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GRDM—A digital field-mapping tool for management and analysis of field geological data ☆

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Abstract

Field geological observations have both spatial and non-spatial aspects and recording them directly on a personal computer using a digital mapping tool has become a practical and effective alternative to traditional methods of field data collection and mapping. This paper presents the design of a cost-effective, stand-alone digital field-mapping tool named GRDM that caters to special requirements of field-based studies concerned with spatial disposition of the statistics of field measurements. Such studies require recording multiple observations for individual attributes at each field location to capture the inter-site variability and automatic computation of their statistics. Field observations include directional data that are circular in nature. Therefore, computation of their exclusive statistics within the field system is also necessary. To meet these requirements, GRDM was designed for field personnel lacking expertise in customizing a GIS. Its design automatically accommodates a list of values for each non-spatial attribute attached to individual location points and generates statistics from the lists. The system treats the orientation values as a distinct numeric data type and computes circular statistics for them. It makes both the original data as well as their statistics simultaneously available for extraction of thematic information.

Keywords: Digital field-mapping tool; Attribute; Data query; Statistics; Thematic maps; Directional data

1. Introduction

During fieldwork geologists traditionally record observations made at different field sites into paper notebooks (Fig. 1) and associate them with the location points marked onto base maps (i.e., topographic maps, aerial photographs, satellite imageries, etc.). With increasing availability of affordable portable computers, recording geological field observations on a personal computer directly in the field has become a practical and effective alternative to traditional methods of field data collection and mapping (Brodaric, 1997, 2004; Williams, 2001; Brimhall et al., 2002; Kramer, 2000; Buller, 2005). During the tenure of a geological investigation, "The observations are continually assimilated into an interpretive geological history for the area, including spatial, temporal and causal process .... Such assimilation is an ongoing process that occurs in the field and afterwards in the office when laboratory and other results maybe incorporated.... Computer-based field systems ...

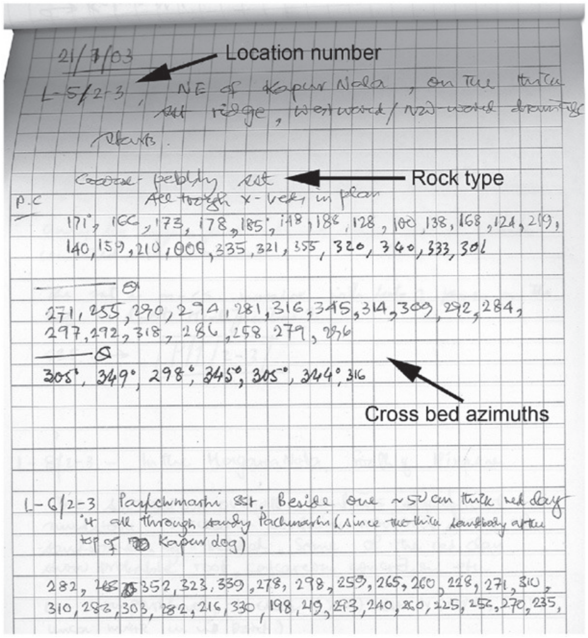

Fig. 1. A typical page from a field note book. Note that a large number of azimuth data have been recorded for two field locations.

aid the ongoing assimilation process by providing digital tools for data exploration, analysis, visualization, etc.'' (Brodaric, 2004).

The data collected in the field have two aspects—spatial and descriptive attributes. Attribute data may be different kinds of linear and angular measurements, text descriptions, field photographs/sketches, color of rocks, textual comments, etc. Though a number of digital field-mapping tools have already been developed (cf. Kramer, 2000; Williams et al., 1996; Brimhall et al., 2002; Brodaric, 1997, 2004; de Donatis et al., 2005) to capture diverse type of field observations, the design of the field systems remains a challenge due to diverse needs arising out of individual's unique techniques, terminologies, or the specific goals of the project (cf. Brodaric, 2004; Buller, 2005).

This paper presents the design of a digital field-mapping tool named GRDM that caters to the requirements of studies concerned with spatial disposition of the statistics of field measurements. It was developed to meet the requirements of field data collection of a group of geologists mapping a sedimentary basin on a 1:50,000 scale under an integrated geological research program. Two major objectives of the project were to understand the regional variation of the overall clast size of the conglomeratic lithounits and the paleocurrent dispersal patterns. At each field location the conglomerate contains innumerable clasts of different sizes. Therefore, at every location a number of clasts were randomly chosen for measurement and the average clast size was estimated. The geological interpretations depended on the spatial variation of the site-specific averages. Similarly, the regional variation of palaeocurrent direction was modeled using the spatial distribution of mean orientations of cross-bed azimuths measurements of individual sites. However, as these directional data are circular in nature (with values restricted between 0° and 360°), their circular statistics (i.e. vector mean) were considered (cf. Krumbein, 1939; Mardia, 1972; Batschelet, 1981; Sengupta and Rao, 1966; Kutty and Ghosh, 1992; Jones, 2006). The spacing of location points and the number of data collected at each location depended on the resources and technologies available. For practical assimilation of such field data individual workers needed a field system with the capability of storing and appending multi-valued attributes. They also required the statistics of the collected data to be automatically computed and displayed as thematic maps to aid onsite scientific interpretations and to make necessary changes in data collection strategies. However, most field personnel lacked advanced knowledge of managing multiple related tables in a GIS. Again, it was not feasible to equip each team member with a GIS.

In most GIS systems, a geographic entity is represented by a vector, comprising a unique identifier and a sequence of attributes (Peuquet, 1999; Worboys and Duckham, 2004). Each attribute is associated with a domain from which it takes up a single value and any single attribute in a vector cannot contain a set, list, or array of values (Worboys, 1999; Rigaux et al., 2002). However, some systems like GCS Field*log* (Brodaric, 2004) as well as a GIS, suitably customized, are capable of accommodating multi-valued attributes. Though most GIS can compute statistical measures for linear data, those for the circular data cannot be computed readily in a field-mapping system.

