

Geological Magazine, Palaeogeography in Exploration, Paul Markwick.

Supplementary Material

# A Standard Legend for Palaeogeography (Version 1)

Paul J. Markwick

*Knowing Earth Limited, U.K*

*School of Earth and Environment, University of Leeds*

*School of Geographical Sciences, University of Bristol*

E-Mail: [paul.markwick@knowing.earth](mailto:paul.markwick@knowing.earth)

# Contents

Contents .....	2
S1. Introduction .....	3
S2. Formats and attribution.....	3
S3. Structural and tectonic elements.....	4
S3.a. Class .....	4
S3.b. Activity.....	4
S3.c. Defined or inferred?.....	4
S3.d. Tectonic elements.....	6
S3.e. Normal and reverse faults.....	7
S3.f. Strike-slip faults .....	8
S3.g. Transpressional and transtensional faults .....	9
S3.h. Undifferentiated folds.....	10
S3.i. Anticlines and antiforms .....	11
S3.j. Synclines and synforms.....	12
S3.k. Inverted and over-turned folds .....	13
S3.l. Lineaments, bedding and foliations.....	14
S4. Sedimentary and geomorphological features.....	15
S5. Crustal type .....	16
S5.a. Oceanic crustal types .....	17
S5.b. Transitional crustal types.....	17
S5.c. Stretched (attenuated) continental crustal types.....	18
S5.d. Unstretched continental crustal types .....	18
S5.e. Additive continental crustal types.....	19
S5.f. Crustal processes.....	19
S6. Geodynamics (thermo-mechanical history).....	20
S7. Depositional Environments .....	22
S7.a. Terrestrial depositional environments.....	23
S7.b. Coastal depositional environments.....	25
S7.c. Marine depositional environments.....	27
S8. Lithologies.....	28
S8.a. Clastics.....	29
S8.b. Carbonates .....	30
S8.c. Interbedded units and non-deposition.....	31
S8.d. Oozes.....	32
S8.e. Chemical lithologies .....	33
S8.f. Igneous and Igneous-related.....	34
S8.g. Metamorphic .....	36
S9. References cited .....	37

## S1. Introduction

This supplementary material comprises the (Knowing Earth) *Standard Legend for Palaeogeography (Version 1)* which is used throughout the accompanying paper to help visualise the representation of each stage of the palaeogeographic mapping workflow. This legend is provided in full as a resource to the geoscience community in order to facilitate communication and collaboration. The aim is that through the workflow and mapping legend this paper will help promote a standard approach to palaeogeographic mapping and encourage the greater application of palaeogeography in Academia and Industry.

Some text has been extracted from the main paper and added to this supplemental material where needed to ensure that the legend can be used as a standalone document. Citation should be to the main paper.

This legend (Version 1) is also available digitally as an ESRI ArcGIS style file that can be downloaded from the Knowing Earth website ([www.knowing.earth](http://www.knowing.earth)) and [www.palaeogeography.net](http://www.palaeogeography.net).

## S2. Formats and attribution

Each database used in the palaeogeography workflow comprises an extensive attribution that provides an audit trail for each feature, semi-quantitative assessment of confidence and referencing. This follows the methodologies outlined in Ziegler *et al.*, (1985), Markwick and Lupia (2001), Markwick (1996).

A symbol code is used to link the feature in each database to the relevant symbol. This comprises a text field of 6 characters in the GIS attribute table. The name of this field is not set; in ArcGIS (ESRI, 2017), the user will be asked what field contains the symbol code. This is the code that is shown above or next to each symbol in this document. Each symbol code comprises a letter(s) that indicates the type of feature, as follows: S, structural and tectonic element; TP, transport direction; GM, geomorphological feature; C, crustal type; T, thermo-mechanical state; E, depositional environment; L, lithology; IG, igneous feature. This is followed by a numerical code: for structural and tectonic elements, except lineaments, bedding and foliation, the first number will be the class of structure; for the thermo-mechanical state, the last digit relates to the age range for that feature relative to the map age (see Fig. S18). At the end of the code, there may be a qualifier as to the state of that feature. For structural and tectonic elements this qualifier comprises the following: A, active; Ai, active inferred; I, inactive; Ii, inactive inferred. For lithologies this qualifier relates to whether the lithology represents the following: o, outcrop; s, subcrop; i, inferred.

## S3. Structural and tectonic elements

The map representation of structural and tectonic elements is relatively standard around the world. Here the legend largely follows that of the USGS, with modifications where there are no corresponding symbols or to avoid confusion. Colours and symbol weights are used to differentiate feature class, activity and mapping confidence. These are explained below.

### S3.a. Class

In this legend, structural and tectonic features are classified according to their influence on the crust and stratigraphy using different line weighting for each. This is through what is referred to here as ‘classes’ of features and has been done in order to facilitate clarity on the maps when high densities of features are presented (Fig. S1).

- **Class 1** – ‘crustal scale’ - features cut through the crust and (may) offset the base of the crust, e.g. major shear zones and sutures
- **Class 2** – ‘basement scale’ - features cut into the basement (upper levels of crust). Includes thick-skinned tectonics, e.g. thrusts in the anticlinal stack of the Pyrenean Axial Zone or rift bounding faults, major basin bounding faults
- **Class 3** – ‘local basement scale’ - features cut into lithified stratigraphy, above regional basement (usually the Precambrian). This includes thin-skinned tectonic features, e.g. thrusts defining allochthonous thrust sheets in the central Pyrenees.
- **Class 4** – ‘sedimentary scale’ - features that cut the sedimentary pile only, e.g. toe thrusts in pro-deltas such as the Niger Delta.

There is a separate code for lineaments, which are not divided by class. Lineaments are defined as linear features identified in the Earth, but where both the kinematics and nature are unknown.

