in 'TABLE VGP' to disk, use option 'SAVE AS (VGP)' in the main menu.

3.11.1 POLE REFERENCE

This option is useful when dealing with displaced and rotated terranes. A reference pole in the term of latitude, longitude and A95 is required

Based on this reference pole, the declination differences between the reference and tabulated data are calculated. This provides estimates of the potential rotation angle (about a vertical axis) of each pole in the table relative to the reference pole. Differences in inclination are also calculated, which provide estimates of palaeolatitudinal differences (or remanence flattening).

When using the `PRINT TABLE' option (above) after performing this calculation, a detailed listing of estimated rotation and flattening angles together with the associated errors will be printed. On the screen the data will be displayed from column 12 and onwards.

3.11.2 RECONSTRUCT

This is the most heavily used routine in performing reconstruction's based on palaeomagnetic data. This function is also available in the main menu under the name `VGP RECONSTRUCT'.

In GMAP, the euler-pole and rotation angle which is required to rotate the selected VGP to the present geographic NORTH or SOUTH POLE is determined and becomes the current setting for the euler rotation listed under the main menu.

The user must note that any pole-position can result in two possible palaeo-positions for a continent, one opposite to the other, depending on the pole-polarity. Therefore, attention should be paid at all times to the polarity of the VGP's in the table, so that proper account can be taken of it. Note that the function below, `GENERATE APW PATH', requires that all the VGP's in the table have the same polarity.

3.11.3 GENERATE APW PATH (only in Professional Edition)

To aid the definition of APW trends within tectonic units and to compare such trends between tectonic units GMAPW includes a method of fitting smooth path to a series of VGP's, of various ages, which has a location and time progression. Path fitting constitutes interpolation; reducing data sets to a simpler, and to some extent interpreted, form.

A number of numerical methods for fitting smooth paths to palaeomagnetic poles have been offered in the literature (Gould, 1969; Parker and Denham, 1979; Thompson and Clark, 1981, 1982; Clark and Thompson, 1984; Jupp and Kent, 1987). In GMAP we have used the method of Jupp and Kent (1987) because it is statistically rigorous, is independent of the co-ordinate system, and is most sympathetic to the concept of APW. The method aims to fit `spherical smoothed splines' to a given data-set, consisting of pole positions and error parameter.

It is possible to generate a number of paths with different levels of smoothing. This is done by adjusting a smoothing parameter used by the computer program. In GMAP the data can be individually weighted according to their α_{95}, so that the route taken by the smooth path through the data set will depend on both the distribution of the data on the globe and the standard error for each of the palaeopole positions. The lower the reported angular error for a pole position, the closer the curve will pass by it. We have also implemented a weighting procedure based on the Van der Voo's (1988) reliability index `Q' (grades 1 to 7; least to most reliable).

It is clear that the angular error associated with a particular palaeomagnetic pole position is far from an adequate description of the quality or reliability of that pole. For example, uncertainty in the age of the result has a direct bearing on the angular uncertainty which should be associated with it, since apparent polar wander might be continuing within the time period of uncertainty. Instead of weighting pole positions solely on the basis of criterion (2) in Van der Voo's reliability scheme (a_{95}), it is informative to weight the data in proportion to their 'Quality factors'. This causes the smooth path to pass close to the data which score `7', full-marks, and be only gently guided by those data with lower reliabilities.

GENERATION OF APW PATH

- Load a VGP file via the main-menu option `OPEN VGP'
- Select option `TABLE VGP'
- Select sub-option `GENERATE PATH'
- Select (a) No weighting
  (b) Weighting according to `Q' factor
  (c) Weighting according to a_{95}

If option `b' is selected, the `Q' factor for every VGP in the table must be encoded in the first character of the VGP `code' (see section 3.8). If a `Q' factor is not present included, `Q' will be set to zero reliability. If option `c' is selected, the a_{95} must be included in the table of data. If a_{95} is not included the program will abort the procedure.

- Input SMOOTHING PARAMETER (value 10 to 10000). A high value results in extreme smoothing. Values in the order of 100 to 200 generally result in moderate smoothing (Fig. 11).

- Input VGP FILE-NAME for output path (DO NOT USE FILE EXTENSION; AUTO ADDED).

The fitted path, when generated, will be displayed on the graphic screen in option `DRAW VGP' (3.9) in the main menu.

Note:

The original VGP file is 'shut down' and replaced with the new APW file (spline file). Thus save the origianal VGP file before using this option.

FIG 10 `GENERATE PATH' option

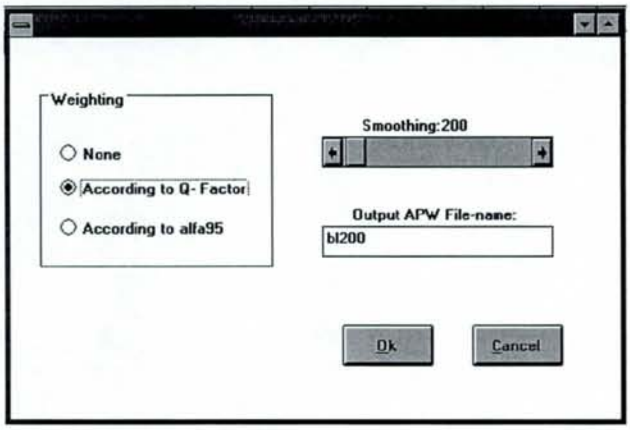
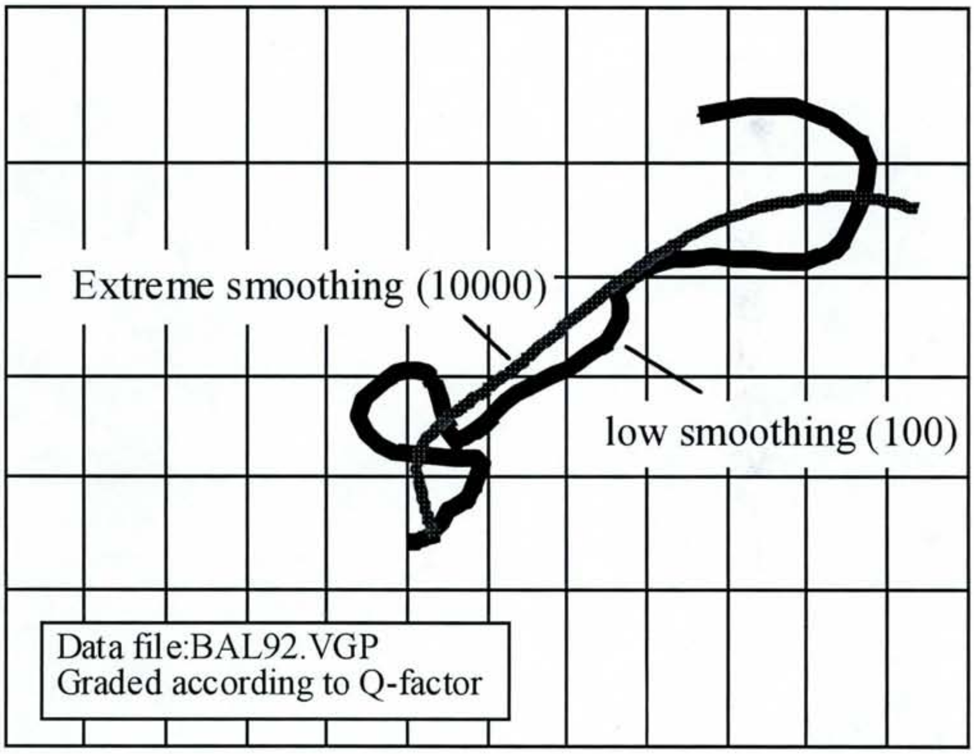
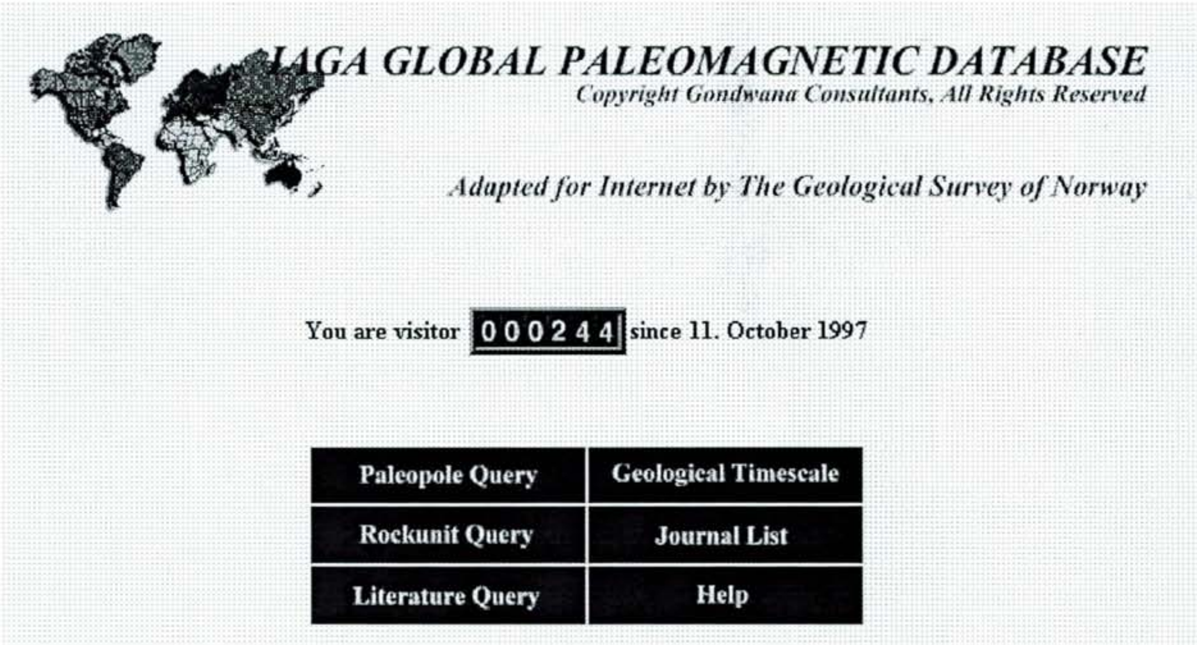


FIG 11
The effect of using a low and high smoothing parameters on a VGP data set for Baltica. A low smoothing parameter of 100 was used in (a) and 10000 in (b).