Thus, GRDM was designed to suite the requirements of field personnel lacking expertise in advanced GIS functionalities. Its design automatically accommodates a list of values for each non-spatial attribute attached to individual location points and generates statistics from the lists. The system treats the orientation values as a distinct numeric data type and computes circular statistics for them. It makes both the original data as well as their statistics simultaneously available for extraction of thematic information. GRDM includes essential functionalities of a stand-alone system (Table 1) that can be operated using a low-end laptop. The data collected with GRDM can be exported to a GIS for more advanced spatial and topologic analyses (cf. Rigaux et al., 2002; Worboys and Duckham, 2004; Getis, 1999; Fischer, 1999).

Table 1
The main functionalities of GRDM, relevant commands and interfaces

Main functionalities of GRDM	Main commands	Relevant interfaces
Creation and modification of geographic features using a graphical interface	Create Point	Viewport/
	Create Line Move Point Move Line Vertex	Pop-up menu/ Main Menu > Create
Geo-referencing of base maps and DEMs and arranging them on the background	Add Map	Arrange Raster Layers and Geo-referencing Tool (automatically activated when necessary)
	Add DEM	
Attaching attributes to the features and populating them with values	Add	Pop-up menu
(Individual attributes can take up a list of values) Modification of the attribute values	Remove Modify Point Data Modify Line Data	Attribute Editor and Modify Attributes
Computations of mean, standard deviation, variance, etc. for the numeric attributes and vector mean, consistency, axial vector mean and mean angular deviation for the directional data	*Automatic*	
Retrieval of spatial and non-spatial data and statistics	Explore, Find	Main Menu > View Explore, Find, and SQL Query
Generation of thematic maps from the data or their statistics using symbologies	Compute Symbology	Main Menu > Create/Main Toolbar
	View (Symbology)	Symbology
Import and export of spatial and non-spatial data	Import Ungenerate File Import ESRI ShapeFile Export Ungenerate File Export ESRI Shape File Attach Data	Main menu > File
Conversion from one attribute type to another	Convert Data Type	Main Menu > Tool Convert Data Type
Displaying bearing lines from a point to facilitate locating oneself in the field by triangulation method	Draw Triangulation Lines	Main Menu > Tool
Specifying locations in terms of geographic coordinates or as bearing and distance		Context sensitive menu activated by right-click in the viewport
Making base maps appear semi-transparent		Arrange Raster Layer
Enhancing visualization of DEMs by rendering logarithms of the elevation values and image processing (embossing)	Logarithmic Plot Shaded Relief	Main Menu > DEM
Generating cross-sectional profiles of the DEMs along a specified line	Draw Profile	Main Menu > DEM/Main Toolbar

2. The design

GRDM is written in Microsoft's Visual Basic 6 programming language and uses Microsoft Access Database. There are two main components of GRDM: (a) a front end and (b) a back end (Figs. 2 and 3).

2.1. The front end

The main components of the front end are a viewport, a canvas, menus and interfaces. The viewport serves as the main graphical user interface for displaying base maps and creating and modifying map features as vectors. It is also the output destination for thematic maps. The canvas, not directly visible to the user, is used internally to compose base map images and to render vectors in the background. Depending on the chosen zoom and pan settings, a part or the whole of the content of the canvas is displayed in the viewport.

2.2. The back end

The data are organized and stored in the back end in a number of database tables (Fig. 3). For every geographic feature three basic types of information are stored: (a) spatial/geometric (i.e. the location of a point or the vertices of polylines and polygons), (b) non-spatial attributes and (c) graphical symbols used to render the features on the canvas.

Every geographic feature is automatically assigned a unique identification number (*Feature_ID*) to maintain the relationship between the features and their corresponding attributes. The locations of the points are stored in the POINT table as latitude–longitude coordinate pairs along with *Feature_IDs* (Fig. 3). The *Feature_IDs* for both the polylines and polygons are contained in the LINE table. The "Type" field in that table distinguishes polylines from polygons. The latitude–longitude coordinates of the vertices of polylines and polygons are stored in a separate table called VERTEX table along with the *Feature_IDs* that

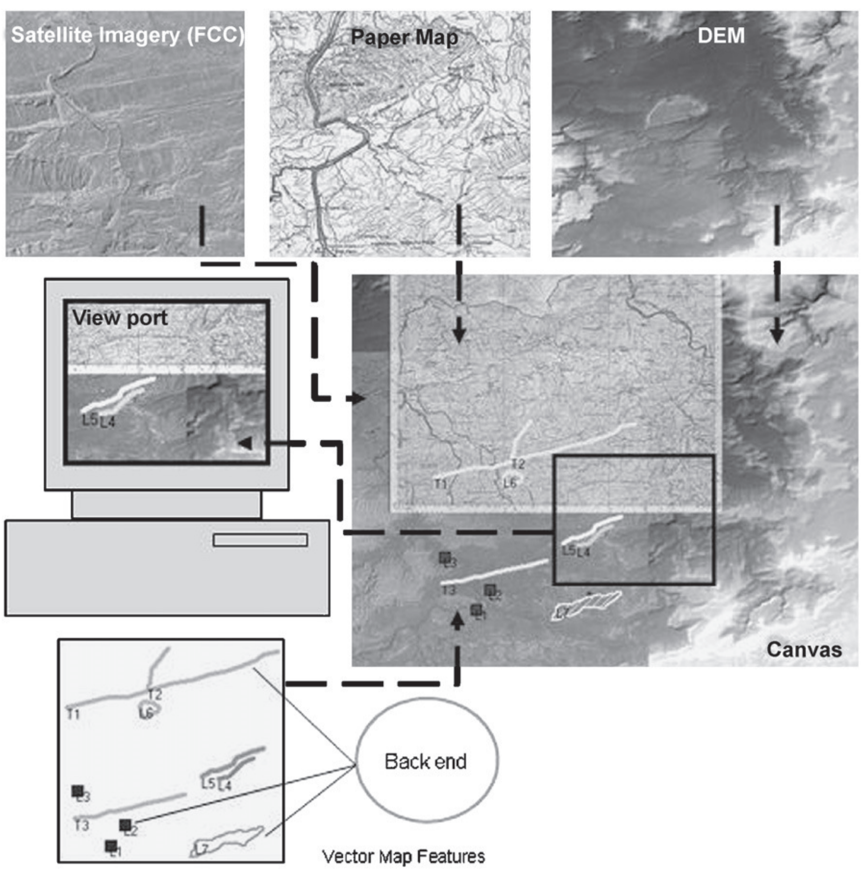

Fig. 2. Organization of different components of front end and its linkage with back end.

