Global Structural Elements User Guide

Table of Contents

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1. Introduction

The Globe Structural Elements database consists of a comprehensive Present Day high resolution global structural and tectonic elements coverage. This not only provides the foundations for understanding the tectonic evolution of a given area but provides the structural framework and tectonic context for the various palaeogeographic reconstructions within Globe. Of particular importance, is that virtually all the elements within the database are mapped from primary data rather than a compilation of mapped elements from the public domain. Careful analysis of Getech's world leading global gravity and magnetic database, supplemented by additional remote sensing data sets and some seismic allows us to accurately map the location and kinematics of these features in high resolution. Publicly available literature is then used to enhance the database, in terms of providing information on the movement history and tectonic context of the individual elements. This integration of primary and public domain data has resulted in a comprehensive and fully attributed structural data set; providing the user with a complete understanding of the structural evolution of a basin, or area of interest, and the various controls this may have had on hydrocarbon prospectivity.

The 1:1 Million scale structural elements map was released in its most recent version in 2017. In 2020, a review and upgrade programme began and has continued into the Globe 2021 and 2022 builds. This upgrade is primarily focused on adding new attribution and, thus, user functionality, to the data set. Areas completed so far are North America, Africa, Europe and Arabia. In the North American and African regions, the structures have also undergone a deep review and in some cases reinterpretation. This has included the remapping of structures in key areas, a redefinition of the structural categories and more accurate and extensive activation histories. New attribution now allows users the option of displaying structures as a function of display scale or to group structures by shared geological history.

As the upgraded data set differs from the original (Globe 1:1M Structures) in its increased attribution and limited geographical coverage, it has not been incorporated into the palaeogeographic maps; it is instead presented as a separate data layer, named 'Enhanced Structural data set.'

2. Methodology

2.1. Literature Review

The initial stage of a structural interpretation entails a detailed review of all publicly available data, including available papers, geological maps, cross-sections and seismic lines. Maps and cross-sections are georeferenced within ArcGIS in order to accurately define features of interest. This process is informative and provides constraints on the timings of activity and the age of structures in addition to the overall tectonic evolution of an area.

2.2. The Qualitative Process

This phase is largely map-based and dominates the early stages of a study. The interpretation involves the analysis of a suite of enhancements and transforms generated from the gravity and magnetic data, the SRTM topography data and Landsat imagery, alongside a review of the available literature, cross-sections and geological maps. The resultant structural element map is the cornerstone of the interpretation. Qualitative interpretation involves recognition of:

- The nature of discrete anomalous bodies including intrusions, faults and lenticular intra-sedimentary bodies.
- Disruptive cross-cutting features such as strike-slip faults.
- Effects of mutual interference, e.g., the imposition of a new fault structural trend on a pre-existing basement fabric.
- Relative ages of intersecting faults.
- Structural styles, such as the nature of the deformation, dip direction of faults, plunge of folds etc.
- Tectonic features/events that link interpreted features.

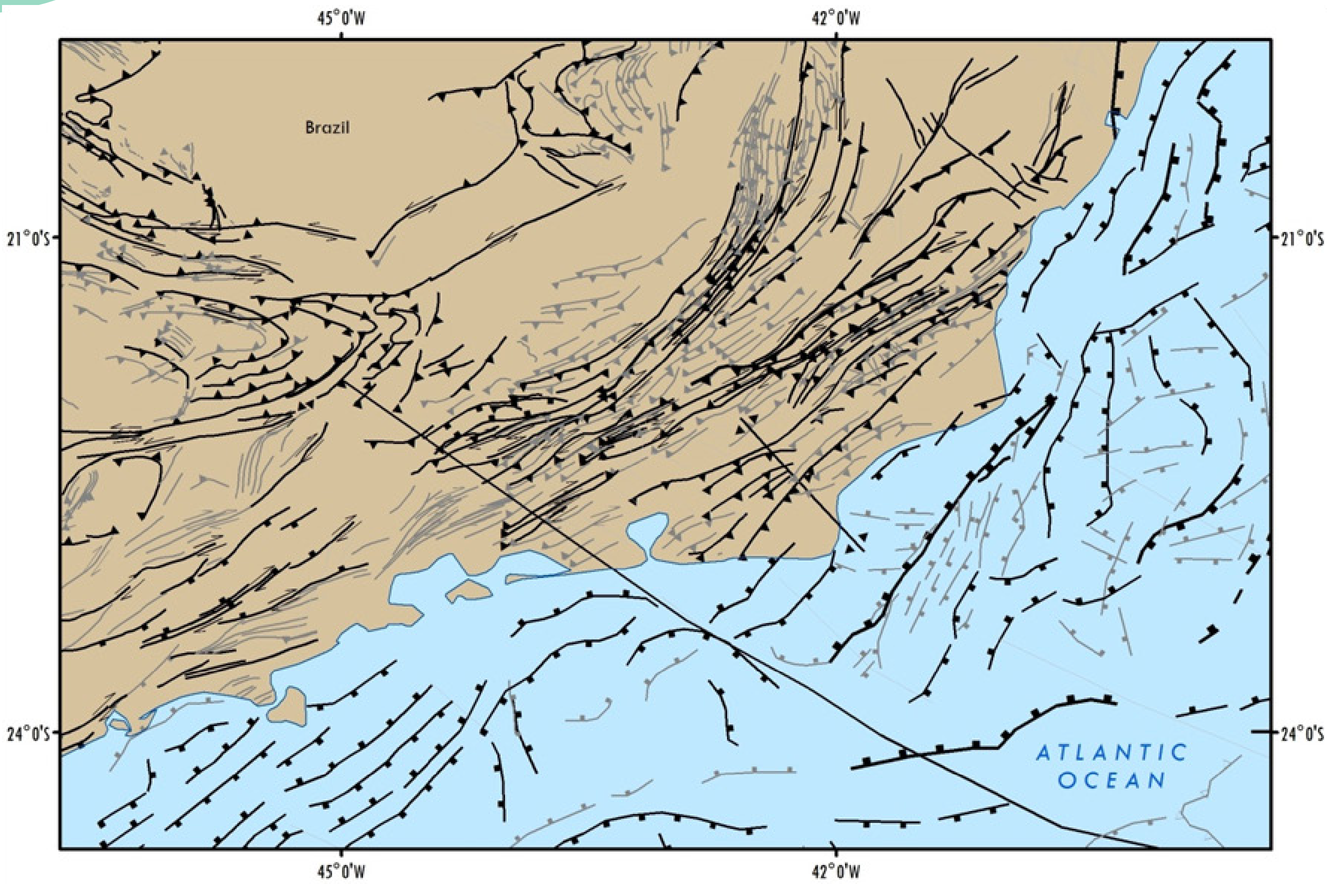
The most important element in the qualitative stage is the recognition of a network of discontinuities (i.e. faults) from the available data. Normal fault patterns produce distinct recognisable anomalies in the potential field data and are often truncated against strike-slip faults. Strike-slip faults and shear zones serve to compartmentalise and delimit discrete anomalies that at first sight may appear complex. Small and large-scale strike-slip faults/shear zones are common, particularly within old intra-continental crust that has experienced numerous tectonic regimes and fault reactivations. They provide the principal means by which major structures are truncated and crustal stress is decoupled (fully or partially) from one crustal block to another.