3.11.4 INTERFACING WITH THE IAGA GLOBAL PALEOMAGNETIC DATABASE

The Global Palaeomagnetic Data Base (GPMDB) was originally Oracle-based (Lock & McElhinny 1991), but it is now available in Microsoft Access format. A separate program was originally supplied with GMAP (named **GLB),** which provided an interface between the GPMDB and **GMAP**. However, this program is now superseded by the NGU DRAGON Web-site (http://dragon.ngu.no):



At this web-site the content of the result table from a 'PALEOPOLE QUERY' can be transferred to the user's own computer in the form of an ASCII text file. 'This is done via a link placed at the top of the Paleopole Query's result table. The file can then be loaded directly into local computer applications for further processing. GMAP has been modified to read the ASCII files directly.

The text file contains the following information:

1. The date, time and details of the query. This information occupies the first few lines of the file. The file looks like this:

    /Query date: 29.10.97
    /Query time: 09:27:24
    /User IP address: [Smethurst]
    /Authors: [Smethurst]
    /Year: >=1920

/Rock age range: 0 to 4000
/Demagnetisation procedure: >=0

2. Headings for columns of data in the file. Individual headings are separated by the TAB character. The file contains more database fields than are displayed in the result table.

   The file looks like this:

   /ROCKUNIT RLAT RLONG COMPONENT LOMAGAGE HIMAGAGE DEC INC N KD ED95 PLAT PLONG DP DM AUTHORS YEAR

   The headings correspond to:

   ROCK UNIT NAME ,
   ROCKUNIT LATITUDE,
   ROCKUNIT LONGITUDE,
   REMANENCE COMPONENT NAME (if any),
   LOW MAGNETISATION AGE,
   HIGH MAGNETISATION AGE,
   REMANENCE DECLINATION,
   REMANENCE INCLINATION,
   NUMBER OF OBSERVATIONS
   FISHER'S PRECISION PARAMETER K,
   95% ERROR LIMIT,
   POLE LATITUDE,
   POLE LONGITUDE,
   POLE ERROR LIMIT DP,
   POLE ERROR LIMIT DM,
   AUTHORS,
   PUBLICATION YEAR

3. The data, one palaeomagnetic pole per line in the file. Values and text strings are separated by the TAB character.

   The file looks like this:

   Honningsvag Complex 71 26 Low Temperature 208 245 30 58 33 26.5 15.1 54 164 16 22 Torsvik,T.H., Olesen,O., Trench,A., Andersen,T.B., Walderhaug,H.J., Smethurst,M.A. 1992
   Devonian Sediments 48.7 26 I Component 250 320 205.7 -19.6 172 95.3 3 45.8 168.2 1.6 3.1 Smethurst,M.A., Khramov,A.N. 1992
   and so on..........

To load the file into GMAP:

1. Download the ASCII file

2. Start GMAP
3. From the "VGP" menu, select "OPEN VGP" and select the ASCII text file

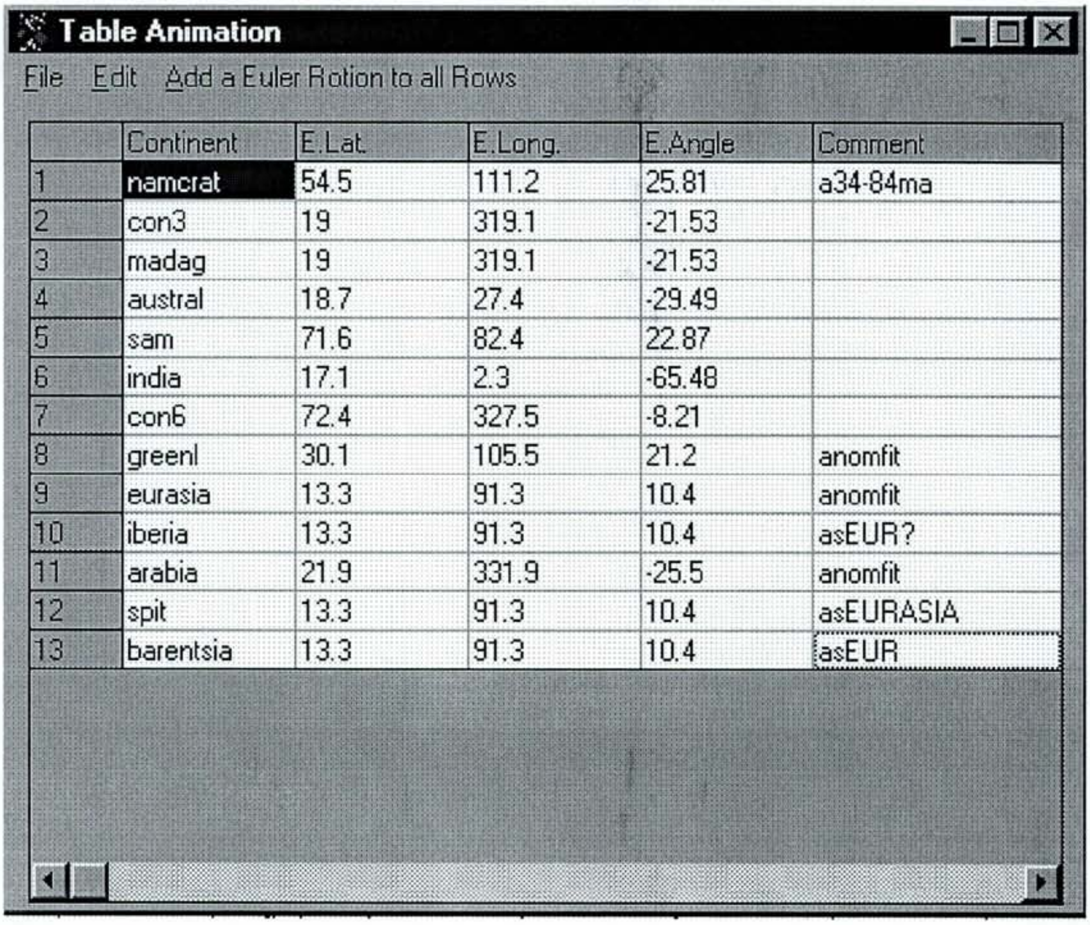
3.12 TABLE ANIMATION

This option is used to edit (use option 'OPEN ANIMATION') or create animation files (*.A97, replaces old *.ANI format)). The main menu consists of the following options:

File	New	Create a new animation table
	Export to Excel	Export animation table to EXCEL format
	Exit	Return to main menu
Edit	Edit a row	Edit a single line. Select line by clicking on numerical row code at the first column
	Add a row	Add lines
	Delete row(s)	Delete one or several lines. Select line(s) by clicking on numerical row code at the first column or drag the mouse to include several lines
Euler Add		Add euler data to the existing data in the Table (combined rotations)

The input-format in ANIMATION files is as follows:

1	CON	Name of continent (`.C97') file (DO NOT WRITE EXTENSION)
2	LAT	Latitude of Euler Pole
3	LONG	Longitude of Euler Pole
4	ANGLE	Rotation angle about Euler Pole (+)=clockwise;(-)=counterclockwise
5	COMMENT	Comment (any text)



	Continent	E.Lat.	E.Long.	E.Angle	Comment
1	namcrat	54.5	111.2	25.81	a34-84ma
2	con3	19	319.1	-21.53	
3	madag	19	319.1	-21.53	
4	austral	18.7	27.4	-29.49	
5	sam	71.6	82.4	22.87	
6	india	17.1	2.3	-65.48	
7	con6	72.4	327.5	-8.21	
8	greenl	30.1	105.5	21.2	anomfit
9	eurasia	13.3	91.3	10.4	anomfit
10	iberia	13.3	91.3	10.4	asEUR?
11	arabia	21.9	331.9	-25.5	anomfit
12	spit	13.3	91.3	10.4	asEURASIA
13	barentsia	13.3	91.3	10.4	asEUR

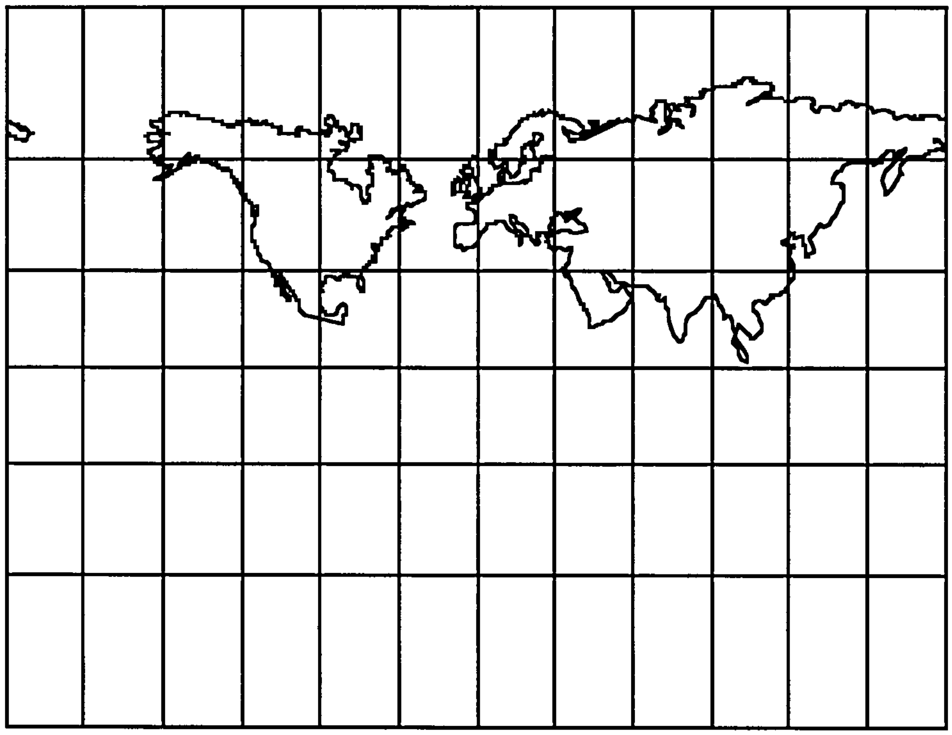
Example:

To display North America in a Bullard et al. fit (1965), and leave Europe where it is, create the following file:

CON	*LAT*	*LONG*	*ANGLE*	*COMMENT*
nam	88	27	38	NA bullard fit
con2	0	0	0	In-situ Europe

Store the file with file-name TEST (extension .A97 is automatically added to file-name). Use sub-option `DRAW ANIMATE' and a map resembling Fig. 12 will be plotted on the screen.