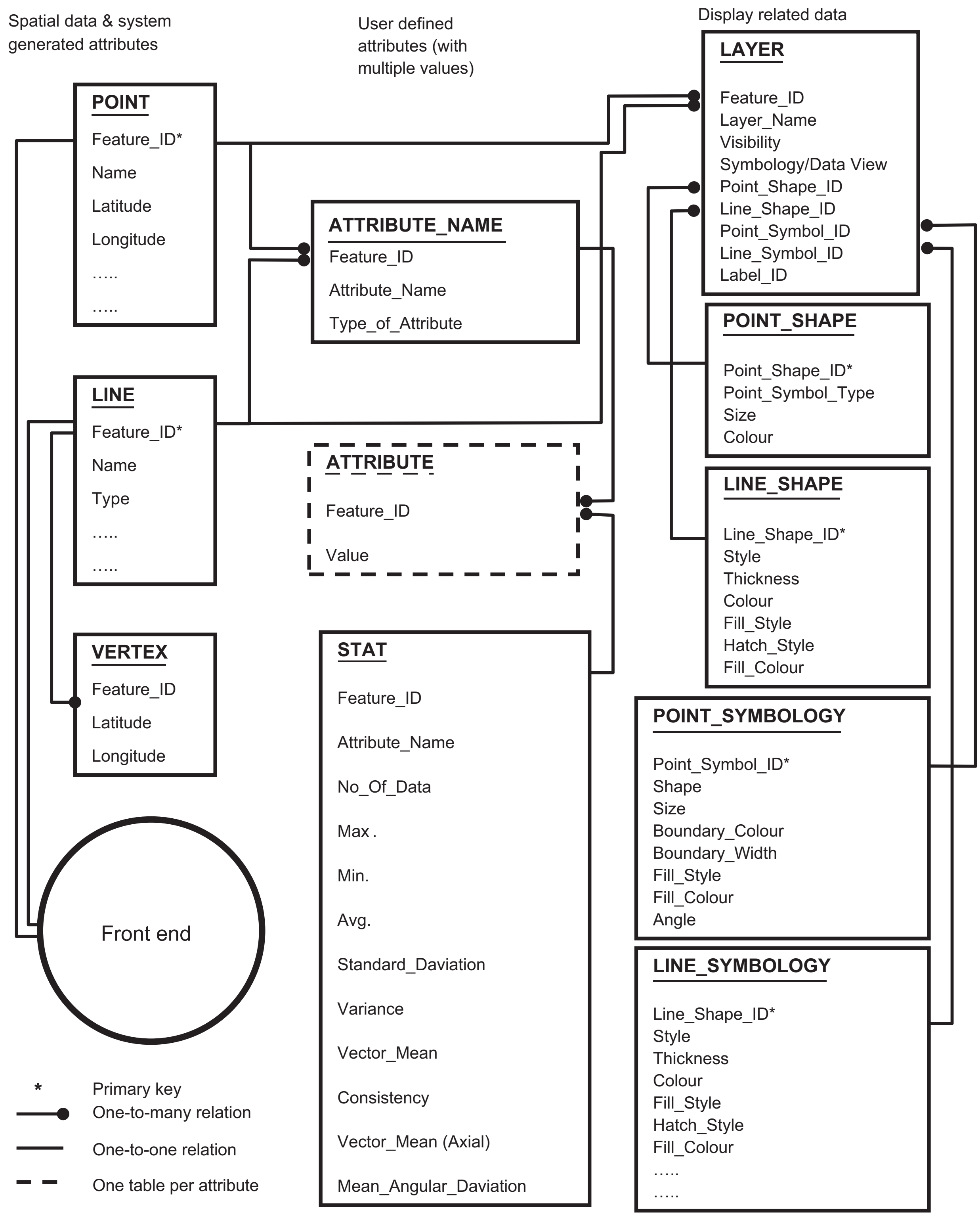

Fig. 3. Organization of different database tables constituting back end and their relations. Linkage with front end is also indicated.

associate the vertices with the features. The symbologies of the points and polylines/polygons are saved in SHAPE tables.

It is not practical to store the attribute values in a single table since each attribute can take up a list of values. Therefore only the names and types (i.e., text, numeric, etc.) of attributes are listed in a table called ATTRIBUTE_NAME, which also stores the "*Feature_ID*" as a foreign key. The attribute values are stored in separate ATTRIBUTE tables, with their names corresponding to those listed in the ATTRIBUTE_NAME table (Fig. 3). The ATTRIBUTE tables are created at run-time and saved within the database. They are available to subsequent sessions of GRDM unless deleted by the user.

Some of the attributes like date and time of creation, length of polylines, perimeter and area of polygons are automatically generated. These system-generated-attributes cannot take multiple values. These attributes are stored directly either in POINT table or in LINE table.

The statistics are computed automatically for the numeric and orientation attribute types and stored together in STAT table (Fig. 3). The STAT table stores the attribute names and *Feature_ID*s to maintain the correspondence with the actual values scattered in the different ATTRIBUTE tables. The statistics that are not relevant to a particular type of attribute are assigned a NULL value. For orientation attribute types, both the unidirectional and axial vector means and measures of circular variance are computed using methodologies described in Kutty and Ghosh (1992) and Jones (2006). The STAT table is updated whenever an attribute is created or deleted or a list is modified in any ATTRIBUTE table.

In GRDM, the features are organized in different groups, called layers. New layers can be added and the existing layers (along with the features belonging to that layer) can be deleted. The display of the individual layers can be turned on or off to facilitate viewing and editing of superimposed features. The LAYER table stores the names of the layers, their display property (on/off), as well as the identifiers of features (i.e. *Feature_ID*) belonging to the individual layers.