2.3. The Quantitative Process

The results of quantitative interpretation of gravity and magnetic data (e.g., basement depth estimates, 2D profile modelling and 3D inversions), and plate modelling are valuable constraints that are fed into the geological mapping phase. 2D profile models chosen across key transects provide and /or confirm information on the plate architecture. The results of the plate modelling in turn help refine the 2D profile models, which in turn may refine the geological mapping. Consequently, the final results are the product of an iterative process involving several technical disciplines.

2.4. The Structural Mapping Workflow

Structural mapping results provide the foundations for understanding the tectonic evolution of a given area, with results feeding back into the construction of the 2D profile models that are used to constrain crustal architecture and basin outlines. In turn, modelling validates the structural interpretation. Consequently, a rigorous workflow has been developed by Getech to improve confidence, remove uncertainty and make interpretation less affected by the individual experience of the mapper (bias). Onshore, the mapping is based on interpretation of Landsat, SRTM and other remote sensing data, calibrated against geological maps and published data, alongside analysis of potential field data. Published data are used to provide additional information on kinematics and history. For offshore areas, the primary data sources are gravity, magnetic and bathymetric data. Example data sets and mapping results are shown in Figures 2.1–2.4. The structural mapping workflow is shown in Figure 2.5.



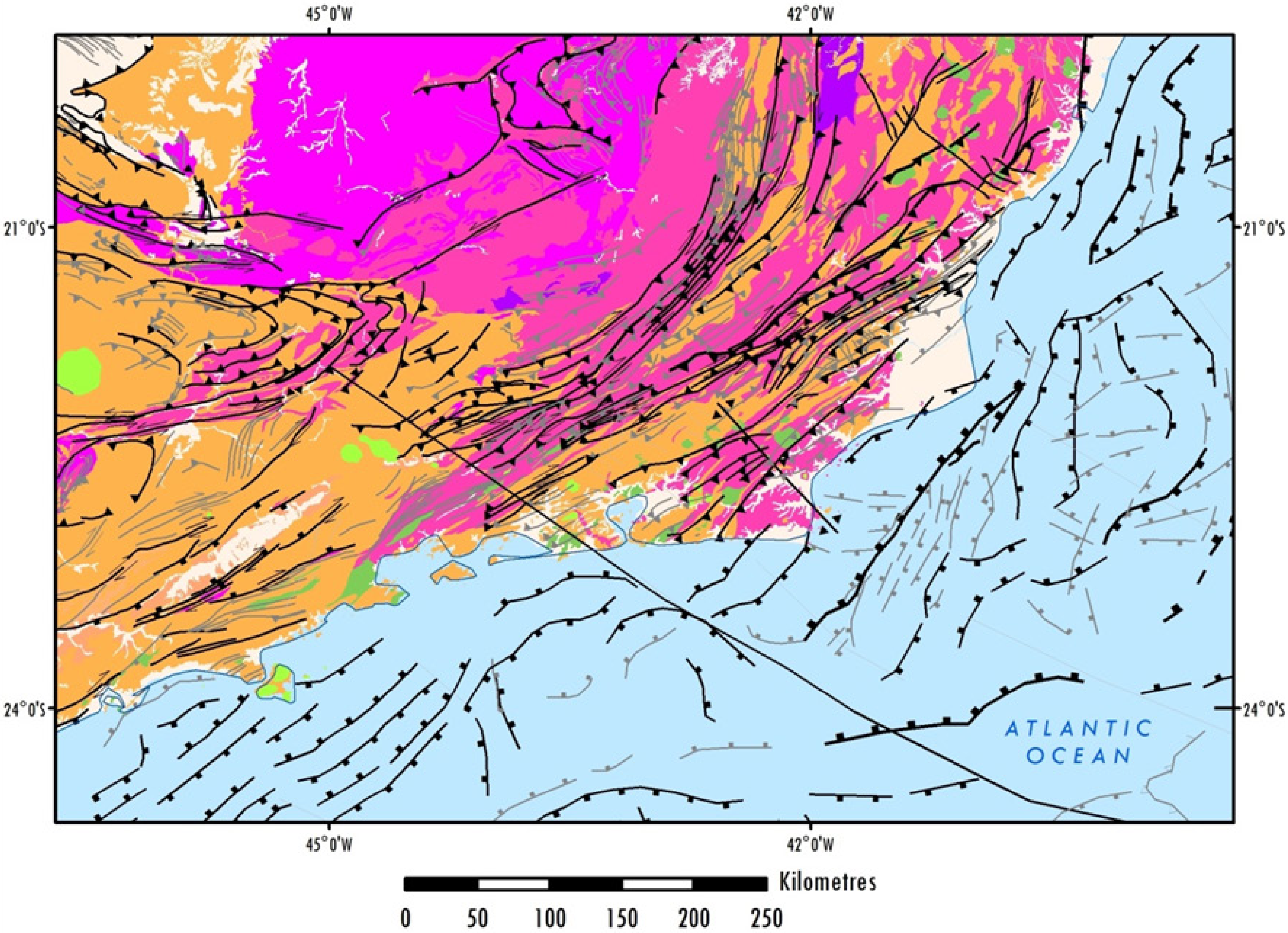


Figure 2.1: ***Examples of interpreted structures (top) and digital surface geology (bottom).***

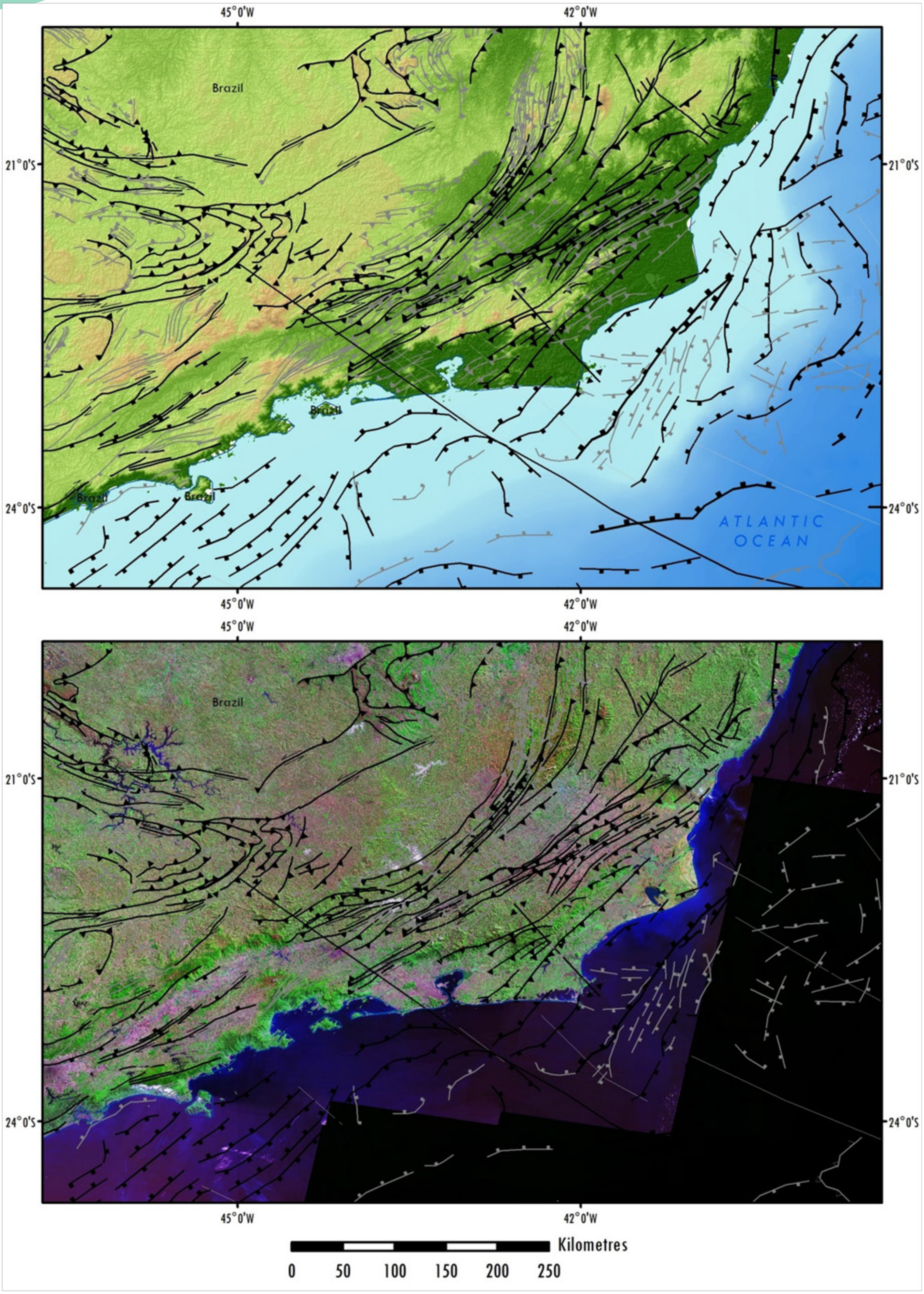


Figure 2.2: Examples of SRTM (top) and Landsat imagery (bottom) used in structural mapping.