FIG 12
Example of plotting an animation files created by EDIT/CREATE ANI option (cf. text).



3.13 OPEN (EULER FILE)

This option displays a list of files which themselves contain lists of finite rotation poles (extension *.FIN). After selecting a file, the Euler poles in the table will be read and listed on the screen. One of the poles can be selected by clicking the appropriate row at the first column followed by clicking <Pick>. Select <Cancel> to quit this option. *GMAP is no longer supplied with *.FIN files, but the option is kept for operators to read own-made files.*

3.14 KEYBOARD INPUT (EULER)

This option enables the input of an Euler rotation pole from the keyboard which can subsequently be used by options `ROTATE CONTINENT (or VGP)' or `EULER ROTATION'. The Bullard et al. (1965) fit can be obtained using the euler pole 87°N, 27°E, angle of rotation=37° (clockwise).

3.15 EULER ROTATION

This utility routine performs euler-rotations on VGP's entered interactively from the keyboard. The currently registered Euler Pole (3.13 or 3.14) is used.

3.16 CALC EULER POLE

This option enables calculation of an Euler rotation pole based on manual input of two geographic point (co-ordinates) or poles. Enter Latitude (LAT) and Longitude (LONG) for pole A and B, and the resultant rotation pole (LAT & LONG) and amount of rotation (A.ROT) will be displayed.

3.17 ADD EULER POLES

This option add/concatenates two Euler poles into a single resultant Euler pole. Enter latitude, longitude and angle for the two Euler poles and click on <Calculate>.

3.18 SETTINGS

This option permits the adjustment of parameters which control program output. The configuration file GMAPW.SET contains names of the variables which are adjusted using this option. Whenever a parameter is changed, the file GMAPW.SET is updated, thus recording the adjustment even after GMAP is terminated. Four groups of settings can be changed in this option:

OPTIONS	SUBOPTIONS	EFFECT
Colors	Backcolor	Background color in 'DRAW' mode
	Continent (ovals)	Continent outlines and VGP oval colors
	Net	Net color
	VGP	VGP symbol color
	BW Palette	Use Black and White Palette
VGP defaults	VGP errors	Ovals (α95), A95 or none
	Plot	VGP (Fig. 14a) or study location (to produce a map of study locations)
	Q-factor filter	List of VGP's can be sub-set using this option. Leave **blank** for no filtering. A value of 7 will permit only poles of Q-factor 7 in Van der Voo's (1988) classification scheme to be plotted. A value of, for example, 567, permits the plotting of poles with Q-factors 5, 6 and 7. For this parameter to function properly the Q-factor must be included in the pole 'code' via option 'TABLE VGP' in the main menu (3.11).
	Plot symbol	Select Yes (reps. No) to plot (not plot) a symbol at VGP positions on graphical hard-copy displays (HPGL).
	Pole Info	
	Print pole age	Print VGP age beside pole position (HPGL)
	None	No information beside pole position (HPGL)
	Pole number	Print VGP number (row) beside pole position (HPGL)
	Draw declination	When plotting study location rather than VGP's, this parameter permits plotting of remanence declination vectors on the map (see above)
	Select pole by age	Set to Yes (resp. No) to selectively plot (resp. not plot) poles on hardcopy output based on their ages (HPGL).
	Connect poles	Set to Yes (resp. No) to draw (resp. not draw) lines between VGP's on graphical output. Useful when drawing APW paths
	Plotting symbol	Cf. list displayed on the screen Default VGP symbol mode uses the Q-factor: 7&6 Open square 5&4 Closed square 3&2 Open circle 1 Closed circle

		none + (plus)
Printer setup		Select default printer defined by the Windows system

FIG 13 `VGP SETTINGS' option

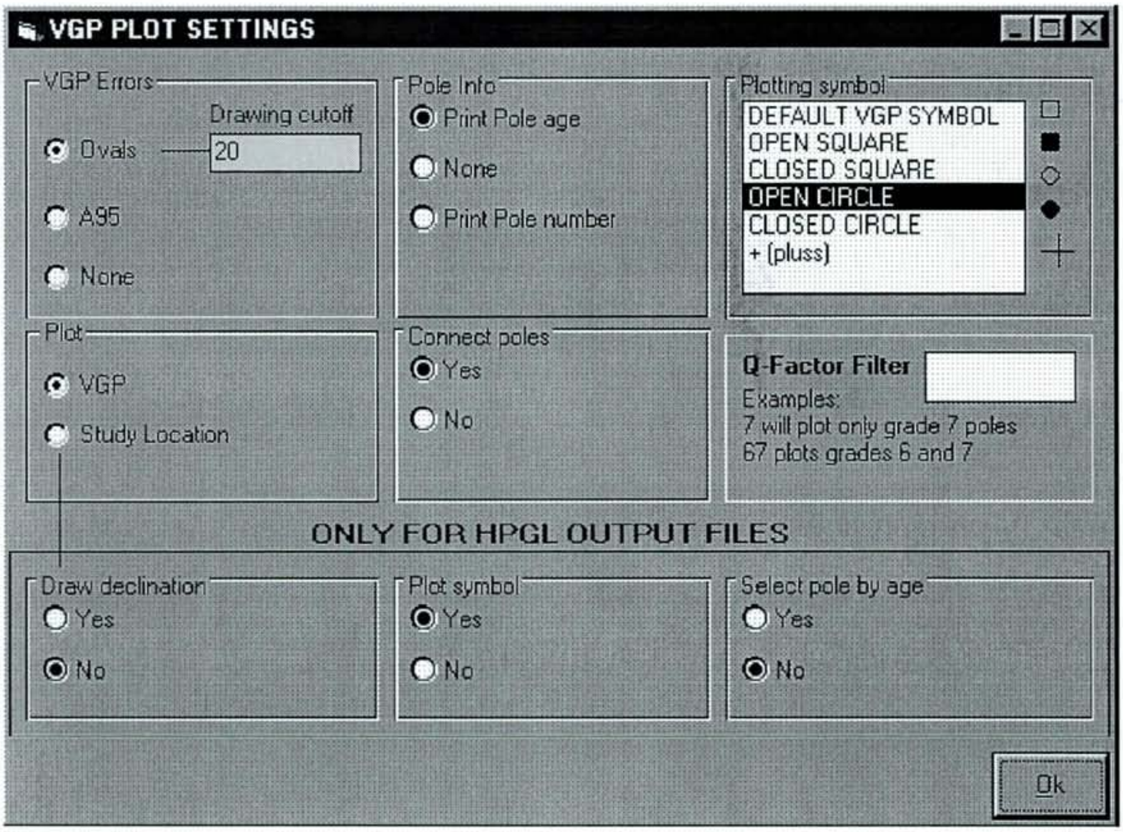
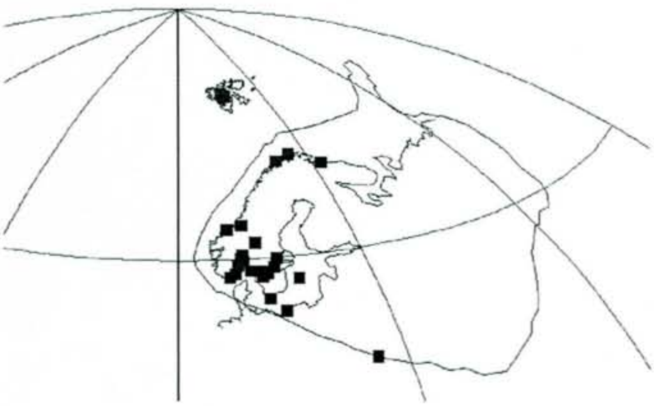


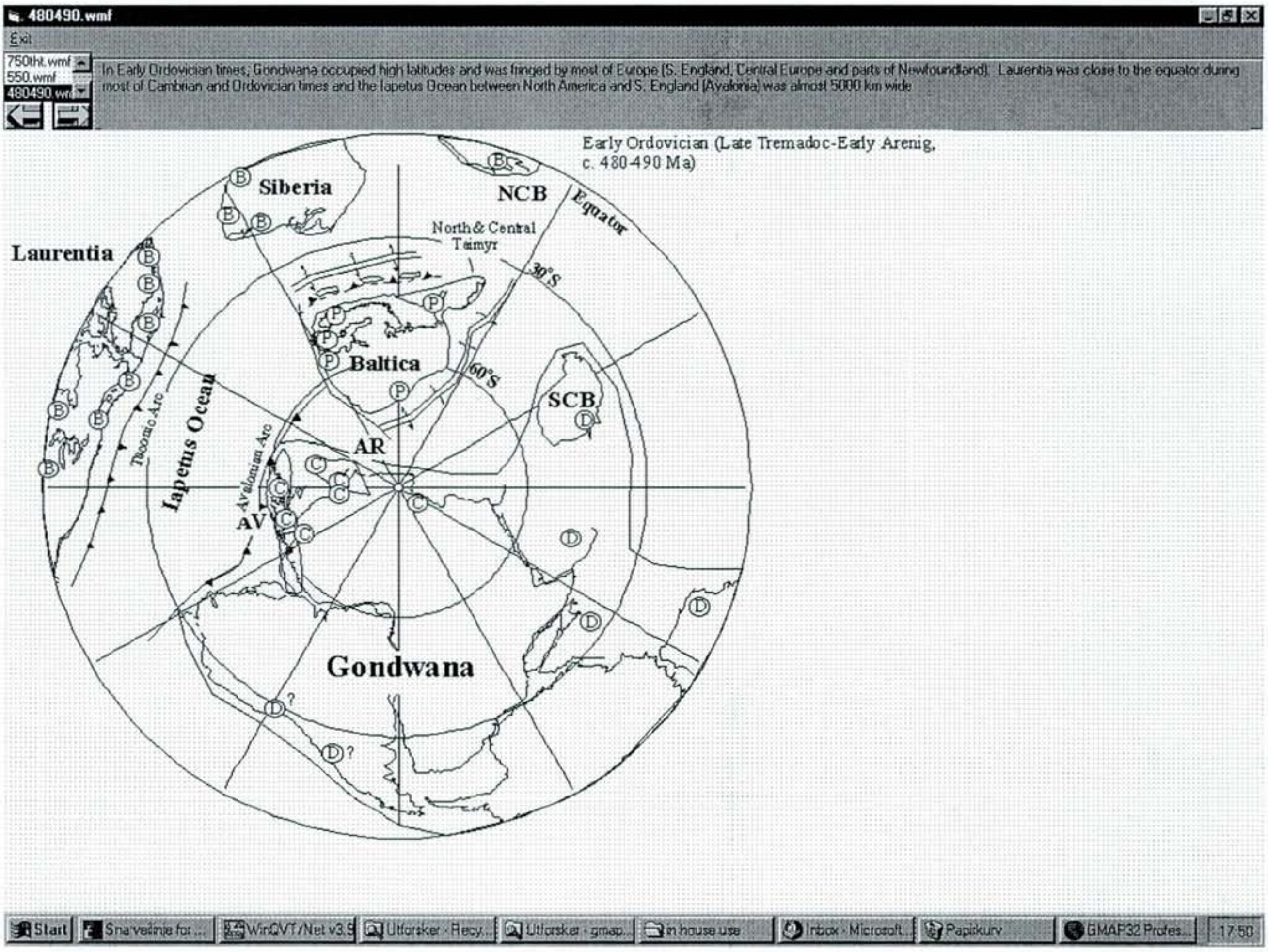
FIG 14
(A) Plot of study-locations from VGP file BAL92, along with continent file BALTICA (zoom centre latitude=65, longitude=-15, equal area projection). (B) Corresponding VGP's plotted with error ovals.