The generation of the thematic maps involves displaying features with similar attribute values with similar symbols and features with dissimilar attribute values with distinct ones. For a chosen theme the symbologies are computed and stored in POINT_SYMBOLOGY or LINE_SYMBOLOGY table along with a unique *Symbol_ID* per definition (Fig. 3). These *Symbol_ID*s are also inserted against the *Feature_ID*s in the *LAYER* table. The definitions stored in SYMBOLOGY tables, rather than those stored in SHAPE tables, are used to render the vectors in the thematic maps.

3. Program steps

3.1. Creation of raster layers

GRDM initializes by creating the viewport on the computer screen with an empty canvas in the background. The user then loads geo-referenced base maps that are placed on the canvas according to their relative geographic locations. Scanned topographic maps, false color composites of multispectral satellite imageries, etc. can be used as base

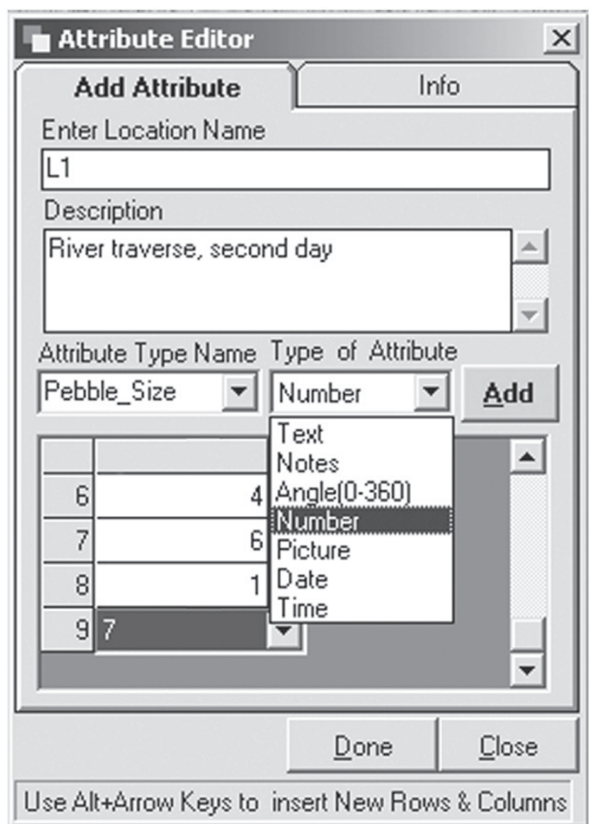

Fig. 4. Interface for creation of new attributes and insertion of attribute values. "Add" button is used to insert individual attributes and their values to database, whereas "Done" button completes the data entry process.

Table 2
The construction of search queries and their applicability for the different attribute types

Attribute types	Applies to	Explanation	Spatial query	Non- spatial query
Text	<List>	Whether a particular value exists in a list	= , < >	
	Only	Single element list having a particular value	=	
	Count	Number of elements in the lists	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
Number	<List>	Whether a particular numeric value exists in a list	= , < >, >, > = , <, < =	
	Max	Maximum numeric value in an individual list	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
	Min	Minimum numeric value in an individual list	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
	Avg	Average of numeric values in individual lists	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
	SD	Standard deviation of numeric values in individual lists	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
	Var	Variance of numeric values in individual lists	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
	Count	Number of elements in individual lists	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
Angle(0–360)	<List>	Whether a particular angular value exists in individual lists	= , < >, >, > = , <, < =	
	Vector Mean	Vector Mean of all values in individual lists	= , < >	Vector Mean, Consistency, Axial Vector Mean, Mean Angular Deviation
	Consistency	Consistency of all values in individual lists	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, Sd, Var
	Axial Vector Mean	Axial vector mean of all values in individual lists	= , < >	Axial Vector Mean, Mean Angular Deviation
	Mean Angular Deviation	Mean angular deviation of all values in individual lists	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
	Count	Number of elements in the individual lists	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
Picture	<List>	Whether a picture name exists in a list corresponding to a feature	= , < >	
	Count	Number of pictures at individual features	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
Date (multiple; user defined)	Date	If a particular date is relevant for a feature	= , < >, >, > = , <, < = , Max, Min	Max, Min
	Count	Number of dates listed for individual features	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var
Date (single; system generated)		Date and time of creation of the feature	= , < >, >, > = , <, < = , Max, Min	
Location	Name		= , < >	
	Type	Geometry of the feature	Point, Polyline, Polygon	
Area/Length		Length of polylines, perimeter and area of polygons	= , < >, >, > = , <, < = , Max, Min	Max, Min, Avg, SD, Var

maps. GRDM provides a tool for geo-referencing (cf. Dowman, 1999) base maps. Either an affine or a projective transformation can be used and the images can be rectified either using a ‘‘nearest-neighbor’’ or a ‘‘bilinear’’ method of interpolation. The images that can be inserted in GRDM include true-color or indexed color RGB images in Microsoft Windows BMP or in JPEG formats, and DEMs in BIL or ESRI ASCII formats. The elevation values in a DEM are classified into 256 classes and the pixels belonging to each class are rendered using one of the 256 different colors. A number of color schemes are available in GRDM.

3.2. Creation of map features as vectors

The position of a point or vertex can either be indicated with a graphic-pointing device or by specifying the geographic coordinates directly. The position of mouse-click is read in terms of the pixel coordinates of the viewport. They are first converted to the pixel coordinates of the canvas using the translation and scaling transformations for the current zoom and pan settings. In the next step the pixel coordinates are transformed to geographic coordinates utilizing the geo-referencing information of the loaded base maps. This spatial information is stored in the database using SQL commands.