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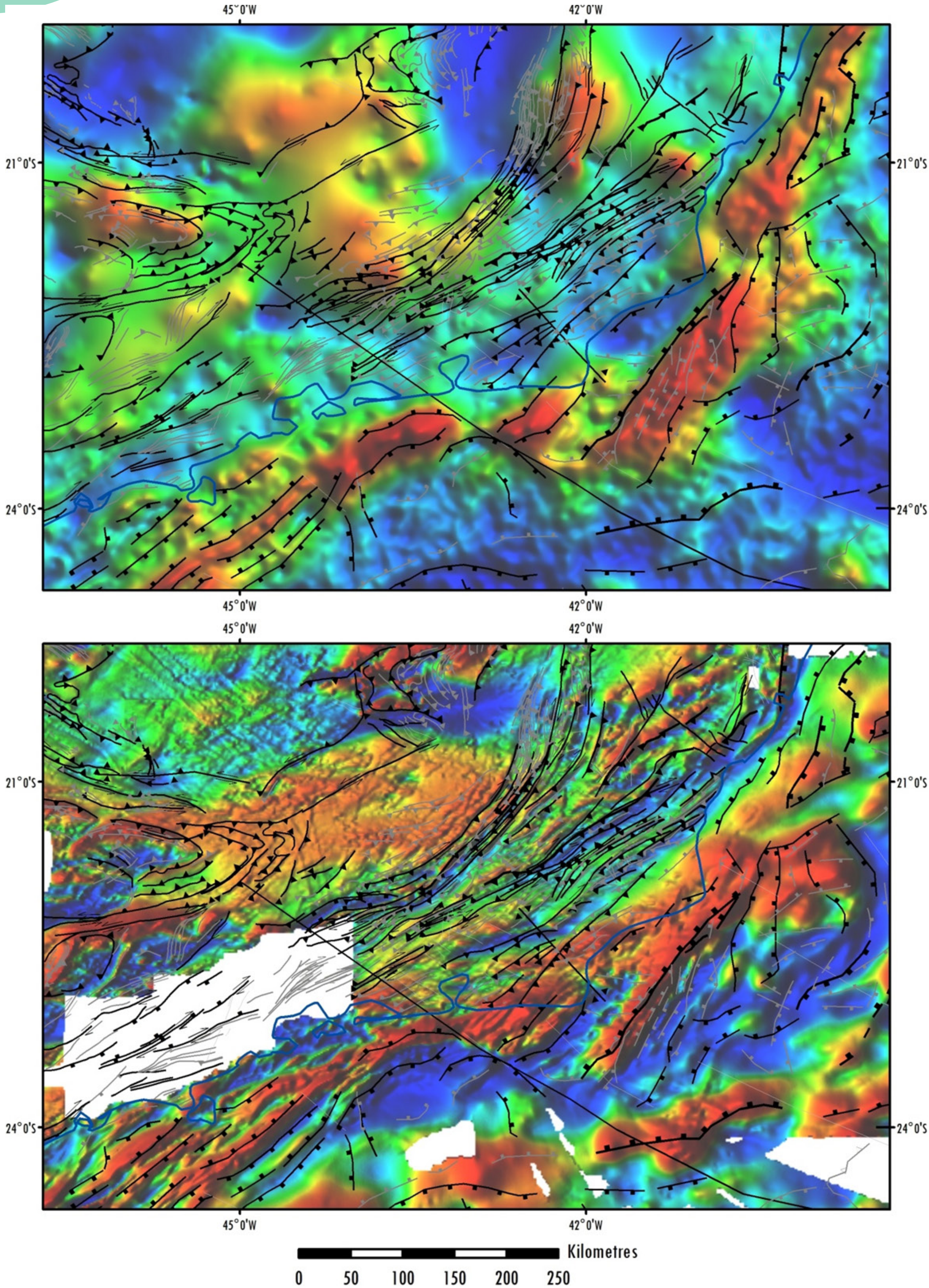

Figure 2.3: ***Examples of gravity data (top) and magnetic data (bottom) used in structural mapping.***