3.19 ATLAS

The option displays a selected range of paleoreconstructions provided by the authors. Select ATLAS file from the list box or use LEFT-RIGHT ARROWS. The operator can make a hard-copy of the image (option 'PRINT') or import his own files using option 'FILE'. Images are stored in WMF vector-format which can be edited with any graphical package. Reconstructions included in ATLAS are described by Torsvik & Eide (1998).

FIG. 15 'ATLAS' option



3.20 VELOCITY (only in professional version)

The main purpose of this option is to calculate latitudinal drift-rates and rotational velocities for continents. Options are as follows:

OPTION	SUBOPTION	EFFECT
Exit		Exit velocity option
VGP	VGP file	Open Open a VGP file from disk (c.f. 3.3)
	Merge VGP file	Open a VGP file from disk; displayed together with existing VGP data in subsequent graphic actions
	Analysis 1	Calculate and display palaeolatitudes, latitudinal velocity and angular rates
	Analysis 2	Calculate and display APW rates
	HPGL	Write graphics to a file (cf. 3.7 and 3.18)
Print		Copy screen to printer
Settings		Change VGP and graphical settings
Timescale	Use Harland 1989	Harland et al. (1989) time-scale except Precambrian/Cambrian boundary which is set to 540Ma instead of 570Ma and the Vendian-Riphean boundary. A new time-scale is currently being implemented.
	Build your own	Modify time-scale (automatic saved to a system file)
Polarity Bias	Open Polarity File	Read a polarity file from disk
	About Polarity	Description of polarity files
	Table	Display polarity data in a table
	Analysis 1	Age sliding
	Analysis 2	Chron sliding
	HPGL	Write graphics to a HPGL file
Calculate		Calculate distance in kilometre and average drift-rate by inputting two geographic sites (latitude & longitude) and time interval.
GraphSys		Run a graphical drawing package

3.20.1 DRIFT/ANGULAR RATES

Based on a sequence of ordered (sorted with increasing magnetic ages) VGP poles (either original data or APW spline data) this option provides an analysis and display of palaeo-latitudes for a given reference locality (see 3.20.2) through geological time (top diagram in Fig. 16).

Analysis of APW paths:

If the VGP file contains an APW or 'spline' path (cf. 3.11.3) parameter `APW path or spline' (see 'SETTINGS'; cf. 3.20.2) and parameter 'Plot declination' should be set to on. This will produce a display as illustrated in Fig. 16 (VGP file B20092; used for Baltica by Torsvik et. al. 1992) where declinations (according to a reference locality: 60°N and 10°E in our example) are plotted along the latitudinal drift-curve (i.e. a natural cubic spline curve). Based on the setting of the `Time Window' parameter (cf. 3.20.2) this option calculates latitudinal drift-rates (in cm/y) and rotational velocities (in °/Ma). Drift-rates are automatically seperated into Northward (UPPER part of diagram) or Southward (LOWER part of diagram) movements (middle diagram in Fig. 16), whereas rotational velocities are separated as clockwise (UPPER part of diagram) or counter-clockwise (LOWER part of diagram) rotations.

Analysis of original data:

If the VGP file contains original data, the parameters `Original data' and 'Plot latitude error' (cf. 'SETTINGS'; 3.20.2) should be set to on. This produces a display as illustrated in Fig. 17 (VGP file Bal92; used for Baltica by Torsvik et. al. 1992) where palaeo-latitudes (according to the reference locality) are plotted with error bars (based on α_{95}).

FIG 16 Example of option `VELOCITY' (VGP file:B20092) using an APW spline path.

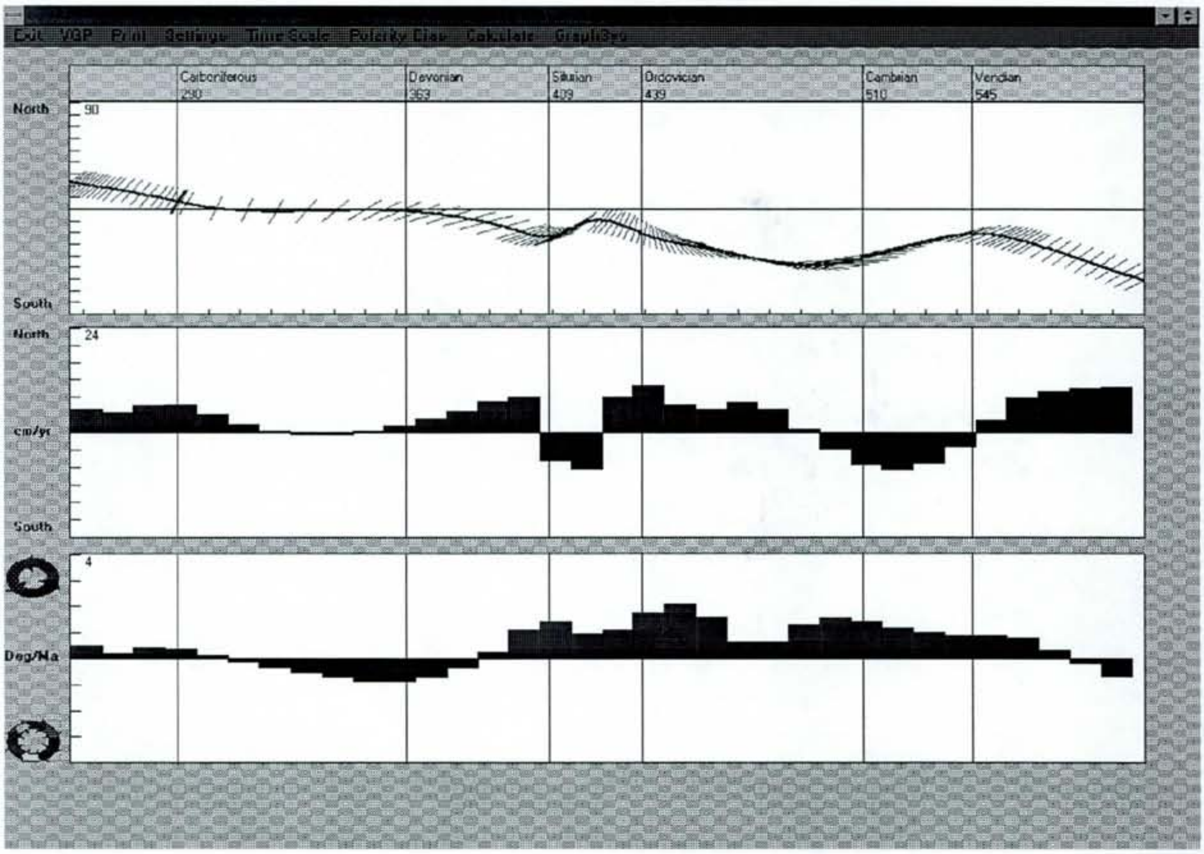
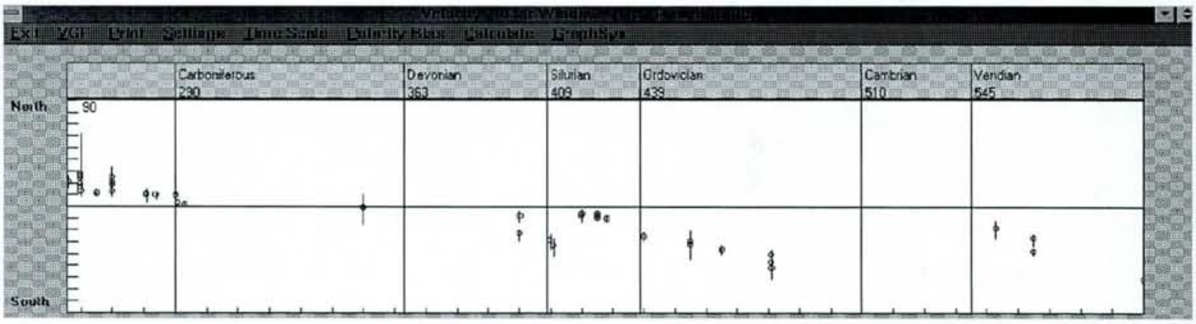


FIG 17 Example of option `VELOCITY' (VGP file:BAL92) using original data.