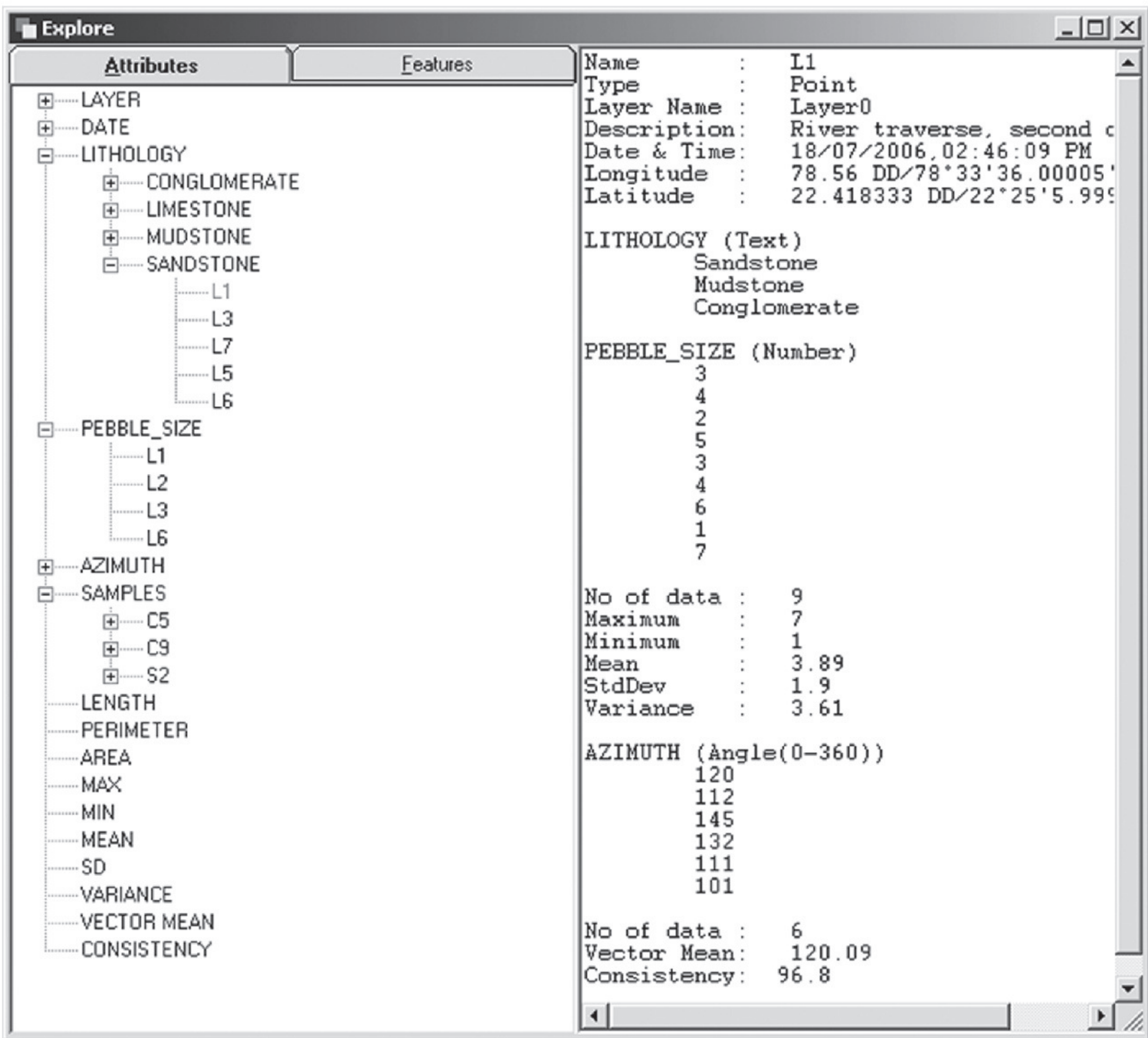

Fig. 5. EXPLORE interface used to retrieve both spatial and non-spatial data.

3.3. Attributes

As soon as the points or the polylines/polygons are created, GRDM automatically computes a set of system-generated attributes for them and then prompts the user for insertion of user-defined attributes.

3.3.1. System-generated attributes

The system-generated attributes comprise date and time of creation of the features, the geodesic length of the polylines, the perimeter and area of polygons. In GRDM locations are stored as a pair of longitude and latitude values (in decimal degrees). In order to determine the physical scale of the map that enables expressing the lengths and areas of the features in spatial units like meters, kilometers, miles, etc., these coordinates are transformed to local Cartesian coordinates considering the parameters of the WGS-1984 ellipsoid definition. The transformed coordinates are used for calculations of the lengths of the polylines and the area of the polygons using equations given in Rigaux et al. (2002), and Worboys and Duckham (2004), Bourke (1988).

3.3.2. User-defined attributes

When presented with the interface for inserting user-defined attributes (Fig. 4), the user can either create a new attribute or enter values to the existing user-defined attributes.

In the first case a new record is inserted in the ATTRIBUTE_NAME table using the following commands:

Insert into ATTRIBUTE_NAME
values Attribute_Name, Type_of_Attribute

The values for Type_of_Attribute can be text, number, angle (0–360), picture, memo, date, or time. All the user-defined attributes can store multiple values except for the case of the "memo" and "picture" type attributes. The tables to store the values for a particular attribute type are created as below:

Create table "Attribute_Name"
Feature_ID as Number
Attribute_Value as "Type_of_Attribute"

The values are inserted to the ATTRIBUTE table with commands similar to:

Insert into "Attribute_Name"
values *Feature*_ID, Attribute_Value

Though GRDM is capable of associating pictures (photographs or sketches) with the geographic features, these binary image data are not stored in database tables. Instead, the location of the image file in the computer hard disk is stored as text in ATTRIBUTE tables.

3.4. Retrieval of data

The information stored can be retrieved in two different ways. A non-spatial query retrieves the values for all the attributes attached to any particular map feature. On the other hand, a spatial query retrieves all the map features that contain a particular type of attribute or a particular attribute value. As attributes can store a list of values, any query in GRDM thus needs to specify if a particular search criterion pertains to an item in the list, or to any statistical property of that list. As attributes can have varying domains, the properties of the lists, the statistics and the constructions of relevant query expressions vary considerably (Table 2).