### S3.b. Activity

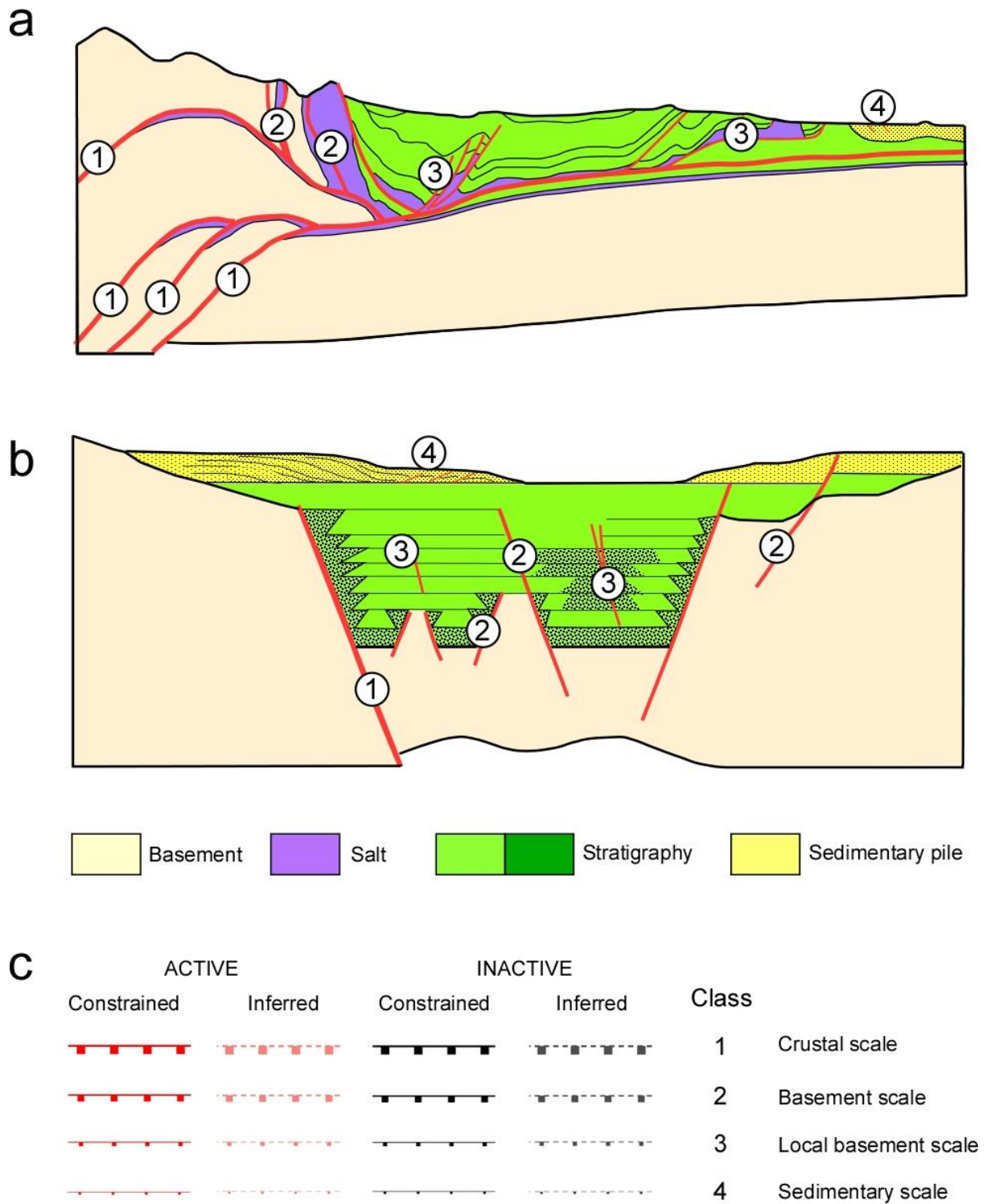
Tectonic and structural elements are attributed as ‘**active**’ or ‘**inactive**’ depending on whether there is evidence of displacement or deformation at the time of the map on which they are displayed (Fig. S1.). The default in the author’s own databases is the activity at the present day, constrained by seismicity or published evidence of motion. This is then linked to an activation history table, which records the kinematic evolution through time. The convention adopted here is to show active faults in red and inactive faults in black.

### S3.c. Defined or inferred?

The underlying database includes a field for whether the field is ‘Defined’ or ‘Inferred’ (Fig. S1). This is shown symbolically using colour shading and a dashed line for ‘inferred’ versions of features:

- ‘**Defined**’ – features that are based on a signal in primary data. This can include Landsat imagery, where the structural nature is clear-cut (folded bedding, fault with offsets or scarp), seismic sections, satellite gravity data, high-resolution station-based gravity and aeromagnetic data (where the interpretation is unequivocal); features supported by observational data and/or evidence of motion (GPS, seismicity).
- ‘**Inferred**’ – features that are required to exist to satisfy a model, but for which there is no clear evidence from any input dataset; features for which there is some evidence, but where that the input data is either of poor resolution or relationship is unclear (e.g. low-resolution gravity data onshore)







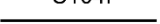

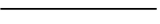







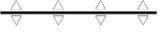
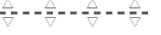


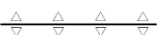
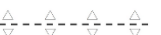
The ‘confidence’ in the position and interpretation is dealt with in the associated database attribution.



**Figure S1.** Structures are classified according to their effect on the crust (class). This is designed to provide graphical depth and facilitate queries of the underlying database. (a) Examples of each class of structural feature in a typical compressional system. (b) Examples of each class in an extensional system. (c) An example of the attribution of structural features (normal faults in this case but applies to all kinematic types) to reflect activity at the time of the map and mapping confidence. ‘Defined’: evidence from at least one primary source. ‘Inferred’: required by the kinematics of the area, but not clearly seen in the data. Line weighting is used to differentiate the fault class, which is a visual representation of the scale effect of each feature on the crust.

### S3.d. Tectonic elements

Comprise crustal-scale features that define plate boundaries or crustal-scale folds (commonly referred to in the literature as ‘arches’) (Fig. S2.).

SYMBOL				CLASS	DESCRIPTION
ACTIVE		INACTIVE			
Defined	Inferred	Defined	Inferred		
				1	Spreading Ridge
				1	Transform Fault
				1	Fracture Zone (Major)
				1	Fracture Zone (Minor)
				1	Subduction Zone
				1	Basement Arch
				2	Basement Arch

**Figure S2.** Tectonic symbols with their associated symbol codes used in the structural elements databases.

### S3.e. Normal and reverse faults









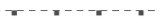














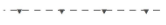




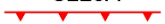

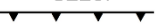
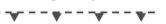

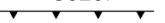



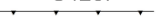
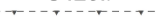
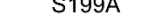
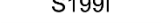
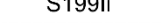
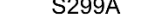
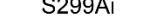
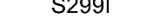
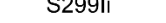
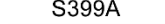
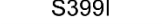
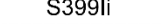
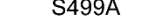
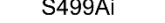
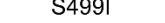
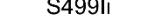
SYMBOL				CLASS	DESCRIPTION
ACTIVE		INACTIVE			
Defined	Inferred	Defined	Inferred		
S110A 	S110Ai 	S110I 	S110Ii 	1	Normal fault
S210A 	S210Ai 	S210I 	S210Ii 	2	Normal fault
S310A 	S310Ai 	S310I 	S310Ii 	3	Normal fault
S410A 	S410Ai 	S410I 	S410Ii 	4	Normal fault
S120A 	S120Ai 	S120I 	S120Ii 	1	Reverse fault
S220A 	S220Ai 	S220I 	S220Ii 	2	Reverse fault
S320A 	S320Ai 	S320I 	S320Ii 	3	Reverse fault
S420A 	S420Ai 	S420I 	S420Ii 	4	Reverse fault
S125A 	S125Ai 	S125I 	S125Ii 	1	Thrust fault
S225A 	S225Ai 	S225I 	S225Ii 	2	Thrust fault
S325A 	S325Ai 	S325I 	S325Ii 	3	Thrust fault
S425A 	S425Ai 	S425I 	S425Ii 	4	Thrust fault
S199A 	S199Ai 	S199I 	S199Ii 	1	Fault undifferentiated
S299A 	S299Ai 	S299I 	S299Ii 	2	Fault undifferentiated
S399A 	S399Ai 	S399I 	S399Ii 	3	Fault undifferentiated
S499A 	S499Ai 	S499I 	S499Ii 	4	Fault undifferentiated

Figure S3. Normal and reverse fault symbols with their associated symbol codes used in the structural elements databases.