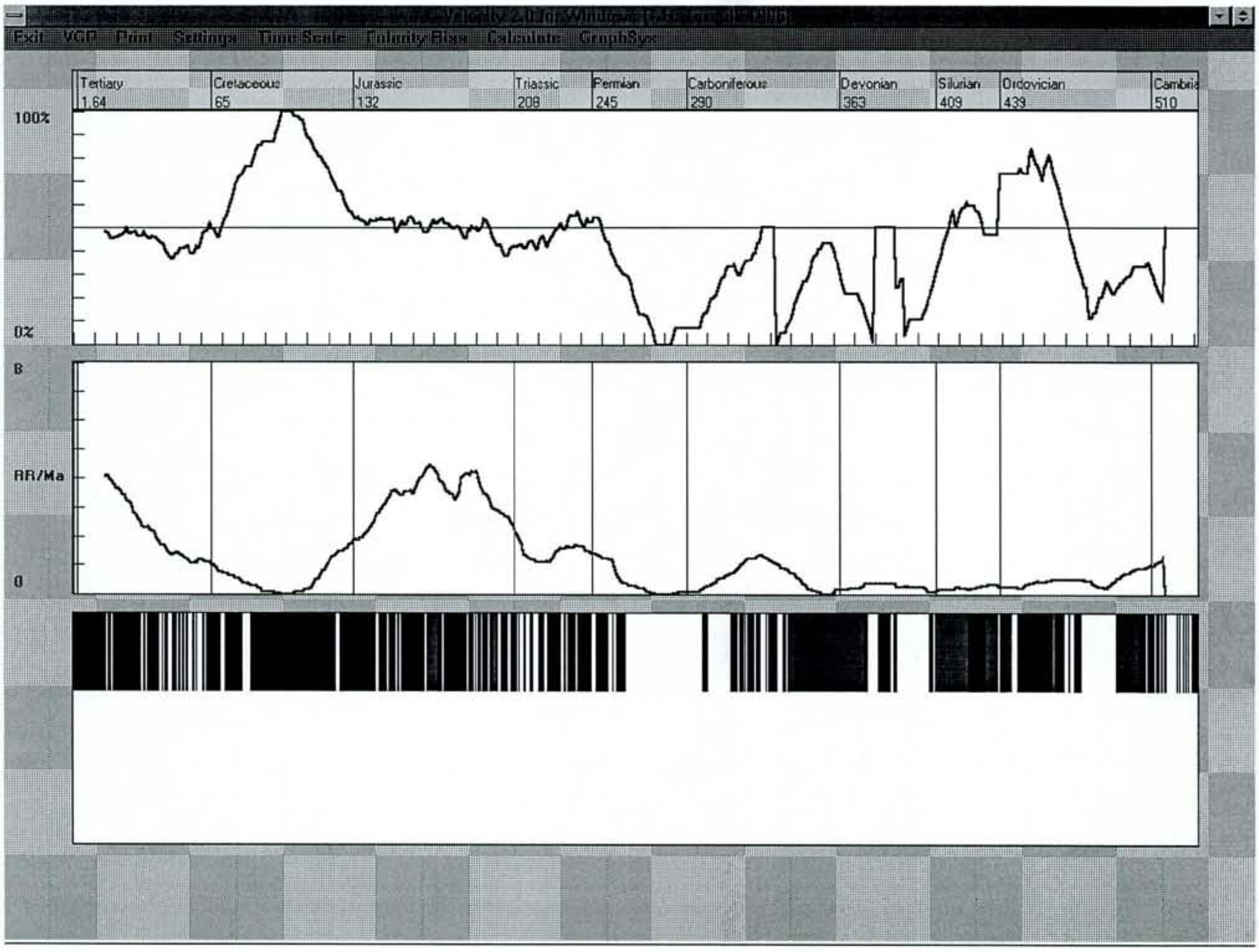
3.20.2 SETTINGS

This option permits the adjustment of parameters which control the `Velocity' option performance. The following parameters can be changed/updated:

PARAMETER	FUNCTION
Reference latitude (in degrees) **Reference longitude** (in degrees)	Palaeolatitudes, drift-rates and angular velocities are always calculated with respect to the selected reference locality
Start Time (in Ma) **End Time (in Ma)**	Whenever a VGP file is loaded the program tests for minimum (start)and maximum (end) age range, and the horizontal time-axis (see Fig. 16) is set accordingly. The operator can, however, change the START and END times **after** having loaded a VGP file. Useful when combining several VGP files with different Start and End times (i.e. plot at same scale)
Time window (in Ma)	Drift-rates and rotational velocities are averaged within the setting of this parameter
Invert Latitudes (Yes or No)	Dependent on the choice of VGP polarity the operator may have to invert latitude estimates. E,g. File B20092 is a VGP south-pole file and 'Invert Latitudes' has to be set to 'Yes' in order to display the latitudinal movements of Baltica correctly
Plot Declination or **Latitude error**	Set 'Plot declination' to ON when analysing APW paths: Use 'Latitude Error' to include latitude error bars for original VGP data (calculate error bars from INC+α95 to INC-α95)
APW path/spline or **Original data**	Set 'APW path/spline' to ON when analysing APW paths
Expanded Latitude plot (Yes/ No)	Display of latitudinal plot (top diagram) two times normal size when set to YES
Amplitude Latitude Plot (in Deg)	Set maximum amplitude (90°<value>0°)
Amplitude drift-velocity (in cm/yr	Set maximum amplitude (Value>0 cm/yr)
Amplitude rotation plot (in °/Ma)	Set amplitude (Value>0 °/Ma)
Amplitude CUM APW (in Deg)	Set amplitude (value >0°) (used in option 'APW rates)
Amplitude APW rate (in cm/year)	Set amplitude (value>0 cm/yr) (used in option 'APW rates')
Printer Setup	Set Printer

3.20.3 POLARITY BIAS

This option is under development and improved mathematical analysis will be implemented in future versions. Based on files (see 'About Polarity') containing the length of normal chrons in million years we can calculate polarity bias (expressed in %Normal polarity length) and reversal rates/Ma (lower diagram). The operator can analyze polarity bias using an age or chron sliding windows. A problem arises when there are gaps in the data sets; in this case we assigned 50% Normal polarity, but some analyses effects can bee seen when we intergrate over gaps. This will be improved, hence analysis covering data gaps should be considered carefully. The example below makes an analysis of file THT95.POL (supplied on disk). We have used age sliding, 30 mill. yr. window, and the sliding interval is 1 Ma. White/Black denote normal/reverse chrons. Gaps are shown in grey (actually green on the computer screen).



4 PALAEOMAGNETIC RECONSTRUCTIONS

4.1 A CASE STUDY

Let us consider a palaeomagnetic investigation of dykes from the Oslo Region (Norway) and we have dated one of the dykes with the $^{40}Ar/^{39}Ar$ method and we obtained an age of 246.2±4.6 Ma. of the Oslo Rift.

Procedure:

(1)

The magnetisation of the collected rocks samples were measured and subjected to magnetic cleaning in the laboratory in order to identify the primary declination and inclination. Magnetizations were mostly single-component with SSW declinations and negative inclinations (Fig. 18). We consider the magnetisation to be primary and to relate the plateau of 246 Ma (Fig. 19).

FIG 18
Example of a single component magnetization recorded from a dyke (Lunner) in the Oslo Rift region.

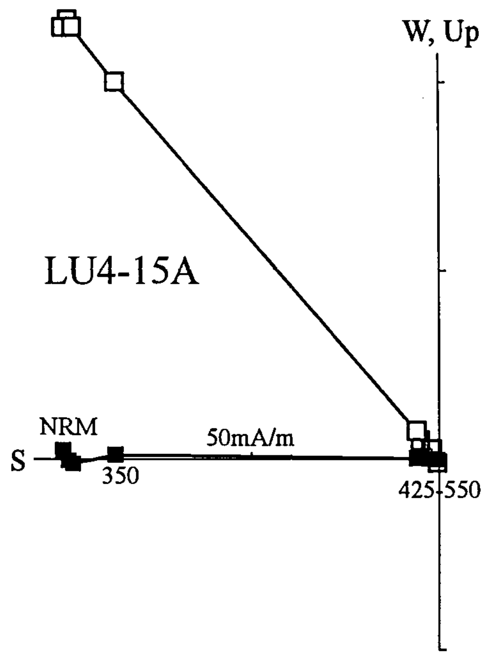
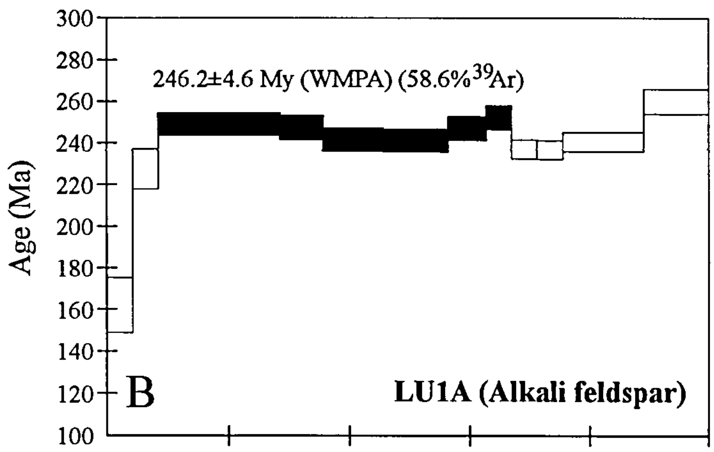


FIG 19
$^{40}Ar/^{39}Ar$ step-heating experiments on the same sample as shown in figure 18. A plateau age of 246.2 Ma is calculated, and probably corresponding to the age of the primary magnetization.



(2)

Based on a statistical average of several samples/dykes (Fig. 20) we calculated an average declination of 197.1 and inclination of -43.2.