Fig. 5 shows the interfaces, called "Explore", that can be used for posing both non-spatial and spatial queries. It has two panels. In one, the names of all the map features are listed. The associated attribute values as well as their statistics can be viewed by selecting one of them. The other panel lists all the existing attributes. If an attribute type is selected, GRDM retrieves only those features that are associated with that particular attribute type. Again, for each attribute, a list of all the unique values is displayed. If a particular value of a specific attribute is selected then the program retrieves only

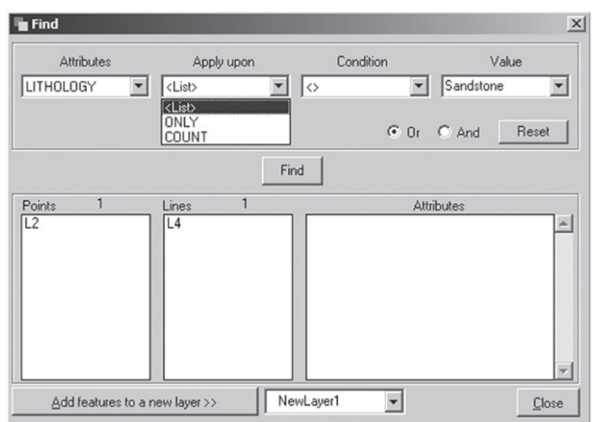

Fig. 6. FIND interface for posing advanced and combined queries.

Table 3
A sample data set used to generate the thematic map in Fig. 8

Type of features	Name	Lithology	Pebble_Size (cm)	Azimuth (degree)	Rock samples
Point	L1	Sandstone Mudstone Conglomerate	3, 4, 2, 5, 3, 4, 6, 1, 7	120, 112, 145, 132, 111, 101	
Point	L2	Conglomerate Limestone	1, 1.5, 3, 3, 1, 2.5	221, 219, 223, 217, 212	C5, S2
Point	L3	Conglomerate Sandstone	5, 2, 4, 7, 5, 3, 4, 6	189, 175, 178, 182, 186, 174	C9
Polyline	L4	Mudstone			
Polyline	L5	Sandstone		256, 252, 263, 269, 258	
Polygon	L6	Sandstone Mudstone Conglomerate	5, 4, 6.2, 3, 5.5, 6		
Polygon	L7	Sandstone		320, 322, 288, 275, 336, 338	

Table 4
The symbology types for the available themes, the number of classes and the geometric representation of the features

Symbology types	Relevant themes	Number of classes	Geometric representation of the features
Symbol size	For multiple values in lists: number of numeric or angular data	User defined or (Max. size of symbol —Min. size of symbol) +1, where the sizes (number of pixels) are positive integers	Points: Point symbol
	Number of unique text combinations		Polylines and polygons: Point symbols placed at the first vertex
	Maximum, minimum, mean, standard deviation and variance for numeric data types Consistency, mean angular deviation for angular data types For single-valued attributes: Numeric values, unique text values, dates, times, lengths, and areas		
Line thickness	- do -	User defined or Max. thickness of line— Min. thickness of line) +1, where the thicknesses (number of pixels) are positive integers	Polylines, perimeter of polygons
Symbol color	- do -	256	Points: Point symbol Polylines and polygons: Point symbols placed at the first vertex
Line color	- do -	256	Polylines, perimeter of polygons
Fill color	- do -	256	Polygons
Symbol orientation	Vector mean, axial vector mean	360	Points: Oriented point symbols Polylines and polygons: Oriented point symbols placed at the first vertex

those features that contain that particular value of that attribute.

A separate interface, FIND (Fig. 6), caters to more advanced and combined queries. For example, to locate and display the features where sandstone is absent (features named L2 and L4 in Table 3), the user can pose the question by setting Attribute to LITHOLOGY, Apply_Upon to LIST, Criteria to <> and Value to SANDSTONE. Again, the features where average pebble size is less than 3 cm can be retrieved by setting Attribute to Pebble_Size, Apply_Upon to Avg, Criterion to < and Value to 3. However, there may be queries the answers to which do not relate to any geographic feature in particular, e.g. the average value for the maximum pebble sizes for the entire map. The answer to this non-spatial query was returned as *Value* in the FIND interface when the Attribute was set to Pebble_Sizes, Apply_Upon to Max and Criterion to Avg.

3.5. Defining symbologies and generating thematic maps

The result of any spatial query generates a map for a single theme. To display more than one theme on a map, varying symbols, colors, etc. are used simultaneously. When an attribute takes up a single value per feature, the values are classified into a number of finite classes and displayed by distinct symbologies. In case of an attribute that takes multiple numeric values, its statistical parameters become relevant for the symbologies. The user can specify, to a limit, the number of classes into which the statistical values (e.g. mean pebble size at all locations) are to be grouped and how each class is to