### S3.f. Strike-slip faults

SYMBOL				CLASS	DESCRIPTION
ACTIVE		INACTIVE			
Defined	Inferred	Defined	Inferred		
S130A	S130Ai	S130I	S130Ii	1	Strike-slip fault, undiff.
S230A	S230Ai	S230I	S230Ii	2	Strike-slip fault, undiff.
S330A	S330Ai	S330I	S330Ii	3	Strike-slip fault, undiff.
S430A	S430Ai	S430I	S430Ii	4	Strike-slip fault, undiff.
S140A	S140Ai	S140I	S140Ii	1	Dextral strike-slip fault
S240A	S240Ai	S240I	S240Ii	2	Dextral strike-slip fault
S340A	S340Ai	S340I	S340Ii	3	Dextral strike-slip fault
S440A	S440Ai	S440I	S440Ii	4	Dextral strike-slip fault
S145A	S145Ai	S145I	S145Ii	1	Sinistral strike-slip fault
S245A	S245Ai	S245I	S245Ii	2	Sinistral strike-slip fault
S345A	S345Ai	S345I	S345Ii	3	Sinistral strike-slip fault
S445A	S445Ai	S445I	S445Ii	4	Sinistral strike-slip fault

**Figure S4.** Strike-slip fault symbols with their associated symbol codes used in the structural elements databases. The undifferentiated strike-slip line graphic is the same as that for an undifferentiated fault, but the code is different.



### S3.g. Transpressional and transtensional faults

SYMBOL				CLASS	DESCRIPTION
ACTIVE		INACTIVE			
Defined	Inferred	Defined	Inferred		
S150A	S150Ai	S150I	S150Ii	1	Dextral transtensional fault
S250A	S250Ai	S250I	S250Ii	2	Dextral transtensional fault
S350A	S350Ai	S350I	S350Ii	3	Dextral transtensional fault
S450A	S450Ai	S450I	S450Ii	4	Dextral transtensional fault
S155A	S155Ai	S155I	S155Ii	1	Sinistral transtensional fault
S255A	S255Ai	S255I	S255Ii	2	Sinistral transtensional fault
S355A	S355Ai	S355I	S355Ii	3	Sinistral transtensional fault
S455A	S455Ai	S455I	S455Ii	4	Sinistral transtensional fault
S160A	S160Ai	S160I	S160Ii	1	Dextral transpressional fault
S260A	S260Ai	S260I	S260Ii	2	Dextral transpressional fault
S360A	S360Ai	S360I	S360Ii	3	Dextral transpressional fault
S460A	S460Ai	S460I	S460Ii	4	Dextral transpressional fault
S165A	S165Ai	S165I	S165Ii	1	Sinistral transpressional fault
S265A	S265Ai	S265I	S265Ii	2	Sinistral transpressional fault
S365A	S365Ai	S365I	S365Ii	3	Sinistral transpressional fault
S465A	S465Ai	S465I	S465Ii	4	Sinistral transpressional fault

Figure S5. Transtensional and transpressional fault symbols with their associated symbol codes used in the structural elements databases.

### S3.h. Undifferentiated folds

SYMBOL				CLASS	DESCRIPTION
ACTIVE		INACTIVE			
Defined	Inferred	Defined	Inferred		
S177A 	S177Ai 	S177I 	S177Ii 	1	Fold undiff.
S277A 	S277Ai 	S277I 	S277Ii 	2	Fold undiff.
S377A 	S377Ai 	S377I 	S377Ii 	3	Fold undiff.
S477A 	S477Ai 	S477I 	S477Ii 	4	Fold undiff.
S175A 	S175Ai 	S175I 	S175Ii 	1	Plunging fold undiff.
S275A 	S275Ai 	S275I 	S275Ii 	2	Plunging fold undiff.
S375A 	S375Ai 	S375I 	S375Ii 	3	Plunging fold undiff.
S475A 	S475Ai 	S475I 	S475Ii 	4	Plunging fold undiff.
S179A 	S179Ai 	S179I 	S179Ii 	1	Double plunging fold undiff.
S279A 	S279Ai 	S279I 	S279Ii 	2	Double plunging fold undiff.
S379A 	S379Ai 	S379I 	S379Ii 	3	Double plunging fold undiff.
S479A 	S479Ai 	S479I 	S479Ii 	4	Double plunging fold undiff.









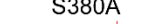
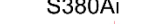
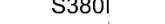
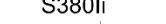
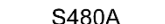
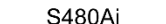
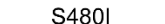
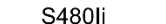




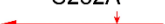
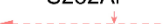
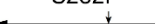
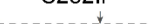
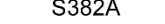
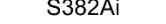
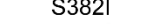
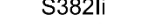
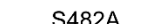
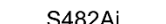
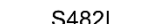
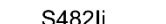





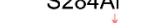
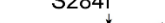
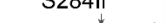
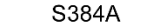
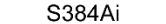
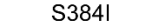
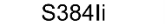
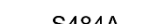

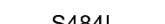
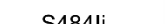
**Figure S6.** Undifferentiated fold symbols with their associated symbol codes used in the structural elements databases. This is especially useful for interpretations based on remote sensing data, such as Landsat, where the age relationships of the beds are not known, and the bedding dip direction is unclear.

### S3.i. Anticlines and antiforms

SYMBOL				CLASS	DESCRIPTION
ACTIVE		INACTIVE			
Defined	Inferred	Defined	Inferred		
				1	Antiform / Anticline
				2	Antiform / Anticline
				3	Antiform / Anticline
				4	Antiform / Anticline
				1	Plunging Antiform / Anticline
				2	Plunging Antiform / Anticline
				3	Plunging Antiform / Anticline
				4	Plunging Antiform / Anticline
				1	Pericline
				2	Pericline
				3	Pericline
				4	Pericline

**Figure S7.** Fold symbols with their associated symbol codes for anticlines and antiforms used in the structural elements databases.

### S3.j. Synclines and synforms

SYMBOL				CLASS	DESCRIPTION
ACTIVE		INACTIVE			
Defined	Inferred	Defined	Inferred		
				1	Synform / Syncline
S180A	S180Ai	S180I	S180Ii		
				2	Synform / Syncline
S280A	S280Ai	S280I	S280Ii		
				3	Synform / Syncline
S380A	S380Ai	S380I	S380Ii		
				4	Synform / Syncline
S480A	S480Ai	S480I	S480Ii		
				1	Plunging Synform / Syncline
S182A	S182Ai	S182I	S182Ii		
				2	Plunging Synform / Syncline
S282A	S282Ai	S282I	S282Ii		
				3	Plunging Synform / Syncline
S382A	S382Ai	S382I	S382Ii		
				4	Plunging Synform / Syncline
S482A	S482Ai	S482I	S482Ii		
				1	Basin
S184A	S184Ai	S184I	S184Ii		
				2	Basin
S284A	S284Ai	S284I	S284Ii		
				3	Basin
S384A	S384Ai	S384I	S384Ii		
				4	Basin
S484A	S484Ai	S484I	S484Ii		

**Figure S8.** Fold symbols with their associated symbol codes, for synclines and synforms used in the structural elements databases.