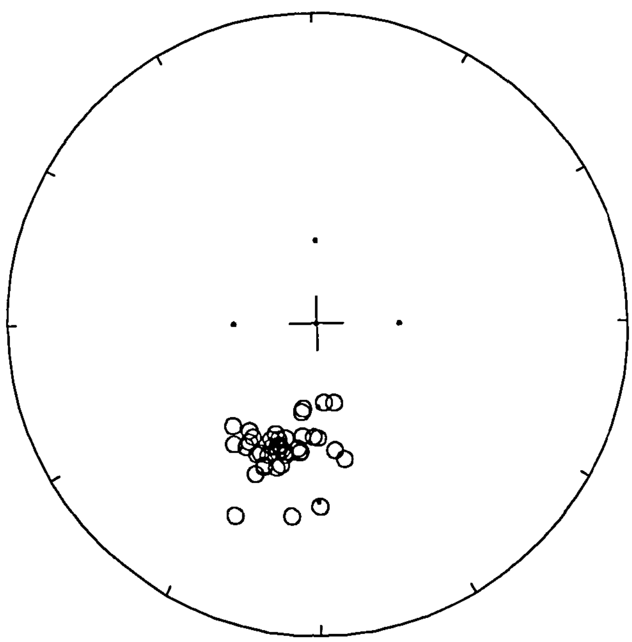
(3) Since the time averaged geomagnetic field-axis approximates the geographic (rotation) axis, all magnetizations should have declinations equal to zero or 180°. Any deviation from the N-S axis indicates how much a terrane or continent has been rotated since the time of magnetization. In our case the declination was 197.1 and the amount of rotation for the Oslo Region or BALTICA is consequently 17.1 degrees (197.1-180). Hence, BALTICA has rotated 17.1 degrees clockwise since the early Triassic.

From the inclination data we can now easily calculate the palaeolatitude for the Oslo Region using the formula:

PalaeoLatitude = ATN (TAN(Inclination)/2)

This results in a palaeolatitude of 25.2°N.

FIG 20
Stereoplot showing distribution of assumed primary magnetizations recorded in several dykes.



(4)

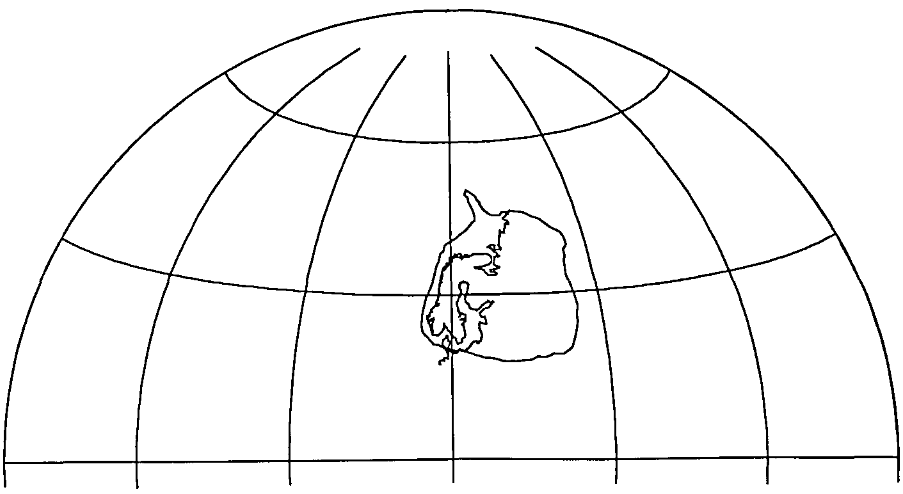
Based on the declination and inclination data we can reconstruct BALTICA as follows:

a. Calculate a palaeomagnetic pole based on the DECLINATION (197.1), INCLINATION (-43.2) and GEOGRAPHIC LATITUDE (60.3°N) & LONGITUDE (10.6°E). This gives a palaeomagnetic pole of 52.9°N & 164.4°E. NOTE that this pole would have corresponded to the geographic pole at the time of lava-eruption, but as Baltica subsequently moved/rotated the palaeomagnetic pole moved along with Baltica, hence our aim is to calculate the Euler Rotation Pole (ERP) that will bring the palaeomagnetic pole to the present geographic NORTH or SOUTH pole.
b. Calculate the ERP which will rotate the palaeomagnetic pole to either the geographic NORTH or SOUTH pole (you must make a choice yourself). In our example we quoted a north pole.
c. Then use this ERP to rotate BALTICA. The result will be as indicated in Fig. 21.

GMAP PROCEDURE:

- LOAD CONTINENT Baltica with option 'OPEN CONTINENT' or 'LIBRARY'
- Select option 'VGP RECONSTRUCT' and input 52.9 (north latitude) and 164.4 (longitude). Select Nouth pole
- Baltica, in its reconstructed position, will be displayed in 'DRAW CONTINENT' mode (Fig. 21).

FIG 21 Reconstruction of Baltica at c. 246 Ma

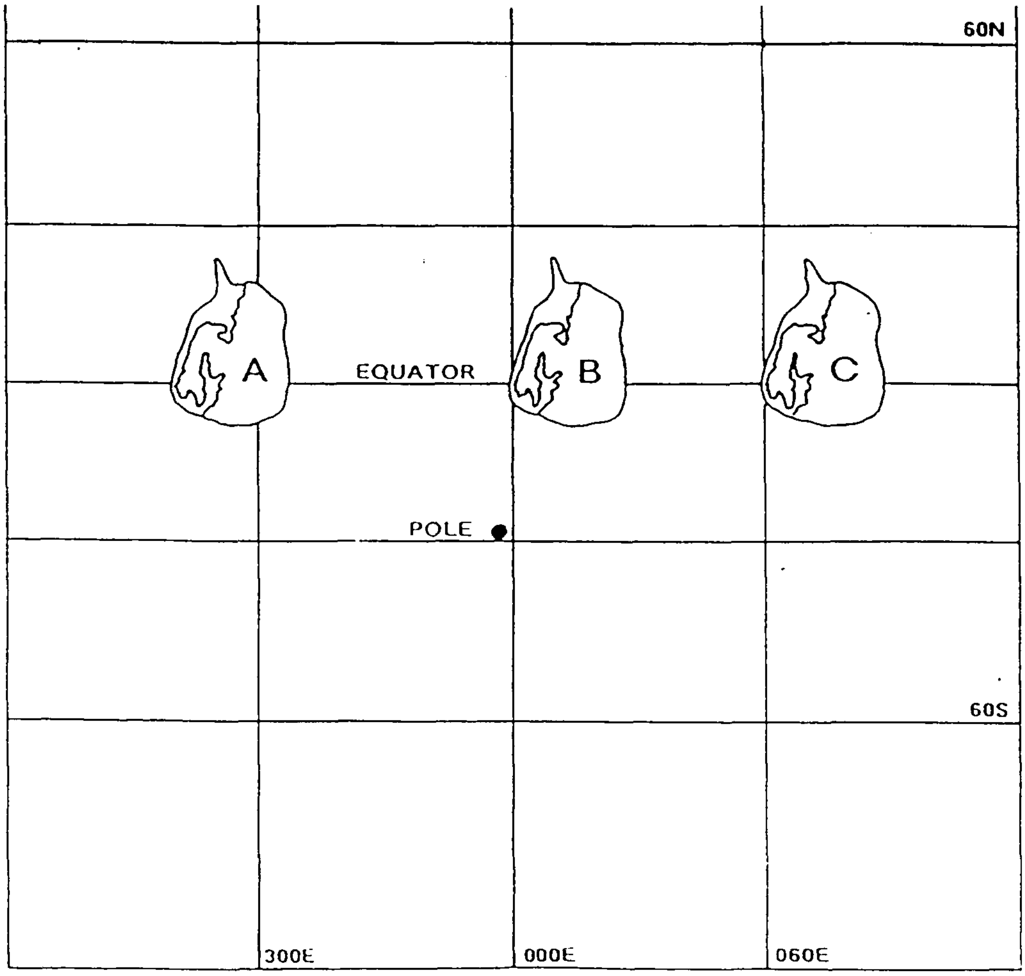


4.2 RECONSTRUCTION ENIGMAS

(a)

Palaeomagnetism can only constrain latitude (based on inclination) and the amount of angular ROTATION (based on declination), hence the palaeolongitude remains enigmatic, and you could place BALTICA in any preferred position in longitude (see Fig. 22).

FIG 22
Palaeomagnetic data cannot determine the palaeolongitude for a continent and after a palaeomagnetic reconstruction you are free to select the palaeolongitude by moving Baltica sideways (examples A,B & C)



(b)

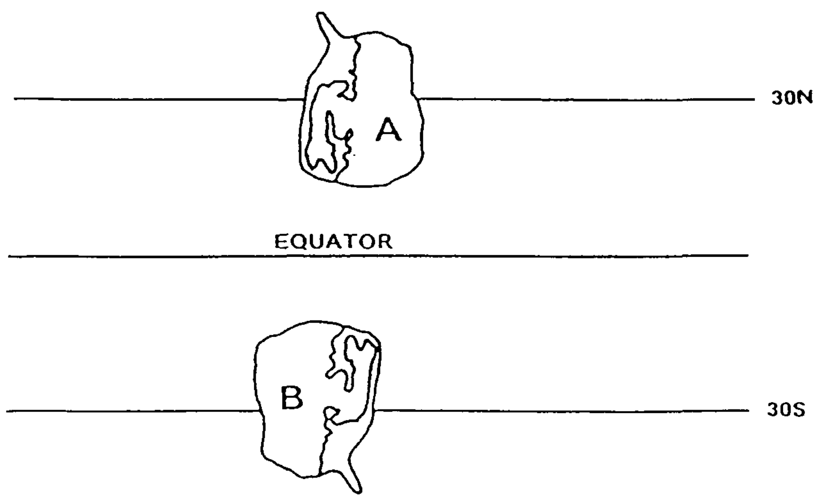
Apart from problems in determing the palaeolongitude, we cannot know in old rocks whether a palaeomagnetic pole is a SOUTH or NORTH pole. In our case we assumed that the pole was a SOUTH pole.

Selecting a NORTH or SOUTH pole results in two contrasting reconstructions. In Fig. 23 we have demonstrated the difference using a PERMIAN pole for BALTICA. Assuming a SOUTH pole places BALTICA in the northern hemisphere at around 30°. On the other hand, assuming a NORTH pole would place BALTICA in the southern hemisphere and geographically inverted.

Hence, the choices produce reconstructions which place the continent in opposite hemispheres and geographic inversion (i.e. rotated 180 degrees). This does not present a problem during the Mesozoic and most of the Palaeozoic, but for Precambrian and the early Palaeozoic this presents problems for palaeomagnetic reconstructions.

FIG 23

Example of using a SOUTH or NORTH pole for reconstruction of Baltica in Permian times. Note the change in hemisphere and the geographic inversion.