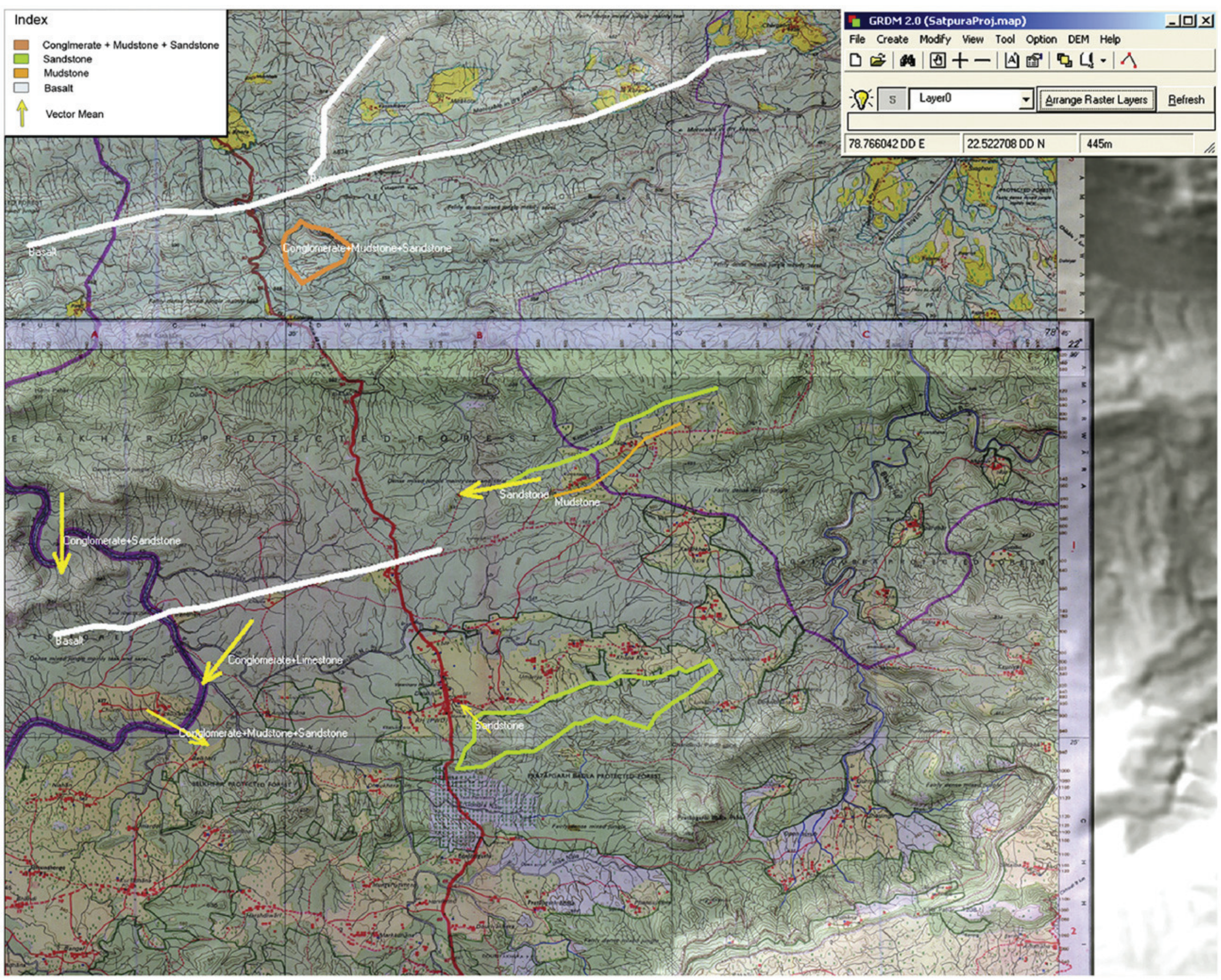

Fig. 7. A thematic map generated for sample data given in Table 3. Inset shows the index of symbols used.

be displayed in the thematic map by the variation of a symbol property. The properties that can be used are the color of the symbols or lines, size of the symbols, thickness of the lines and orientation of the symbols (Table 4). The number of classes available for classification of numeric attribute depends on the type of property used for symbology (see Table 4). If the range of numeric values falls short of the number of classes available, then fewer classes have to be used but the class widths are enlarged to accommodate for the entire available range for that particular symbology type.

In case of texts the set of all possible unique combinations of the text values for a particular attribute is classified. For example, say in locations a and b, the rock types observed are sandstone, mudstone and limestone and the location c has only sandstones and mudstones. Therefore, though some rock types are common for all the three locations, the rock assemblages of locations a, and b are similar and are distinct from that of location c.

Fig. 7 shows a thematic map for the data in Table 3, where the paleo-current vector means ("Azimuths: Vector Mean") at individual locations are represented by the orientations of the symbol (an arrow) and the consistency values ("Azimuths: Consistency") are represented by the size of the symbols that are colored according to their lithologic characteristics. The features are labeled by their lithologic assemblages ("LITHOLOGY: Unique Combinations"). The interface used for specifying symbologies for the thematic map is shown in Fig. 8.

3.6. Export of spatial and non-spatial data

GRDM can export the geometry of the features either as a text file, containing comma-separated coordinate pairs prefixed with an identification number, or as an ESRI Shapefile (see http://