### S3.k. Inverted and over-turned folds

SYMBOL				CLASS	DESCRIPTION
ACTIVE		INACTIVE			
Defined	Inferred	Defined	Inferred		
S176A 	S176Ai 	S176I 	S176Ii 	1	Inverted anticline
S276A 	S276Ai 	S276I 	S276Ii 	2	Inverted anticline
S376A 	S376Ai 	S376I 	S376Ii 	3	Inverted anticline
S476A 	S476Ai 	S476I 	S476Ii 	4	Inverted anticline
S186A 	S186Ai 	S186I 	S186Ii 	1	Inverted syncline
S286A 	S286Ai 	S286I 	S286Ii 	2	Inverted syncline
S386A 	S386Ai 	S386I 	S386Ii 	3	Inverted syncline
S486A 	S486Ai 	S486I 	S486Ii 	4	Inverted syncline
S178A 	S178Ai 	S178I 	S178Ii 	1	Overtuned anticline
S278A 	S278Ai 	S278I 	S278Ii 	2	Overtuned anticline
S378A 	S378Ai 	S378I 	S378Ii 	3	Overtuned anticline
S478A 	S478Ai 	S478I 	S478Ii 	4	Overtuned anticline
S188A 	S188Ai 	S188I 	S188Ii 	1	Overtuned syncline
S288A 	S288Ai 	S288I 	S288Ii 	2	Overtuned syncline
S388A 	S388Ai 	S388I 	S388Ii 	3	Overtuned syncline
S488A 	S488Ai 	S488I 	S488Ii 	4	Overtuned syncline

**Figure S9.** Fold symbols with their associated symbol codes for overtuned and inverted folds used in the structural elements databases.



























### S3.1. Lineaments, bedding and foliations

SYMBOL	DESCRIPTION
S9000	Lineament undifferentiated
S9100	Bedding
S9200	Foliation

**Figure S10.** Line symbols with their associated symbol codes for lineaments, bedding and foliations used in the structural elements databases.

## S4. Sedimentary and geomorphological features

The current symbols in this category comprise features that either describe transport direction or the status of the palaeo-shoreline.

SYMBOL		DESCRIPTION
Defined	Inferred	
TP110 	TP110i 	Submarine transport direction
TP120 	TP120i 	Water transport direction
TP130 	TP130i 	Wind transport direction
TP140 	TP140i 	Ice transport direction
GM500 	GM500i 	Submarine canyon
GM600 	GM600i 	River
GM650 	GM650i 	palaeo-River
GM100 	GM100i 	palaeo-Shoreline
GM120 	GM120i 	palaeo-Shoreline, maximum transgression
GM130 	GM130i 	palaeo-Shoreline, maximum regression
GM610 	GM610i 	River trend
GM660 	GM660i 	palaeo-River trend
GM670 	GM670i 	palaeo-Drainage divide (white dash line on maps, replaced with dashed red line when background is white )

**Figure S11.** Line symbols with their associated symbol codes, for sedimentary and geomorphological features used in (palaeo)drainage analysis and palaeogeographic mapping.


## S5. Crustal type

The crustal type databases are divided into those representing observational and process-based classifications. Although definitions of ‘true’ or ‘normal’ ocean crust (Fig. S12), and ‘normal’, unstretched continental crust (Fig. S15), are largely uncontroversial, the ‘real-estate’ that lies in between is more problematic. The scheme presented here differentiates between ‘stretched (attenuated) continental crust’ (Fig. S14) and a zone of ‘transitional’ crust (Fig. S13), the latter including a variety of sub-types and which encompasses the zone formerly referred to as the Continent-Ocean Boundary (COB), but which is now recognized as a ‘transitional’ zone rather than a distinct boundary. A category for the thickened continental crust (Fig. S16) has been added that includes crust thickened due to continent-continent (e.g. Alps, Himalayas, Tibetan Plateau) and continent-ocean (e.g. continental arcs) collisions.

The classification of process-based crustal types (Fig. S17) follows that of Péron-Pinvidic and Manatschal (Manatschal, 2012; Péron-Pinvidic and Manatschal, 2010).

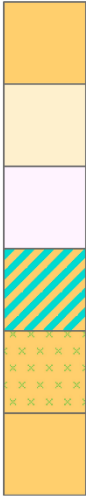


### S5.a. Oceanic crustal types

SYMBOL		DESCRIPTION
C9000		Ocean crust, undiff.
C9010		'Normal' oceanic crust
C9020		Thickened oceanic crust




**Figure S12.** Fill colours with their associated symbol codes, for differentiating oceanic crustal types, used in building the crustal architecture databases that underpin the palaeogeographic mapping.

### S5.b. Transitional crustal types

SYMBOL		DESCRIPTION
C9200		Transitional crust, undiff.
C9210		'Hyper-extended' crust
C9220		Allochthonous continental crust
C9230		Mixed crust
C9240		Magma-rich (intruded) crust
C9250		Magma-poor crust




**Figure S13.** Fill colours with their associated symbol codes, for differentiating 'transitional' crustal types, used in building the crustal architecture databases that underpin the palaeogeographic mapping.

### S5.c. Stretched (attenuated) continental crustal types

SYMBOL		DESCRIPTION
C9400		Stretched continent crust, undiff.
C9410		Volcanic
C9420		Non-volcanic

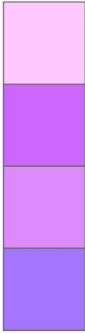
**Figure S14.** Fill colours and symbols, with their associated symbol codes, for differentiating ‘stretched’ (attenuated) crustal types used in building the crustal architecture databases that underpin the palaeogeographic mapping.

### S5.d. Unstretched continental crustal types

SYMBOL		DESCRIPTION
C9600		Unstretched continent crust, undiff.
C9610		Craton
C9620		Mobile belts

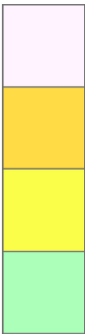
**Figure S15.** Fill colours with their associated symbol codes for differentiating ‘unstretched’ continental crustal types, which are used in building the crustal architecture databases that underpin the palaeogeographic mapping.

### S5.e. Additive continental crustal types

SYMBOL		DESCRIPTION
C9800		Additive continent crust, undiff.
C9810		Continental volcanic arc
C9820		Accretionary complex
C9820		Collisional

**Figure S16.** Fill colours with their associated symbol codes for differentiating ‘additive’ continental crustal types (those for which crust has been added to generate thickened crust), which are used in building the crustal architecture databases that underpin the palaeogeographic mapping.


### S5.f. Crustal processes

SYMBOL		DESCRIPTION
C9910		Proximal (stretching)
C9920		Necking (thinning)
C9930		Distal (hyper-extension)
C9940		Outer (exhumation-oceanization)

**Figure S17.** Fill colours with their associated symbol codes for differentiating crustal processes using the definitions presented in Péron-Pinvidic and Manatschal (Manatschal, 2012; Péron-Pinvidic and Manatschal, 2010).

## S6. Geodynamics (thermo-mechanical history)

Crustal type dictates first-order heat flow and elevation, but the key for palaeogeographic reconstruction is how geodynamics then acts on this crust. This process is represented by mapping the age and nature of the last thermo-mechanical event with respect to the palaeogeographic timeslice being reconstructed. This method was first discussed in Markwick and Valdes as *tectonophysiology* (Markwick and Valdes, 2004) with regards to defining areas above contemporary base-level and therefore areas of net erosion (sediment source areas in source-to-sink analysis). The age of the last thermo-mechanical event was added to better represent the decay of landscapes (Campanile *et al.*, 2007; Pazzaglia, 2003; Tucker and Slingerland, 1994; Van der Beek and Braun, 1998; Whipple and Meade, 2004) following the ideas presented in the 1997 USGS thermo-tectonic age map of the world that was used to model heat-flow following Pollack *et al.*, (1993) and crustal thickness and structure (Mooney, Laske and Masters, 1998). An updated scheme for tectonophysiological terrains was then presented by Markwick and co-workers in several presentations (Galsworthy *et al.*, 2011; Markwick, Wilson and Lefterov, 2008; Markwick, 2011; Markwick, Galsworthy and Raynham, 2015; Raddadi, Markwick and Hill, 2010). The latest version is shown in Figure S18.