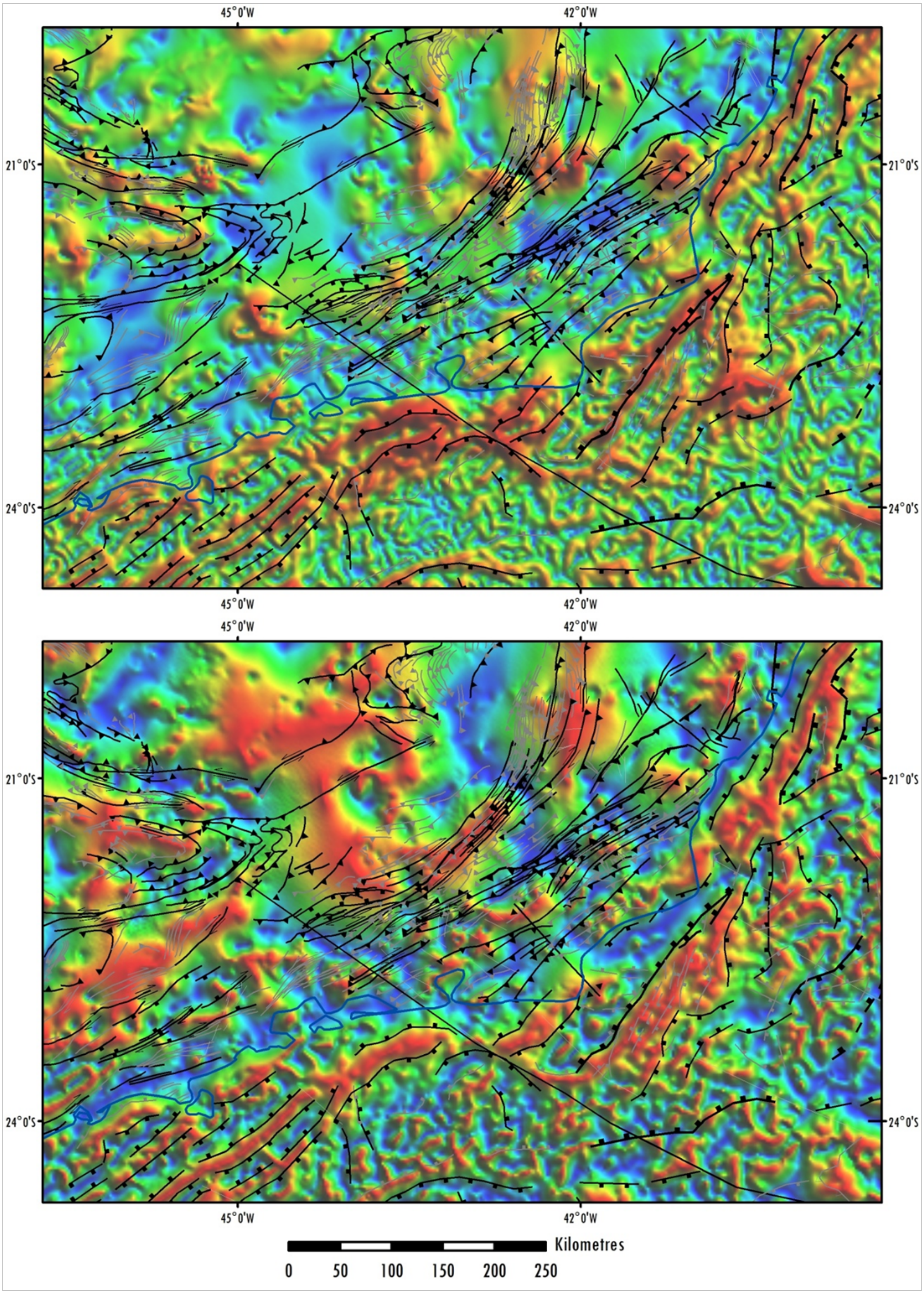

Figure 2.4: ***Examples of the Total Horizontal Derivative (top) and Tilt Derivative (bottom) of the isostatic residual gravity (ISO), used for edge detection.***

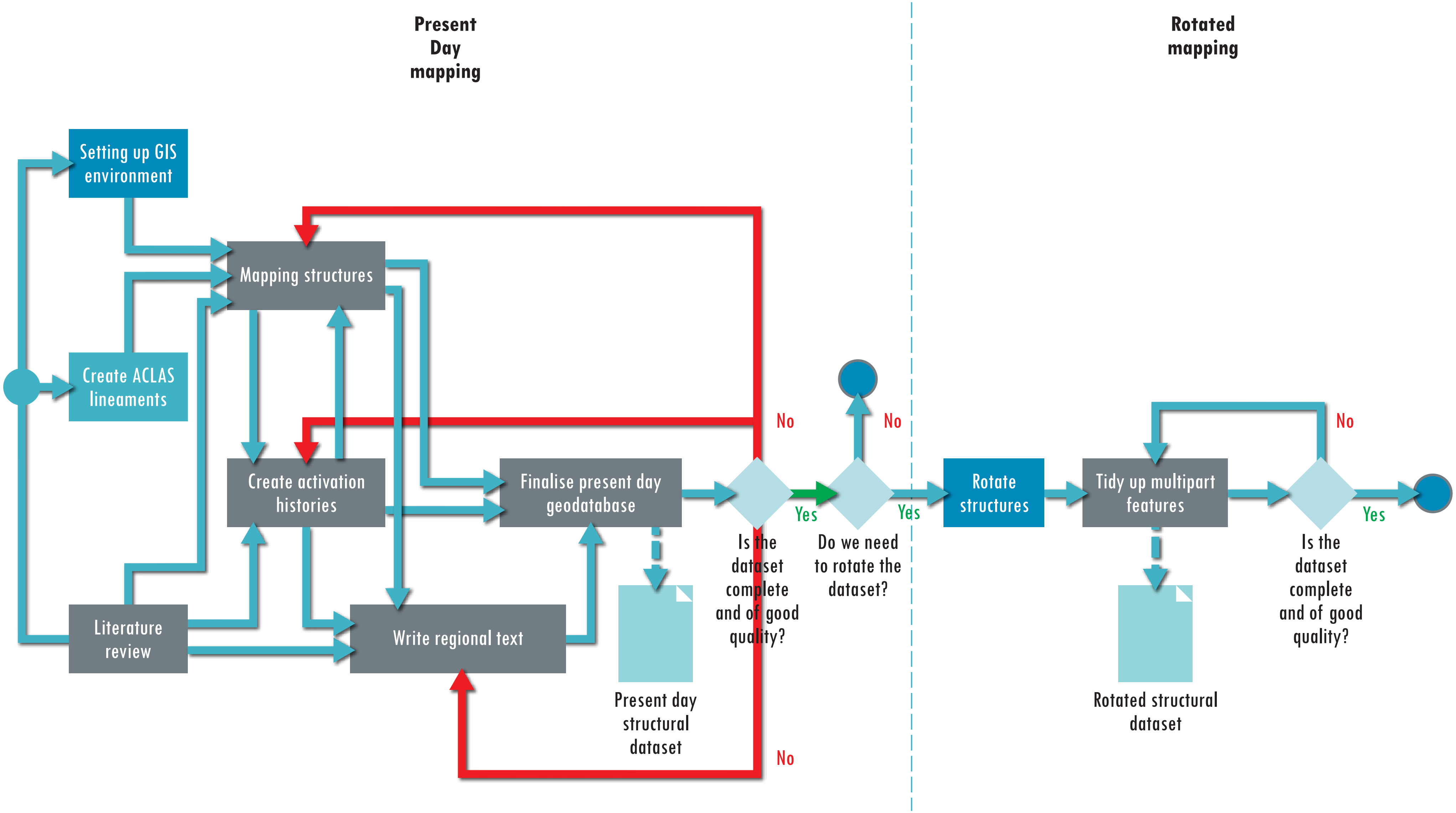

Figure 2.5: ***Workflow for Getech structural mapping.***

2.4.1. Structural Mapping Data Types

The mapping of structures is performed using a number of data types described in the first table. Of particular importance, Getech uses several edge detection methods in order to help identify the locations of discontinuities (faults) within the crust. The most important edge-detection derivatives applied to gravity and magnetic data are the Total Horizontal Derivative (THD), First Vertical Derivative (1VD) and Tilt Derivative.