5. COMPOSITE RECONSTRUCTIONS AND ANIMATION FILES

In this section we will provide some guidelines concerning the build-up of reconstruction maps, and we will use an example (Fig. 24) which is published in international journals with the aid of GMAP (Torsvik & Trench 1991; Torsvik et al. 1992). Newer reconstructions are documented in Torsvik et al. (1996).

Example:

- Palaeoreconstruction of Gondwana, Baltica, Laurentia, Avalonia and Armorica in mid-Ordovician (Llanvirn-Llandeilo, c. 470Ma) times.

Fig. 24 was printed using a Schmidt equal-area polar (projection centre -90) projection. VGP data for reconstruction were as follows:

VGP (SOUTH POLES)			
CONTINENT	**LATITUDE**	**LONGITUDE**	**REFERENCE**
BALTICA	18N	049E	Torsvik et al. 1992
AVALONIA	12N	023E	Trench & Torsvik 1991
ARMORICA	33N	345E	Torsvik et al. 1990a
GONDWANA	34N	007E	Van der Voo 1988
LAURENTIA	22S	019E	Torsvik et al. 1990b
SIBERIA	30N	310E	Torsvik et al. 1990a

GMAP Procedure by writing data to HPGL file (later imported with a drawing package)

Note: Use the same HPGL file name for all HPGL operations.

(1) Enter option 'DRAW CONTINENT' in main menu
Set Projection to Schmidth equal area with 30 degrees grid spacing and projection center latitude to -90°.

(2) Enter option 'HPGL'
Select NET; confirm HPGL file name and click on <OK>. The net-grid will now be written to file.

Gondwana.

(3) Enter option OPEN CONTINENT in main menu and select GONDWANA

(4) Enter option VGP RECONSTRUCT
Enter VGP data listed above and select SOUTH-POLE

(5) GONDWANA will now be displayed in DRAW CONTINENT mode
Select HPGL continent and GONDWANA will be written to file.

(6) You may now use option SAVE CONTINENT in main menu to permanently save your mid-Ordovician reconstruction of GONDWANA, e.g. with the name GOND470 (supplied on disk).

Laurentia

(7) Enter option OPEN CONTINENT in main menu and select palaeocontinent LAURENTIA (or LAUROT to avoid points 9 & 10).

(8) Set EULER DATA to correct for North Atlantic Opening, i.e. 87 (latitude), 27 (longitude) and 37 (Euler angle) for a Bullard et al. fit (1964) with option EULER KEYBOARD INPUT.

(9) Enter option ROTATE CONTINENT -Laurentia is now in European co-ordinates

(10) Enter option VGP RECONSTRUCT
Enter VGP data listed above and select SOUTH-POLE

(11) LAURENTIA will now be displayed in DRAW CONTINENT mode
Palaeolongitudes are unconstrained with palaeomagnetic data and in Fig. 22 the reconstructed LAURENTIA has been translated 50 degrees Westward using option TRANSLATE in DRAW CONTINENT mode.
Select HPGL continent and LAURENTIA will be written to file.

(12) You may now use option SAVE CONTINENT in main menu to permanently save your mid-Ordovician reconstruction of LAURENTIA, e.g. with the name LAU470 (supplied on disk).

Avalonia.

(13) Enter option OPEN CONTINENT in main menu and select palaeocontinent AVALONIA

(14) Enter option VGP RECONSTRUCT

Enter VGP data listed above and select SOUTH-POLE

(15) AVALONIA will now be displayed in DRAW CONTINENT mode
Palaeolongitudes unconstrained and the reconstructed AVALONIA has been moved 70 degrees westward.
Select HPGL continent and AVALONIA will be written to file.

(16) You may now use option SAVE CONTINENT in main menu to permanently save your mid-Ordovician reconstruction of AVALONIA, e.g. with the name AVA470 (supplied on disk).

Baltica.

(17) Enter option OPEN CONTINENT in main menu and select palaeocontinent BALTICA (18). Enter option VGP RECONSTRUCT
Enter VGP data listed above and select SOUTH-POLE

(19) BALTICA will now be displayed in DRAW CONTINENT mode
The reconstructed BALTICA has been translated 60 degrees westward in Fig. 22.
Select HPGL continent and BALTICA will be written to file.

(20) You may now use option SAVE CONTINENT in main menu to permanently save your mid-Ordovician reconstruction of BALTICA, e.g. with the name BAL470 (supplied on disk).

Siberia

(21) Enter option OPEN CONTINENT in main menu and select palaeocontinent SIBERIA (22). Enter option VGP RECONSTRUCT
Enter VGP data listed above and select SOUTH-POLE

(23) SIBERIA will now be displayed in DRAW CONTINENT mode
The reconstructed SIBERIA has been translated 20 degrees Eastward in Fig. 22.
Select HPGL continent and SIBERIA will be written to file.

(24) You may now use option SAVE CONTINENT in main menu to permanently save your mid-Ordovician reconstruction of SIBERIA, e.g. with the name SIB470 (supplied on disk).

Armorica.

(25) Enter option OPEN CONTINENT in main menu and select ARMORICA

(26) Enter option VGP RECONSTRUCT
Enter VGP data listed above and select SOUTH-POLE

(27) ARMORICA will now be displayed in DRAW CONTINENT mode
The reconstructed ARMORICA has been translated 75 degrees Westward in Fig. 22.
Select HPGL continent and ARMORICA will be written to file.

(28) You may now use option SAVE CONTINENT in main menu to permanently save your mid-Ordovician reconstruction of ARMORICA, e.g. with the name ARM470 (supplied on disk).

<u>GMAP Procedure with printer:</u>

Use similar procedure as outlined above, but instead of HPGL 'hard-copying' each continent use option 'Print - Send to Printer Buffer' (the grid is automatically send with this option). Select option 'Print -End printing' after all the reconstructed continents have been sent to the buffer.

GMAP Procedure using animation files

Having saved your individual reconstructions to files you may wish to create an animation file for later printing as follows:

(1) Enter option 'TABLE ANIMATION'

(2) Click on the first line/row followed by 'EDIT'. Enter e.g. GOND470 in the continent column

(3) Click on successive lines followed by 'EDIT' or alternatively 'ADD' and enter BAL470, LAU470 etc.at each data-line. Leave blank or zero in the data columns for EULER LAT, LONG and ANGLE since we have already rotated the continents.

(4) Exit 'Table Animation'

(5) Use option 'Save As Animation' to store the animation file (e.g. MIDORD; supplied on disk)

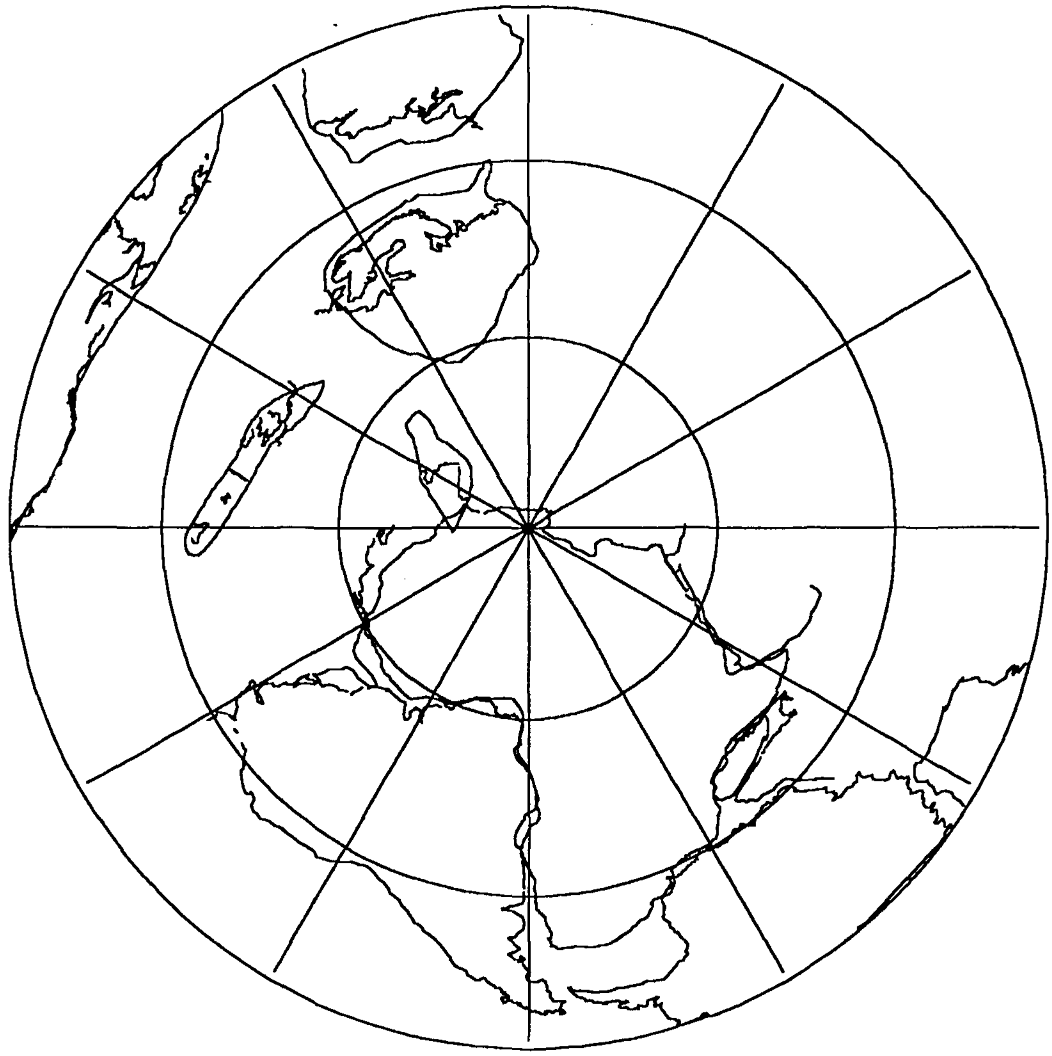
(6) Select option HPGL Animation and all continents will be written to file (the grid is automatically transfered to the file)

To send data to printer use option 'DRAW ANIMATION' followed by option 'PRINT-Send data to buffer' and option 'PRINT-End Printing'..