SYMBOL		DESCRIPTION								
T1000		Anorogenic land <i>no thermo-mechanical event</i> <i>&lt;300myr before the mapped timeslice</i>								
<b>DOMINANTLY HORIZONTAL STRESS FIELD</b>										
0.01	5	10	25	50	75	100	150	200	300	myr prior to timeslice
T2000	T2001	T2002	T2003	T2004	T2005	T2006	T2007	T2008	T2009	Compression, undiff.
T2100	T2101	T2102	T2103	T2104	T2105	T2106	T2107	T2108	T2109	Continent-continent, undiff.
T2110	T2111	T2112	T2113	T2114	T2115	T2116	T2117	T2118	T2119	Continent-continent, thick-skinned
T2120	T2121	T2122	T2123	T2124	T2125	T2126	T2127	T2128	T2129	Continent-continent, thin-skinned
T2200	T2201	T2202	T2203	T2204	T2205	T2206	T2207	T2208	T2209	Continent-ocean, undiff.
T2210	T2211	T2212	T2213	T2214	T2215	T2216	T2217	T2218	T2219	Continent-ocean, thick-skinned
T2220	T2221	T2222	T2223	T2224	T2225	T2226	T2227	T2228	T2229	Continent-ocean, thin-skinned
T2300	T2301	T2302	T2303	T2304	T2305	T2306	T2307	T2308	T2309	Ocean-ocean, undiff.
0.01	5	10	25	50	75	100	150	200	300	myr prior to timeslice
T3000	T3001	T3002	T3003	T3004	T3005	T3006	T3007	T3008	T3009	Extension, undiff.
<b>DOMINANTLY VERTICAL STRESS FIELD</b>										
0.01	5	10	25	50	75	100	150	200	300	myr prior to timeslice
T5000	T5001	T5002	T5003	T5004	T5005	T5006	T5007	T5008	T5009	Vertical, undiff.
T6000	T6001	T6002	T6003	T6004	T6005	T6006	T6007	T6008	T6009	Flexure, undiff.
T6500	T6501	T6502	T6503	T6504	T6505	T6506	T6507	T6508	T6509	Isostatic, undiff.
T7000	T7001	T7002	T7003	T7004	T7005	T7006	T7007	T7008	T7009	Volcanic, undiff.
T8000	T8001	T8002	T8003	T8004	T8005	T8006	T8007	T8008	T8009	Mantle, undiff.

**Figure S18.** Fill colours and patterns with their associated symbol codes for differentiating the thermo-mechanical state of the crust, which is used to define the dynamics of the landscapes reconstructed as part of the palaeogeographic mapping.










## S7. Depositional Environments

The mapped depositional environment in this workflow represents the full extent of each environment at the time of the palaeogeography. This extent represents areas below contemporary base-level and potentially able to accumulate sediments (Markwick and Valdes, 2004), but will also include areas with no deposition due to by-passing. Base-level and depositional environments can vary rapidly in time and space, especially in tectonically active areas, and this must be considered. Strictly speaking, depositional environment maps are distinct from a facies map, the latter representing the products of deposition (the rock record). A palaeogeography in this definition would show a submarine canyon system, slope, rise and abyssal plain as environments, but not refer to a ‘turbidite’ depositional environment, which is a facies. With digital systems, these can be kept separate and overlain later during analysis. In reality, many published palaeogeographies ‘mix’ facies, gross depositional environments (GDEs) and depositional environments and users should be aware of this.






Most symbology schemes for depositional environments are relatively standard, if not always self-explanatory, for example, the use of yellow polygon fill to denote delta tops has been used by numerous authors (Golonka, Ross and Scotese, 1994; Markwick, 2011). Most mappers use various shades of blue to represent marine conditions (Markwick and Valdes, 2004; Vinogradov, Grossheim and Khain, 1967; Vinogradov, 1968; Vinogradov, Vereschchagin and Ronov, 1968; Vinogradov, 1969; Ziegler *et al.*, 1985), except for Ziegler (1990). There are numerous published schemes now available including those of Shell (Hulshof, 2012) and the USGS (Federal Geographic Data Committee, 2006).

### S7.a. Terrestrial depositional environments

Terrestrial environments have been divided into fluvial, lacustrine, glacial and desert environments (Figs. S19, S20). Subdivisions to allow differentiation between meandering and braided fluvial systems, different lacustrine types (based on salinity) and alluvial as distinct from fluvial systems, have been included given the needs of source-to-sink analysis and climate modelling.

SYMBOL		DESCRIPTION
E140		Alluvial fan
E100		Fluvial, undiff.
E110		Fluvial, meandering
E120		Fluvial, braided
E150		Fluvio-lacustrine
E200		Lacustrine, undiff.
E210		Lacustrine, saline
E215		Lacustrine, playa
E220		Lacustrine, freshwater

**Figure S19.** Fill colours with their associated symbol codes for differentiating terrestrial depositional areas.














SYMBOL		DESCRIPTION
E300		Desert, undiff.
E350		Desert, sand sea
E400		Glacial, undiff.
E410		Sub-glacial
E420		Peri-glacial

**Figure S20.** Fill colours with their associated symbol codes for differentiating desert- and ice-related depositional environments. The use of ‘desert’ in this context does not differentiate between ‘hot’ and ‘cold’ deserts, although in most applications the sedimentary indicators are more typical of ‘hot’ deserts, viz. sand seas.