Data		Interpretation
Topography/bathymetric data		In offshore areas we use the General Bathymetric chart of the Oceans (GEBCO) data from the British Oceanographic Data Centre. Onshore, we use the Shuttle Radar Topography Mission (SRTM-3) data, which provides a near-global digital elevation model from 56°S to 60°N. Topographic and bathymetric relief highlight active and inactive faults and other structures such as folds.
Landsat 7 imagery		Landsat Enhanced Thematic Mapper Plus (ETM+) images record radiation from the Earth's surface in bands of the electro-magnetic spectrum. The most commonly used Landsat bands at Getech are 7, 4 and 2, which are commonly considered to be the most useful bands for geological interpretation of Landsat data. Problems can include cloud cover and vegetation. Structures can be highlighted by abrupt truncations of landforms, texture and band response.
Digital geology		Includes both country data (usually high resolution) and AGI global geology data (lower resolution). Geological boundaries are often defined by faults.
Seismicity		Seismicity data are from from the USGS Global Earthquakes database. Areas of seismicity highlight tectonically active areas and may also give information on the thickness of the crust, if the earthquakes occur at depth.
Gravity Data		The gravity method determines the sub-surface spatial distribution of the rock density, ρ, which causes small changes in the Earth's gravitational field strength.
	BAFA	Bouguer anomaly onshore, free air gravity offshore. The Free Air Anomaly is corrected for height above sea level on land. Over the ocean, the Free Air Anomaly is limited to the correction applied for latitude. Useful for highlighting 'edge effects'.
	BABA	Bouguer anomaly onshore and offshore. In addition to the Free Air Correction, the Bouguer Anomaly includes the Bouguer Correction, correcting for mass between the measuring site and the height datum. This removes the effects of topography/bathymetry.
	ISO	Isostatic residual gravity correction removes the effect of the position of the Moho, therefore focusing on the gravity response from the crust.
Magnetic Data		The magnetics method determines the sub-surface spatial distribution of rock magnetisation properties, J, (or susceptibility and remanence) which causes small changes in the Earth's magnetic field strength and direction.
	TMI	Total magnetic intensity, after the removal of a IGRF regional correction
	DRTP	Differential Reduction to Pole transforms the TMI field to that which would be seen at poles, where the inclination is 90 degrees. This generally centres the anomalies over their causative bodies, allowing more accurate mapping of geological features.
Gravity and Magnetic Derivatives		Various derivatives, filters and band-pass filters are applied to potential field data in order to enhance aspects of the data for interpretation.
	1VD	This enhancement sharpens the anomaly locations over causative bodies (hopefully aiding the mapping of structures), and can be used alongside the THD to infer the dip direction of normal faults, for example.
	THD	The maxima of the total horizontal gradient indicates the locations of lateral density variations, normally assumed to be the locations of faults or discontinuities.
	Tilt Derivative	The zero contours of the Tilt Derivative aid the mapping of edge features. Another advantage is the normalisation of the signal range – i.e., amplifying weak anomalies and suppressing strong signals. This allows for easier identification of potential subtle trends and geological fabrics.
	Wavelength filtering	Various low-pass, high-pass and band-pass filters are used for regional/residual separation based upon the spectral content of the signal.
Wells and outcrops datapoints		Information from the wells and outcrops database help constrain horizon and thickness maps, 2D profile modelling and assigning activation histories to structures.

2.4.2. Structural Mapping Attribution

2.4.2.1. Structures

Structural mapping results are attributed within ArcGIS with information including, geography, kinematics of the mapped feature, timings of activation and source information. The structures are also individually linked to an Activation History Table that details the specific activation history of the structure, including its initiation, periods of activity, and periods of quiescence.

2.4.2.2. Structural Attribute Table

Each structure has an accompanying table of attributes that details the geography, structure type/kinematics, activation history, mapping and other information relating to each structure. This information is detailed below.

2.4.2.3. Geography

Detailing the location of the structure:

Field Heading	Structure ID	Country	Basin Name	Feature Name	Alternative Names	Association
Description	Unique identifier linking this feature table and activation history table.	Country in which the feature resides.	Name of the Getech sedimentary basin in which the feature resides.	Name of the specific mapped feature.	A list of commonly used alternative names for the feature.	The association with which the feature is linked.
Example	926	*Iraq*	*Mesopotamian Basin*	*Bofan-Baghdad Fault*	*Tikrit Amara Fault*	*Nadj Fault System*

2.4.2.4. Structure Type/Kinematics

Detailing the nature of the structure during its latest phase of activity:

Field Heading	Category	SID	CSID	Legend Description
Description	Coded from A and D, assigning geological significance to the feature. A. Trans-regional and basin defining. e.g., basin-bounding faults. B. Major basin-scale, cutting basement. e.g., define sub-basins C. Minor basin-scale. e.g., cutting sedimentary pile D. Lineaments of unknown kinematics.	The symbol ID code for each line type in the feature class.	A concatenation of 'Category' and 'SID'.	Getech description of the feature relating to the SID/CSID.
Example	C	1500	C1500	*Active Antiform/Anticline, Certain*

2.4.2.5. Timings

From the Activation History Table (see below), detailing the first and last activities of the structure:

Field Heading	First Appearance	First Appearance (Ma)	Last Activity	Last Activity (Ma)	Dating Reliability
Description	The given age quoted for the first appearance of the feature.	The age in Ma of the first appearance of the feature, based on an absolute age, or the age in Ma corresponding to the base of the stratigraphic age unit quoted (using Cohen et al., 2013)	The given age quoted for the first appearance of the feature.	The age in Ma of the last activity of the feature, based on an absolute age, or the age in Ma corresponding to the top of the stratigraphic age unit quoted (using Cohen et al., 2013)	Derived from the 'Age Confidence' field of the Activation History Table: I. Absolute age II. Magnetostratigraphy III. Biostratigraphy, seismic control IV. Geological Inference V. Secondary Information G. Estimated
Example	*Lower Miocene (Aquitanian)*	23.03	*Holocene*	0	*II - Magnetostratigraphy.*