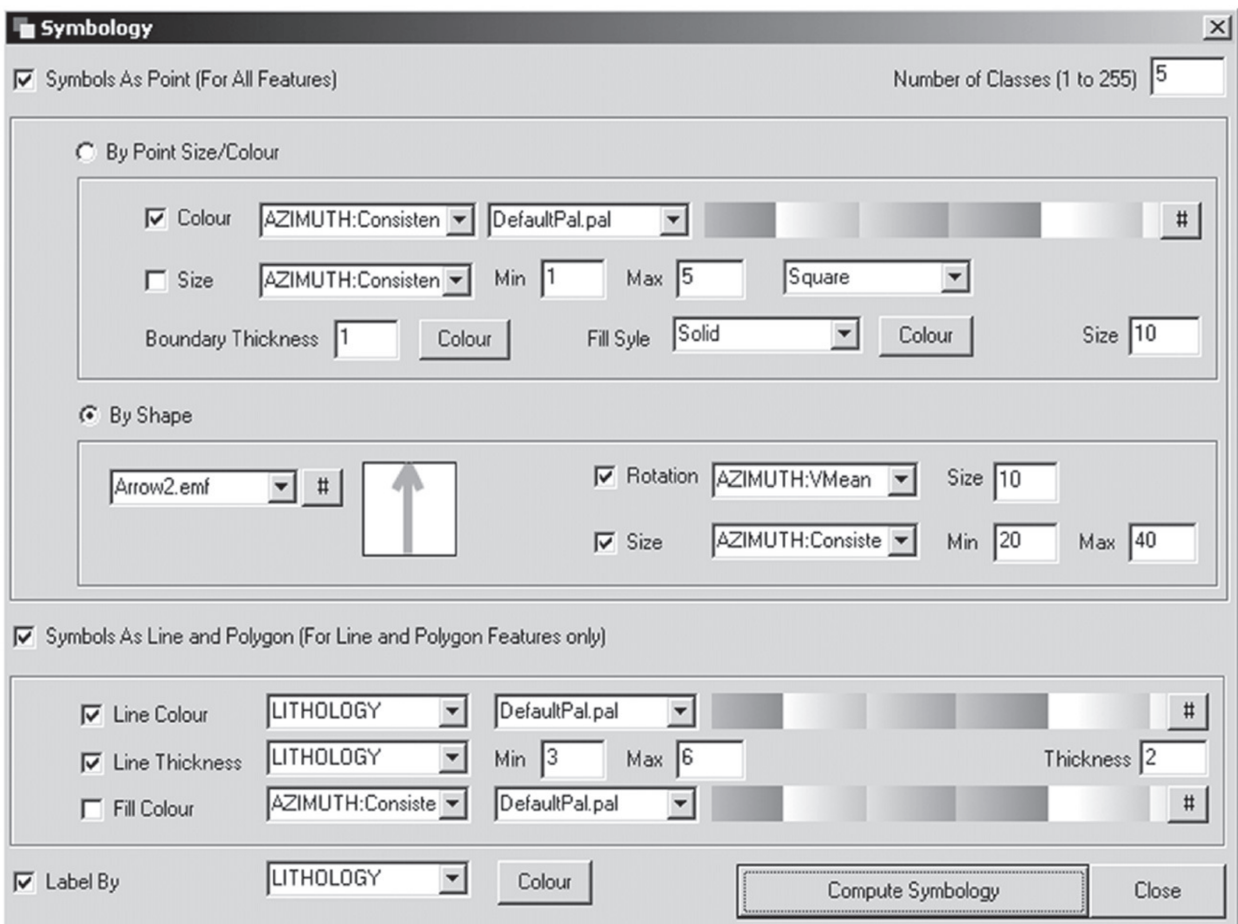

Fig. 8. SYMBOLOGY interface for defining symbologies for different themes.

arcscripts.esri.com/). The coordinates are expressed in decimal degrees with respect to WGS 1984 Spheroid.

The attribute data are written in a DBASE format file. GIS programs usually expect attribute values arranged in a vector against each feature identification number. Therefore, the entire attribute data, containing multiple values for any attribute, cannot be directly exported. For numeric and orientation type attributes, the average values and the unidirectional vector means are exported. For text type attributes, only the first entries of the individual lists are exported. In addition to the DBASE file, GRDM creates a text file (with DAT extension) where the entire list of values for the individual attributes are written against the identification numbers of the features. A number of rows are used per feature, if necessary (Table 5).

3.7. Import of spatial and non-spatial data

For both text and Shapefile formats, each file containing geometric data is imported to a new map layer of GRDM to avoid ambiguity in identification of the newly imported features. The system-generated attributes are computed and stored during the import process and a special numeric attribute is automatically generated that stores the serial numbers of the features imported (*Ref_ID*). GRDM does not automatically import the attribute data. They need to be imported separately at a later stage and then the *Ref_ID* is used to link the attributes with the features. The benefit of decoupling the processes of importing spatial and attribute data is that the features can acquire attribute data from multiple database files. In standard GIS software

Table 5
Contents of the text files exported by GRDM[a,b]

Spatial data (partial)	Non-spatial attribute data (multiple values).
File: ATT_PT.txt	**File: ATT_PT.dat**
1, 78.5600, 22.4183	ID, NAME, LITHOLOGY, PEBBLE_SIZE, AZIMUTH, SAMPLES
2, 78.5706, 22.4341	1, L1, Sandstone, 3, 120,
3, 78.5350, 22.4599	1, L1, Mudstone, 4, 112,
END	1, L1, Conglomerate, 2, 145,
	1, L1, , 5, 132,
	1, L1, , 3, 111,
	1, L1, , 4, 101,
	1, L1, , 6, ,
	1, L1, , 1, ,
	2, L2, Conglomerate, 1, 221, C5
	2, L2, Limestone, 1.5, 219, S2
	2, L2, , 3, 223,
	2, L2, , 3, 217,
	2, L2, , 1, 212,
	2, L2, , 2.5, ,
	3, L3, Conglomerate, 5, 189, C9
	3, L3, Sandstone, 5, 175,
	3, L3, , 5, 178,
	3, L3, , 7, 182,
	3, L3, , 5, 186,
	3, L3, , 3, 174,
	3, L3, , 4, ,
	3, L3, , 6, ,
File: ATT_LN.txt	**File: ATT_LN.dat**
1	ID, NAME, LITHOLOGY, PEBBLE_SIZE, AZIMUTH, SAMPLES
78.6412, 22.4679	1, L4, Mudstone, , ,
78.6487, 22.4702	2, L5, Sandstone, , 256,
…..	2, L5, , , 252,
END	2, L5, , , 263,
2	2, L5, , , 269,
78.6293, 22.4695	2, L5, , , 258,
78.6358, 22.4737	
……	
END	
END	
File: ATT_POL.txt	**File: ATT_POL.dat**
1	ID, NAME, LITHOLOGY, PEBBLE_SIZE, AZIMUTH, SAMPLES
78.6239, 22.4202	1, L6, Sandstone, 5, ,
78.6239, 22.4154	1, L6, Mudstone, 4, ,
…..	1, L6, Conglomerate, 6.2, ,
78.6256, 22.4212	1, L6, , 3, ,
78.6239, 22.4202	1, L6, , 5.5, ,
END	1, L6, , 6, ,
2	2, L7, Sandstone, , 320,
78.5825, 22.5233	2, L7, , , 322,
78.5833, 22.5181	2, L7, , , 288,
…..	2, L7, , , 275,
78.5833,22.5252	2, L7, , , 336,
78.5825,22.5233	2, L7, , , 338,
END	
END	

[a]Sample data set presented in Table 3.
[b]These files can be used to import spatial and non-spatial data to a new GRDM session.

this process is similar to joining newer tables to an existing attribute table. However, in GRDM if an attribute name in the table to be joined matches with an existing attribute name, instead of adding a new column to the record, the new value is appended to the existing list of that attribute. If the attribute values stored in text files (Table 5) are used, then it is possible to import the lists of values associated to the individual attributes too.

4. Discussion

A number of geologists have been using GRDM to record field data and to generate thematic maps at different stages of data collection. The maps of the sampling localities were produced for particular lithologic types as needed for a basin-wide petrographic study. They helped to decide future sample collection schemes. Paleoflow dispersal maps created from the vector means and consistency ratios of azimuth data aided interpretations of depositional environments and basin evolution (Chakraborty et al., 2003; Chakraborty and Ghosh, 2005). The individual workers exported their thematic information to a laboratory-based GIS to prepare an integrated geological map of the entire study area.

GRDM is flexible enough to be utilized by subjects other than geology for field data management. The source code and a set of sample data can be found in the IAMG web site. The executables for Microsoft Windows operating system may be obtained from the authors.

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