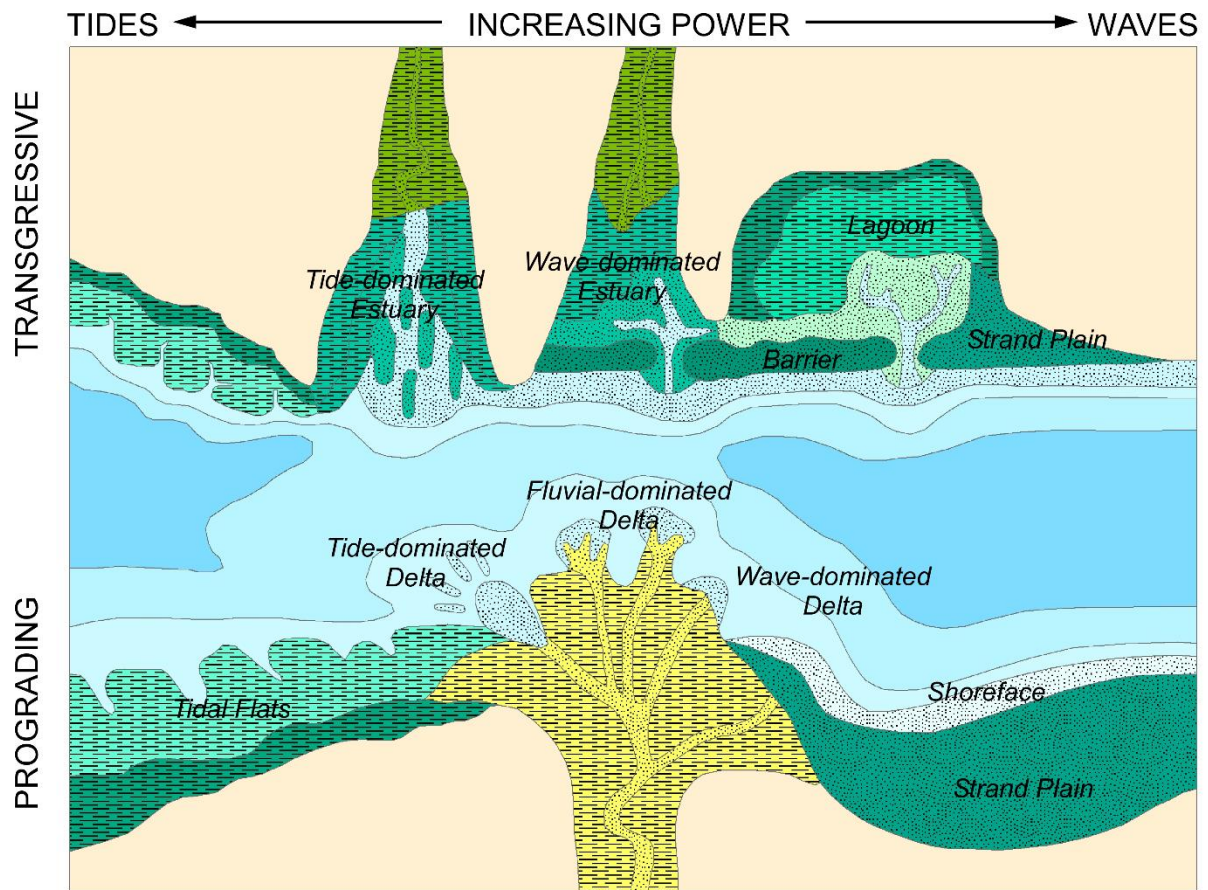


### S7.b. Coastal depositional environments

For coastal and near-shore environments (Fig. S21) this legend follows the definitions in Boyd *et al.* (1992) (Fig. S22) given the importance of such environments to reservoir systems (Armentrout, 2000). Delta tops also fall into the group of coastal or near-shore environments (Fig. S21).

SYMBOL		DESCRIPTION
E170		Delta top, undiff.
E172		Delta top, tide-dominated
E174		Delta top, wave-dominated
E176		Delta top, fluvial-dominated
E181		Estuary, undiff.
E182		Estuary, tide-dominated
E183		Estuary, wave-dominated
E180		Coastal
E190		Supratidal
E185		Barrier
E184		Strand plain
E186		Lagoon
E187		Tidal flat






**Figure S21.** Fill colours with their associated symbol codes for differentiating terrestrial depositional areas.



**Figure S22.** The symbol set defined in this paper applied to a modified version of the coastal and near-shore environments classification of Boyd et al., (1992).

### S7.c. Marine depositional environments

Marine environments are generally classified by depth following Ziegler *et al.* (Table 2 in Ziegler *et al.*, 1985), who related environments to sedimentological and fossil evidence. Similar definitions were used by Vinogradov *et al.* (1967; 1968; 1968; 1969) and adopted to lesser or greater degrees by Scotese (1992; 2014a; 2014b), Golonka (1994; 2011), Ziegler (1982; 1990), Markwick (2000; 2004; 2007; 2011; 2015), and most other palaeogeographers.

SYMBOL		DESCRIPTION
E500		Intertidal
<i>Low-tide</i> -----		
E505		Shoreface
<i>Fair weather wave-base</i> -----		
E510		Shallow shelf
<i>Storm wave-base</i> -----		50m
E520		Deep shelf
E530		Very deep shelf
-----		200m
E540		Slope
-----		2000m
E550		Rise
-----		4000m
E560		Abyssal plain
E570		Trench

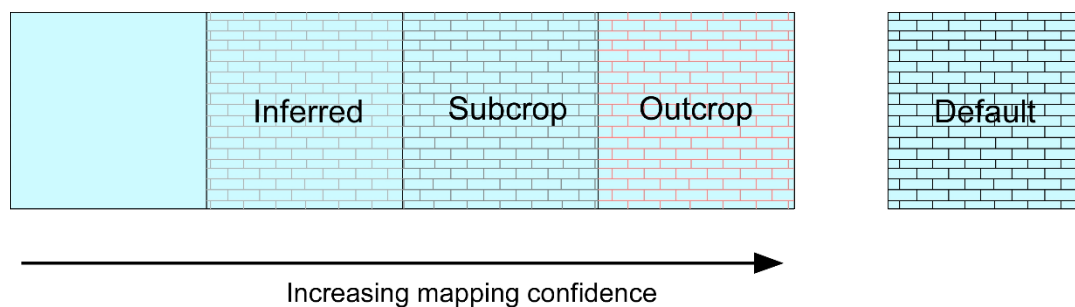
**Figure S23.** Fill colours with their associated symbol codes for differentiating marine depositional environments. The bathymetric definitions are those of Ziegler *et al.* (1985).

## S8. Lithologies

Lithologies, like depositional environments, can change rapidly spatially and temporally in response to changing accommodation space. In most palaeogeographic reconstructions the ‘dominant’ lithology of the depositional environment is usually represented, which can miss key lithologies of interest. Lithological qualifiers can be used on the maps to show key lithological detail if needed, such as the presence of thin coal layers or evaporites used to constrain model results or the presence of thin, coarse sand units in turbidite systems that are critical for understanding reservoir potential. Alternatively, additional higher resolution depositional and lithological maps need to be drawn.

In this scheme, all lithological symbol codes are prefixed with an “L” and then a suffix is added to differentiate between lithologies based on “o” outcrop data, “s” subcrop data, or is “i” inferred. The default symbology has no suffix.

The graphical representation of lithologies is relatively standardized. The symbologies used here largely follow those of the USGS and reports of the deep-sea drilling projects (DSDP, ODP and IODP). Following Vinogradov *et al.* (1967; 1968; 1968; 1969) the lithological symbology is also used to show data confidence and coverage (Fig. S24).



**Figure S24.** The use of fill patterns to show different levels of mapping confidence based on the mapping methods of Vinogradov et al. (1967; 1968; 1968; 1969). Increasing mapping confidence is indicated by the addition of lithological symbology using different line colours.