2.4.2.6. Source/Mapping Information

Detailing the source of the information relating to the structure, how the structure was interpreted, the confidence of the structure, and the scale at which it was interpreted:

Field Heading	Outcrop or Subcrop	Data Source	Explanation	References	Mapping Confidence	Compilation Scale
Description	Whether the structure is forming any topographic or bathymetric relief.	List of primary data sources used to map the feature, e.g., gravity, magnetics, radar, landsat, bathymetry, topography, seismicity, geological map, literature, fieldwork, seismic data.	Information explaining how the feature was defined (source of the interpretation).	List of references that refer to the feature or were used in its interpre-tation.	A value between 1 and 5 providing a qualitative assessment of the confidence of the mapper in the mapped feature as recorded: 1. Revision and testing required. Feature taken from publication with no primary data sources. 2. Changes expected. Features identified from primary data with no defined kinematics. 3. Changes probable. Features identified from primary data with kinematic information 4.. Features identified from primary data with significant supporting information. 5. Features interpreted from high resolution data constrained by multiple significant sources and our own observations such as fieldwork or seismic.	The approximate scale at which the feature was captured. Values are: 10,000,000; 5,000,000; 1,000,000; 750,000, 500,000, 250,000, 100,000, 50,000, 10,000.
Example	Outcrop	*Landsat; Geological Map*	*Getech Interpretation: Landsat checked against and modified from geological map of Uys & Enslin (1970)*	*Tikku et al. (2002); Leinweber & Jokat (2011).*	*3*	*1,000,000*

2.4.2.7. Other Information

Field Heading	Notes	Compiler
Description	Any relevant geological information or comments relating to the explanation.	The interpreter's name and date of interpretation.
Example	*Anticlines of the Zagros Fold and Thrust Belt.*	*BSGF (May 2014)*

2.4.3. Activation History Table

Where applicable, interpreted features are created with a corresponding Activation History that details the kinematics, timing, tectonic information and source information of the phases of activity/quiescence of the structure. Specified ages of deformation are obtained from reference data (e.g., published papers), geological inference (e.g., relationship to other structures of known age) and the plate model, which can also give information concerning the activity of selected features. The information held within the Activation History Table is detailed below:

2.4.3.1. Kinematics

Detailing the kinematics of each phase of activity/inactivity of the structure:

Field Heading	Structure ID	Fault Category	SID	CSID	Legend Description
Description	Unique identifier for the feature, linking the structural feature attribute table and the activation table.	Coded from A and D, assigning geological significance to the feature. A. Trans-regional and basin defining. e.g., basin-bounding faults. B. Major basin-scale, cutting basement. e.g., define sub-basins. C. Minor basin-scale. e.g., cutting sedimentary pile. D. Lineaments of unknown kinematics.	The symbol ID code for each line type in the feature class.	A concatenation of 'Category' and 'SID'.	Getech description of the feature relating to the SID/CSID.
Example	*241*	*B*	*1135*	*B1135*	*Active left-lateral transpressional fault, certain.*
	241	*B*	*1100*	*B1100*	*Active normal fault, certain*
	241	*B*	*3100*	*B3100*	*Inactive normal fault, certain*
	241	*B*	*1136*	*B1136*	*Active right-lateral transpressional fault, certain*

2.4.3.2. Timings

Detailing the phases of activity/inactivity of the structure:

Field Heading	Start Age	Start Age (Ma)	End Age	End Age (Ma)
Description	The given age quoted for the start of a period of activity or inactivity of the feature.	The age in Ma of the first appearance of the feature, based on an absolute age, or the age in Ma corresponding to the base of the stratigraphic age unit quoted (using Cohen et al., 2013)	The given age quoted for the end of a period of activity or inactivity of the feature.	The age in Ma of the last activity of the feature, based on an absolute age, or the age in Ma corresponding to the top of the stratigraphic age unit quoted (using Cohen et al., 2013)
Example	*Cryogenian*	680	*Cryogenian*	640
	Cryogenian	640	*Lower Cambrian (Fortunian)*	530
	Lower Cambrian (Fortunian)	530	*Upper Oligocene (Chattian)*	23.03
	Lower Miocene (Aquitanian)	23.03	*Holocene*	0

2.4.3.3. Tectonic Information

Detailing information on the tectonic regime during periods of activity:

Field Heading	Tectonic Regime	Tectonic Notes	Notes
Description	Gives the overall tectonic setting of the structures.	Description of the regional setting e.g., NE-SW extension propagating from the opening of the South Atlantic.	Geological information or comments on notes
Example	*Transpression*	*Transpression during the Nabitah Orogeny associated with deep ductile deformation, resulting in the rise of gneissic domes.*	*Associated with thrust faulting.*
	Extension	*Associated dykes and volcano-sedimentary basins, related to crustal thinning due to destacking of the Nabitah Orogeny.*	*Associated with volcanism.*
	Inactive	*Inactive.*	—
	Compression	*Development of the Zagros Fold and Thrust Belt.*	—

2.4.3.4. Source/Mapping Information

Detailing the sources of information relating to the structure and the dating reliability:

Field Heading	Dating Reliability	Activation Explanation	References	Compiler
Description	Derived from the 'Age Confidence' field of the Activation History Table: I. Absolute age II. Magnetostratigraphy III. Biostratigraphy, seismic control IV. Geological Inference V. Secondary Information G. Estimated	Information detailing how timings, kinematics etc were defined for each period of activity/inactivity of each structure.	List of references that refer to the activity of the feature or were used in its interpretation.	The interpreter's name and date of interpretation
Example	*IV - Geological Inference*	*Geological Inference, checked against plate model.*	*Mouthereau et al., 2011; de Vera et al., 2009*	*DAS (Feb 2014)*
	II - Magnetostratigraphy	*Seismicity and GPS.*	*Mouthereau et al., 2011; de Vera et al., 2009*	*DAS (Feb 2014)*

2.5. Enhanced Structural Data Set

For the Enhanced Structural data set, it is now possible to display the structures as a function of display scale and the option to group structures by their shared geological history. The Enhanced Structures have also undergone a deep review of structural categories, with both more accurate, extensive activation histories and a full reinterpretation of key areas (e.g. Appalachian and Rocky Mountains).