NOTE

Whenever a VGP reconstruction has been performed the calculated euler rotation is displayed in the information box below the main menu. It is therefore possible to create the same animation file by writing GONDWANA, BALTICA etc. along with the euler-data.

FIG 24 Mid-Ordovician (c. 470Ma) reconstruction (cf. text).



6. INTERFACING WITH GRAPHICAL DRAWING SYSTEMS

From the main menu the operator can access several graphical packages and we have included Aldus Freehand (defaults to version 4, but the operator can select a different version by changing path and file-name), Lotus Freelance and Corel Draw on our list. However, any graphical package which can import HPGL files can be used. The main purpose with this interface is to import GMAP plots, improve the design, labelling etc. such as they can be published/printed directly from the PC.

Example of Aldus Freehand - GMAP HPGL Interfacing:

IN GMAP

1. Create a plot in GMAP and Save the plot to a HPGL file. Use file-extension .PLT since Aldus uses this extension when importing HPGL plots (Lotus Freelance uses file extension .HGL)
2. Select option 'GRAPHSYS' in the main menu and select sub-option 'ALDUS'.

IN ALDUS

1. Select option 'OPEN FILE' in the main menu
2. Change file format to HPGL import
3. Select file created in GMAP and click <OPEN>

The plot-file created in GMAP can now be coloured, labelled etc. and printed. Cf. Aldus manuals for details.

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APPENDIX 1 LISTING OF VGP FILES

We have included a few VGP files (original VGP data and spherical spline paths) used by the authors of the program, but these should only be used as training files. More updated data-sets (based on Torsvik et al. 1996) and a VGP library is available in Professional Edition.

VGP file name	APW Path	Area/Plate	Reference
ARMORICA	ARMB	Armorica	Torsvik et al. (1990)
	SYNOK	S. Britain/E.Avalonia	Torsvik et al. (1993)
BAL92	B20092	Baltica	Torsvik et al. (1992)
B95	B95200	Baltica	Torsvik et al (1996)
L93THT	L20093	Laurentia (E. co-ordin.)	Updated from MacNiocail & Smethurst 1994

APPENDIX 2 LISTING OF CONTINENTAL FILES (could be some additions)

ACADIA.C97	Acadia
AMAZCR.C97	Amazon craton (South America)
ARABIA.C97	Arabia
ARM470.C97	Armorica paleocontinen at 470 mat
ARMORICA.C97	Armorica paleocontinent
AVA470.C97	Avalon paleocontinent at 470 ma
AVALONIA.C97	Avalon paleocontinent
BAL470.C97	Baltica paleocontinent at 470 Ma
BALTICA.C97	Baltica paleocontinent
BOHEMIA.C97	Bohemian massif
CA.C97	Central Atlantic
CAAXIS.C97	Central Atlantic axis
CASIA.C97	Asia coastline
CON1.C97	North, Central & South America
CON2.C97	Scandinavia, Russia, Asia & Europe
CON3.C97	Africa
CON4.C97	Greenland & Arctic Canada
CON5.C97	Australia
CON6.C97	Antarctica
CONGO.C97	Congo Craton (Africa)
ECA.C97	East Central Atlantic magnetic anomalies
ELLMTS.C97	Ellesworth Mountains
ENA.C97	East North Atlantic magnetic anomalies
ENAOLIVE.C97	North Atlantic magnetic anomalies (East)
ENASHARI.C97	North Atlantic magnetic anomalies (East)
ENGLAND.C97	England

EURASIA.C97	Eurasia
EUROPE.C97	Europe
GOND470.C97	Gondwana paleocontinent at 470Ma
GONDWANA.C97	Gondwana paleocontinent
GREENL.C97	Greenland
HERCEU.C97	Hercynian Europe
IBERIA.C97	Iberia
ICELAND.C97	Iceland
ICHINA.C97	Indo-china
ICON1.C97	Islands for CON1
ICON2.C97	Islands for CON2
IGREENL.C97	Islands for Greenland
INDIA.C97	India
INDO.C97	Indonesia & islands
ITALY.C97	Italy
KALAHARI.C97	Kalahari craton (Africa)
KAZAHK.C97	Kazahkstan
LABOLIVE.C97	Labrador magnetic anomalies
LAU470.C97	Laurentia paleocontinent at 470 Ma
LAURENTI.C97	Laurentia paleocontinent
LAUROT.C97	Laurentia rotated into European co-ordinates (Bullard et al. fit)
MADAG.C97	Madagaskar
MBYRD.C97	Marie Byrd Land
NA.C97	North Atlantic fractures
NAAXIS.C97	North Atlantic axis
NAMPAL:CON	North America Palaeozoic
NAMCRAT	Cratonic North America
NAM.C97	North America
NCB.C97	Northern China Block
NCHINA.C97	Northern China Block
NEWF.C97	Newfoundland
NIRE.C97	Northern Island
NORWAY.C97	Norway
PACIFIC.C97	Pacific Islands
PASIA.C97	Political boundaries Asia
PCON2.C97	Political boundaries CON2
PCON3.C97	Political boundaries CON3
PSAM.C97	Poltical boundaries South America
SAF.C97	Africa
SAM.C97	South America
SCB.C97	Southern China Block
SCHINA.C97	South China
SIAP.C97	South of iapetus Suture UK
SIB470.C97	Siberia paleocontinent at 470 Ma
SIBERIA.C97	Siberia paleocontinent
SPIT.C97	Spitsbergen
TARIM.C97	Tarim
TAYMIR	Taymir Peninsula (Siberia)

UK.C97	UK
UKRAINA.C97	Ukraina
WCA.C97	West Central Atlantic magnetic anomalies
WESTAFR.C97	West Africa craton (Africa)
WNA.C97	West North Atlantic magnetic anomalies
WNAOLIVE.C97	West North Atlantic magnetic anomalies
WNASHARI.C97	West North Atlantic magnetic anomalies
INDLIN.C97	Indian Ocean Magnetic anomalies
NALIN.C97	North Atlantic magnetic anomalies
PALIN.C97	Pacific magnetic anomalies
PALIN2.C97	Pacific magnetic anomalies
PALIN3.C97	Pacific magnetic anomalies
PLATES.C97	Plate boundaries
SALIN.C97	South Atlantic magnetic anomalies

APPENDIX 3 LISTING OF ANIMATION FILES

A complete set of animation files (extension *.A97) is available in professional edition.

Animation files:

MIDORD.ANI	Mid-Ordovician example file
WORLD.ANI	Selected continents around the world

APPENDIX 4 LIST OF FINITE EULER POLES (Professional edition)

Old *.FIN files has been replaced by *.SDV files which contains listing of finite rotation poles for various fits and magnetic anomalies. These new files are restricted to the Professional Edition of GMAP, and are described by Torsvik & Eide (1998).

APPENDIX 5 LIST OF MAGNETIC POLARITY DATA (Professional edition)

CAND95.POL	Cande & Kent (1995)
CANDE.POL	Cande & Kent (1992)
OGG.POL	Ogg (1995)
THT95.POL	Cande & Kent (1995), Ogg (1995) + modified Early Mesozoic-Palaeozoic by the authors

APPENDIX 6 ATLAS FILES

These are stored in Windows Metafile Format (extension *.wmf). File names denote total reconstruction at <XXX> million years.

APPENDIX 7 - CONTINENTAL DATA-FILE FORMAT AND DIMENSIONS

**.C97 FILES (used to be *.Con in earlier versions)*

Maximum number of paired grid-points =25000 and own-made old *.CON files can be converted to new format under 'FILE' option in the main menu.

GMAP uses a BINARY RANDOM ACCESS format for continental files. Individual records consist of latitude and longitude, 4 bytes each (total 8 bytes pr. record). Latitudes and longitudes are stored as single precision values. ASCII files can be converted using option ASCII import in the main menu. GMAP files can also be exported to ASCII files.

APPENDIX 8 POLE RELIABILITY SCHEMES

When constructing APW paths it is important to assess the reliability of palaeomagnetic data in order to avoid low-quality palaeomagnetic data. There exist various schemes for assessing the reliability of palaeomagnetic data, but it is now common to classify published data according to the criteria proposed by Van der Voo (1988). Van der Voo recognises seven fundamental reliability criteria for palaeomagnetic results which we briefly reiterate below:

1. Well-determined rock/magnetic age
2. Result based on >25 samples with high precision k>10 and low error-confidences
3. Demagnetisation/magnetic cleaning results reported in sufficient detail
4. Positive field (fold-, conglomerate-, contact-) tests, i.e. evidence for a primary magnetisation
5. Tectonic coherence with continent - structural control
6. Antipodal reversals identified to assure a good time average of the geomagnetic field.
7. Lack of similarity with younger poles, i.e. no suspicion that the pole is an overprint if field-tests are inadequate.

In general, palaeomagnetic results as reported will either satisfy, or not, each of the seven criteria. A result's 'score' (0 to 7) can be used as a measure of overall reliability. This 'score' is referred to as the 'quality factor' or 'Q' by Van der Voo (1988).

When it comes to the reliability of palaeomagnetic data, palaeomagnetic field-tests are of vital importance. There are three major field-tests (Fig. 27) to test if magnetisation's are 'primary' or secondary (overprints):

(1) FOLD-TEST

If the magnetisation vector follows the geometry of the fold, the test is said to be positive; the magnetisation is primary or least pre-date the folding event. If the magnetisation is identical along the fold-structure we are dealing with an overprint which post-dates the folding (negative test).

(2) CONGLOMERATE TEST

An intra-formational conglomerate is useful for this test. If the magnetisation's are randomly distributed between various boulders, the magnetisation in the underlying/overlying sequence is most probably primary (positive test). If they are similar, as well as e.g. matching the magnetisation in the underlying sedimentary sequence, the magnetisation is secondary (negative test).

(3) CONTACT TEST

This test is used for palaeomagnetic investigation of dikes. If the magnetisation in the dike and the baked country rock is similar, but deviated from the host-rock at some distance from the dike, the magnetisation in the dike is primary (positive test). On the other hand, if the dike and the country rock display the same magnetisation, the magnetisation must relate to a later regional overprint (negative test).

FIG 27 Examples of positive/negative field-, conglomerate and contact tests.