## S8.a. Clastics

	SYMBOL				DESCRIPTION
	Default	Outcrop	Subcrop	Inferred	
L100		L100o	L100s	L100i	Conglomerate
L110		L110o	L110s	L110i	Breccia
L120		L120o	L120s	L120i	Gravel, grit
L150		L150o	L150s	L150i	Diamictite
L200		L200o	L200s	L200i	Sandstone
L250		L250o	L250s	L250i	Siltstone
L300		L300o	L300s	L300i	Mudstone, clay
L240		L240o	L240s	L240i	Argillaceous sandstone
L280		L280o	L280s	L280i	Silty mudstone
L310		L310o	L310s	L310i	Shale

**Figure S25.** Fill colours and patterns with their associated symbol codes for differentiating clastic lithologies.

## S8.b. Carbonates

	SYMBOL				DESCRIPTION
	Default	Outcrop	Subcrop	Inferred	
L500		L500o	L500s	L500i	Limestone
L505		L505o	L505s	L505i	Marl
L510		L510o	L510s	L510i	Argillaceous limestone
L520		L520o	L520s	L520i	Silty limestone
L530		L530o	L530s	L530i	Arenaceous limestone
L550		L550o	L550s	L550i	Dolomite, dolostone
L555		L555o	L555s	L555i	Dolomitic limestone
L560		L560o	L560s	L560i	Chalk
L565		L565o	L565s	L565i	Oolitic limestone
L570		L570o	L570s	L570i	Carbonate, undiff.

**Figure S26.** Fill colours and patterns with their associated symbol codes for differentiating carbonate lithologies.

### S8.c. Interbedded units and non-deposition

	SYMBOL				DESCRIPTION
	Default	Outcrop	Subcrop	Inferred	
L412		L412o	L412s	L412i	Limestone and mudstone
L414		L414o	L414s	L414i	Limestone and shale
L416		L416o	L416s	L416i	Limestone and sandstone
L418		L418o	L418s	L418i	Limestone and conglomerate
L422		L422o	L422s	L422i	Sandstone and mudstone
L424		L424o	L424s	L424i	Sandstone and shale
L426		L426o	L426s	L426i	Sandstone and siltstone
L428		L428o	L428s	L428i	Sandstone and conglomerate
L448		L448o	L448s	L448i	Mudstone and conglomerate
L458		L458o	L458s	L458i	Siltstone and conglomerate
				L000	Non-deposition

**Figure S27.** Fill colours and patterns with their associated symbol codes for differentiating interbedded lithologies. This is not an exhaustive list but captures the most common. Non-deposition is an important qualifier in palaeogeography since it indicates an area below base-level, but with no record.

## S8.d. Oozes

	SYMBOL				DESCRIPTION
	Default	Outcrop	Subcrop	Inferred	
L600		L600o	L600s	L600i	Calcareous ooze
L610		L610o	L610s	L610i	Nannofossil ooze
L620		L620o	L620s	L620i	Foraminiferal ooze
L630		L630o	L630s	L630i	Siliceous ooze
L640		L640o	L640s	L640i	Diatom ooze
L650		L650o	L650s	L650i	Radiolarian ooze
L660		L660o	L660s	L660i	Porcellanite

**Figure S28.** Fill colours and patterns with their associated symbol codes for differentiating deep sea ‘ooze’ lithologies, based on the most common symbology’s used in the reports of the Deep Sea Drilling Program (DSDP), Ocean Drilling Program (ODP), International Ocean Drilling Program (IODP).



## S8.e. Chemical lithologies

	SYMBOL				DESCRIPTION
	Default	Outcrop	Subcrop	Inferred	
L700		L700o	L700s	L700i	Evaporites, undiff.
L710		L710o	L710s	L710i	Halite
L720		L720o	L720s	L720i	Gypsum, anhydrite
L730		L730o	L730s	L730i	Potash salts
L780		L780o	L780s	L780i	Chert

**Figure S29.** Fill colours and patterns with their associated symbol codes for differentiating chemically formed lithologies.

## S8.f. Igneous and Igneous-related

	SYMBOL				DESCRIPTION
	Default	Outcrop	Subcrop	Inferred	
L800		L800o	L800s	L800i	Igneous, undiff.
L810		L810o	L810s	L810i	Volcanic lavas, undiff.
L820		L820o	L820s	L820i	Volcanic ash, undiff.
L825		L825o	L825s	L825i	Volcaniclastics
L830		L830o	L830s	L830i	Igneous intrusives, undiff.
L840		L840o	L840s	L840i	Rhyolite
L845		L845o	L845s	L845i	Granite
L850		L850o	L850s	L850i	Andesite
L855		L855o	L855s	L855i	Diorite
L860		L860o	L860s	L860i	Basalt
L865		L865o	L865s	L865i	Gabbro
L870		L870o	L870s	L870i	Peridotite, dunite
L880		L880o	L880s	L880i	Syenite, phonolite
L885		L885o	L885s	L885i	Trachyte

**Figure S30.** Fill colours and patterns with their associated symbol codes for differentiating igneous and igneous related petrologies and lithologies.

SYMBOL		DESCRIPTION
IG300		Igneous feature, undiff.
IG315		Extrusive feature, undiff.
IG320		Intrusive feature, undiff.

SYMBOL				DESCRIPTION
ACTIVE		INACTIVE		
Defined	Inferred	Defined	Inferred	
IG20A	IG20Ai	IG20I	IG20Ii	Igneous dike (dyke)

**Figure S31.** Fill and line colours and patterns with their associated symbol codes for differentiating igneous features. The use of lines rather than polygons is a function of mapping scale. For most palaeogeographic purposes, with the exception of large-scale dykes (dikes) such as that Great Dyke in Zimbabwe most dykes (dikes) will be shown by lines.

## S8.g. Metamorphic

	SYMBOL				DESCRIPTION
	Default	Outcrop	Subcrop	Inferred	
L900		L900o	L900s	L900i	Metamorphics, undiff.
L910		L910o	L910s	L910i	Quartzite
L920		L920o	L920s	L920i	Slate
L930		L930o	L930s	L930i	Schist
L940		L940o	L940s	L940i	Gneiss
L950		L950o	L950s	L950i	Serpentine