To provide a sense of the scale of tectonics, a new attribute field has been added to the Enhanced Structural data set which identifies the structure's shared geological history; these are defined as megafamilies or families. This allows the user to have a clearer understanding of the regional tectonic events and, furthermore, it allows the user to view the structures which are grouped by their shared activation history. Megafamilies are defined as groups of structures which have been activated due to major orogenic or tectonic plate scale processes. Families are defined as the smaller-scale terrane and/or basin forming scale events; these may form part of a larger-scale orogen.

The ability to display different structures using the display scale attribute when viewing the map at different scales, will allow the user to get a clear overview of the main features without overcomplicating the map. The user can choose which subset(s) of structures to display at any given time to best aid their understanding or image/map generation activities. Definition queries are the most efficient way to apply the display scale. There are four differing numbers in the 'display scale' field, which indicate scale:

- 1:1M - for viewing small-scale intrabasinal features (local structures)
- 1:5M - for viewing intrabasinal features (country-scale)
- 1:15M - for viewing basin boundaries (continent-scale)
- 1:40M - for viewing plate boundaries (global scale).

Please note that this is for viewing scale only and does not affect the compilation scale.

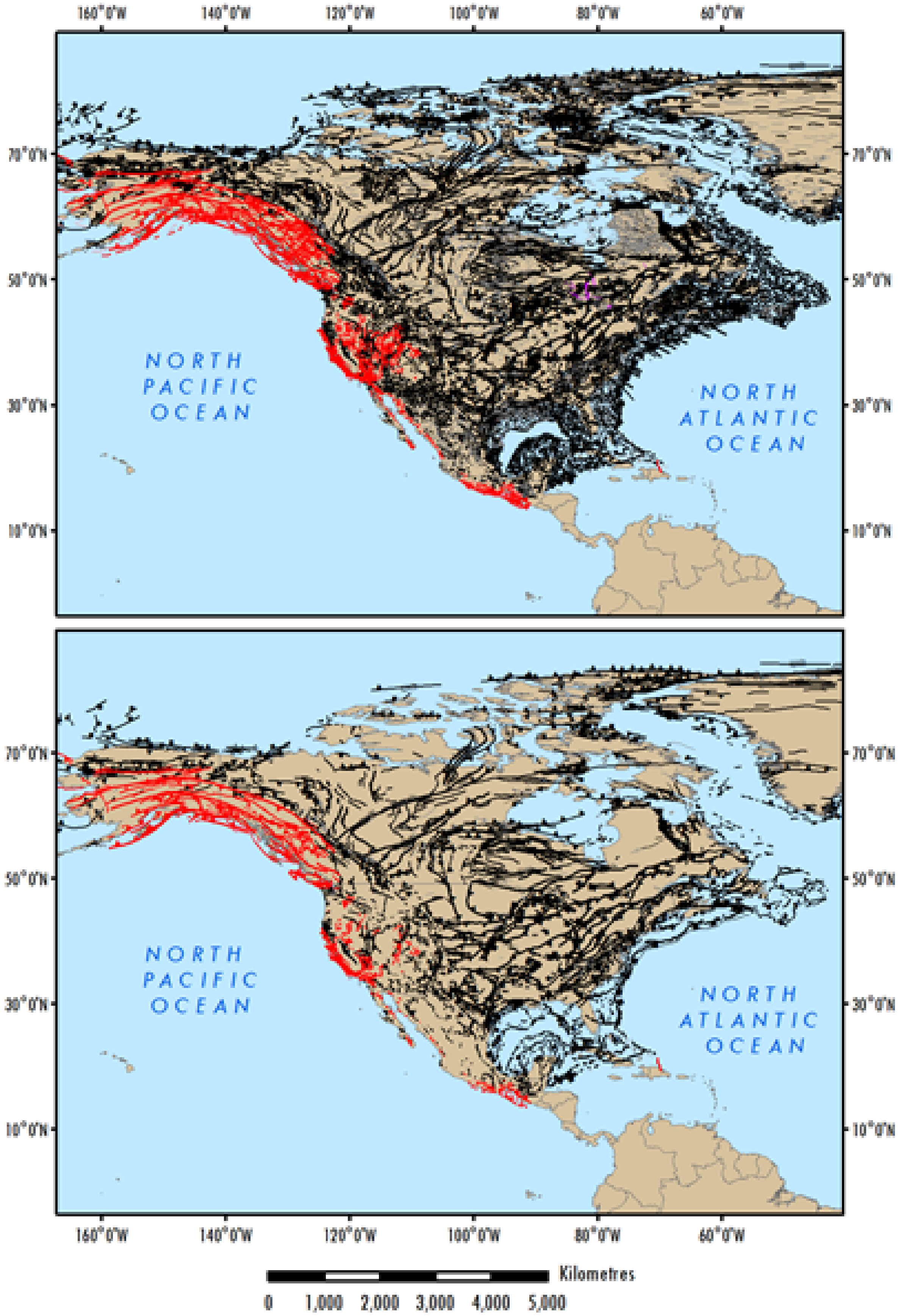

Figure 2.6: ***The structural data set with the display scale set at 1:15M (top) and with the display scale at 1:40M (bottom). Both images are shown at a scale of 1:8M.***

3. References

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