**Figure S32.** Fill and patterns with their associated symbol codes for differentiating the major metamorphic features.

## S9. References cited

- ARMENTROUT, J. M. 2000. Sedimentary Basin Analysis. In *AAPG Treatise of Petroleum Geology: Exploring for Oil and Gas Traps* eds E. A. Beaumont and N. H. Foster). pp. 4.1-4.123. Tulsa: American Association of Petroleum Geologists.
- BOYD, R., DALRYMPLE, R. W. & ZAITLIN, B. A. 1992. Classification of clastic coastal depositional environments. *Sedimentary Geology* 80 (3-4), 139-50.
- CAMPANILE, D., NAMBIAR, C. G., BISHOP, P., WIDDOWSON, M. & BROWN, R. 2007. Sedimentation record in the Konkan-Kerala Basin: implications for the evolution of the Western Ghats and the Western Indian passive margin. *Basin Research* 20 (1), 3-22.
- ESRI 2017. ArcGIS Desktop. Redlands, CA: Environmental Systems Research Institute.
- FEDERAL GEOGRAPHIC DATA COMMITTEE 2006. FGDC digital cartographic standard for geologic map symbolization. p. 290. Reston, VA.: Prepared for the Federal Geographic Data Committee by the U.S. Geological Survey.
- GALSWORTHY, A., RAYNHAM, L., MARKWICK, P. J., CAMPANILE, D., BAILIFF, R., BENNY, K. E., HARLAND, M., EUE, D., BONNE, K., HAGEN, L., EDGECOMBE, E. & WROBEL, N. 2011. A new model of the palaeogeographic and tectonic evolution of Tethys from 150 Ma to Present: implications for depositional systems and source-to-sink relationships. In *AAPG International Conference and Exhibition, 23-26 October 2011* p. Article #90135. Milan, Italy.
- GOLONKA, J., ROSS, M. I. & SCOTESE, C. R. 1994. Phanerozoic paleogeographic and paleoclimatic modeling maps. In *Pangea: global environments and resources* pp. 1-47. Canadian Society of Petroleum Geologists.
- GOLONKA, J. 2011. Chapter 6 Phanerozoic palaeoenvironment and palaeolithofacies maps of the Arctic region. *Geological Society, London, Memoirs* 35, 79-129.
- HULSHOF, B. 2012. Shell Standard Legend. p. 38. Amsterdam: Shell Global Solutions International B.V.
- MANATSCHAL, G. 2012. Tectono-magmatic evolution of Atlantic type rifted margins. In *Magmatic Rifting and Active Volcanism Conference, 10-13th January, 2012* Addis Ababa.
- MARKWICK, P. J. 1996. Late Cretaceous to Pleistocene climates: nature of the transition from a 'hot-house' to an 'ice-house' world. In *Geophysical Sciences* p. 1197. Chicago: The University of Chicago.
- MARKWICK, P. J., ROWLEY, D. B., ZIEGLER, A. M., HULVER, M., VALDES, P. J. & B.W., S. 2000. Late Cretaceous and Cenozoic global palaeogeographies: mapping the transition from a "hot-house" world to an "ice-house" world. *GFF* 122 (1), 103.
- MARKWICK, P. J. & LUPIA, R. 2001. Palaeontological databases for palaeobiogeography, palaeoecology and biodiversity: a question of scale. In *Palaeobiogeography and biodiversity change: a comparison of the Ordovician and Mesozoic-Cenozoic radiations* eds J. A. Crame and A. W. Owen). pp. 169-74. London: Geological Society, London.

MARKWICK, P. J. & VALDES, P. J. 2004. Palaeo-digital elevation models for use as boundary conditions in coupled ocean-atmosphere GCM experiments: a Maastrichtian (late Cretaceous) example. *Palaeogeography, Palaeoclimatology, Palaeoecology* 213, 37-63.

MARKWICK, P. J. 2007. The palaeogeographic and palaeoclimatic significance of climate proxies for data-model comparisons. In *Deep-time perspectives on climate change* eds M. Williams, A. M. Haywood, F. J. Gregory and D. N. Schmidt). pp. 251-312. London: The Micropalaeontological Society & The Geological Society of London.

MARKWICK, P. J., WILSON, K. L. & LEFTEROV, V. 2008. Middle Miocene palaeogeography and palaeolandscape of Indochina. In *AAPG 2008 Annual Convention and Exhibition, April 20-23, 2008* p. Article #90078. San Antonio, Texas: AAPG.

MARKWICK, P. J. 2011. South Atlantic palaeogeography: reconstructing palaeolandscapes for New Ventures. *GEOExpro* 8 (4).

MARKWICK, P. J., GALSWORTHY, A. & RAYNHAM, L. 2015. The paleogeography of the World in 101 stages. *Geological Society of America Abstracts with programs* 45 (7), 234.

MOONEY, W. D., LASKE, G. & MASTERS, T. G. 1998. CRUST 5.1: A global crustal model at 5° x 5°. *Journal of Geophysical Research B. Solid Earth and Planets* 103 (B1), 727-47.

PAZZAGLIA, F. J. 2003. Landscape evolution models. *Development in Quaternary Science* 1, 247-74.

PÉRON-PINVIDIC, G. & MANATSCHAL, G. 2010. From microcontinents to extensional allochthons: witnesses of how continents rift and break apart? *Petroleum Geoscience* 16 (3), 189-97.

POLLACK, H. N., HURTER, S. & JOHNSON, J. R. 1993. Heat Flow from the Earth's Interior: Analysis of the Global Data Set. *Reviews of Geophysics* 31 (3), 267-80.

RADDADI, M. C., MARKWICK, P. J. & HILL, C. 2010. Palaeogeographic evolution and petroleum potential of the Equatorial Atlantic margins. In *AAPG Annual Convention and Exhibition, 11-14 April 2010* p. Article #90104. New Orleans, Louisiana: AAPG.

SCOTESE, C. R. & GOLONKA, J. 1992. PALEOMAP Paleogeographic Atlas. In *PALEOMAP Progress Report* Arlington, Texas: Department of Geology, University of Texas at Arlington.

SCOTESE, C. R. 2014a. Atlas of Neogene Paleogeographic Maps (Mollweide Projection), Maps 1-7, Volume 1, The Cenozoic. Evanston, IL: PALEOMAP Project.

SCOTESE, C. R. 2014b. Atlas of Late Cretaceous Paleogeographic Maps, PALEOMAP Atlas for ArcGIS, volume 2, The Cretaceous, Maps 16 – 22, Mollweide Projection. Evanston, IL.: PALEOMAP Project.

TUCKER, G. E. & SLINGERLAND, R. L. 1994. Erosional dynamics, flexural isostasy, and long-lived escarpments: a numerical modeling study. *Journal of Geophysical Research* 99 (B6), 12229-43.

VAN DER BEEK, P. A. & BRAUN, J. 1998. Numerical modelling of landscape evolution on geological time-scales: a parameter analysis and comparison with the south-eastern highlands of Australia. *Basin Research* 10, 49-68.

VINOGRADOV, A. P., GROSSHEIM, V. A. & KHAIN, V. E. 1967. *Atlas of lithological-paleogeographical maps of the USSR. Volume IV. Paleogene, Neogene and Quaternary*. Moscow: Ministry of Geology in the USSR and Academy of Sciences of the USSR, 100 pp.

VINOGRADOV, A. P., ed. 1968. *Atlas of the lithological-paleogeographical maps of the USSR. Volume I. Pre-Cambrian, Cambrian, Ordovician and Silurian*. Moscow: Ministry of Geology in the USSR and Academy of Sciences of the USSR, 52 pp.

VINOGRADOV, A. P., VERESCHCHAGIN, V. N. & RONOVA, A. B. 1968. *Atlas of lithological-paleogeographical maps of the USSR. Volume III. Triassic, Jurassic and Cretaceous*. Moscow: Ministry of Geology in the USSR and Academy of Sciences of the USSR, 110 pp.

VINOGRADOV, A. P., ed. 1969. *Atlas of the lithological-paleogeographical maps of the USSR. Volume II. Devonian, Carboniferous and Permian*. Moscow: Ministry of Geology in the USSR and Academy of Sciences of the USSR, 65 pp.

WHIPPLE, K. X. & MEADE, B. J. 2004. Timescale of Orogen Response to Tectonic and Climatic Forcing. *EOS Transactions, AGU, Fall Meeting Supplement* 85 (47).

ZIEGLER, A. M., ROWLEY, D. B., LOTTES, A. L., SAHAGIAN, D. L., HULVER, M. L. & GIERLOWSKI, T. C. 1985. Paleogeographic interpretation: with an example from the Mid-Cretaceous. *Annual Review of Earth and Planetary Sciences* 13, 385-425.

ZIEGLER, P. A. 1982. *Geological atlas of western and central Europe*. Elsevier, 130 pp.

ZIEGLER, P. A. 1990. *Geological Atlas of Western and Central Europe 1990*, 2 ed.: Shell Internationale Petroleum Maatschappij BV, 239 pp.