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COMMISSION FOR THE GEOLOGICAL MAP OF THE WORLD  
*COMMISSION DE LA CARTE GÉOLOGIQUE DU MONDE*

**STRUCTURAL MAP OF THE  
WESTERN PACIFIC OCEAN**

First edition, scale 1:20 000 000

**2016**

Explanatory notes

by

**Peter Miles**

President CGMW Subcommittee for Seafloor Maps



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# STRUCTURAL MAP OF THE WESTERN PACIFIC OCEAN

At the scale of 1:20 000 000 – First edition

2016

## EXPLANATORY NOTES

### Physiographic and Structural Mapping of an Ocean

#### ABSTRACT

*This booklet accompanies the Structural map of the western Pacific Ocean. It explains how the cartography has been compiled from the interpretation of geological and geophysical data obtained from oceanographic research spanning several decades. Published scientific results and datasets have been constrained by satellite data to represent the morphology and various structural entities created during the formation of this complex region. The oceanic areas include the following parameters:*

*The age of the oceanic crust in Series/EPOCHS.*

- *Magnetic anomaly chron picks where they have been observed or interpreted and published magnetic lineations.*
- *Seafloor spreading axes, active and fossil.*
- *Transform faults and fracture zones.*
- *Subduction zones with associated Benioff zones constrained by earthquake distribution at depth*
- *Anomalous relief*
- *Seaward dipping reflector (SDR) volcanic sequences*
- *Thinned continental crust.*
- *Hotspots*
- *Deep ocean drilling sites – DSDP, IPOD, ODP and IODP - where basaltic basement or transitional crust was reached.*
- *Sediment thickness - contours over oceanic crust and thinned continental crustal areas.*
- *Crustal deformation zones.*
- *Selected continental geology related to the geodynamic evolution of the oceans.*

*The map is also accompanied by a corresponding Geodynamic Sketch to illustrate the tectonic plates and relate the morphology and oceanic features included in the text. In addition the earthquake epicentres are shown separately owing to the density of occurrences.*

*This map does not represent the ocean – continent boundaries as defined by the United Nations Commission on the Law of the Sea (UNCLOS)*

#### FOREWORD

The Commission for the Geological Map of the World (CGMW/CCGM) is a scientific Non-Governmental Organization (NGO) recognised as Category A by UNESCO and affiliated to the International Union of Geological Sciences (IUGS). It was initiated in an early form in 1881 during the 2nd International Geological Congress (IGC) held in Bologna. During the 1980s the CGMW co-published with UNESCO the maps of the five oceans of the globe for the first time (including the “Antarctic Ocean”). These were part of the ‘Geological Atlas of the World’ and printed at a relatively small scale. Three decades later our knowledge of the deep seafloor of the world’s oceans has improved to such an extent that during the 1990s the Commission decided to initiate a new series of seafloor maps featuring whole oceans. This map of the western Pacific Ocean<sup>1</sup>, issued for the 35th IGC in Cape Town in 2016, is the third in this series and accompanies that for the Atlantic Ocean and adjoining Indian Ocean map which it overlaps contiguously. Publication of the map received financial support from UNESCO.

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1 Authors of the map: Peter Miles with the collaboration with Manuel Pubellier, Julien Collot and Yves Lagabrielle.

## MAPPING AN OCEAN

From an Earth science perspective the compilation of a structural map of an ocean, as opposed to an atlas or onshore cartography, is not as straightforward an exercise as may be at first apparent. The reasons for this are:

- The map cannot be a truly geological, that is, the seabed geology and other formations cannot be mapped as in land geology otherwise it would mainly represent Plio-Quaternary sediments.
- It is also not possible to construct a conventional tectonic map because the evolution of the oceanic lithosphere is never greater than ~200 Ma in age.
- The map cannot be a simple illustration of one geophysical parameter (seismicity, magnetic anomalies, spreading rate etc.) but a representation of all physical parameters, plus observed and interpreted features.
- The compilation also needs to include some land structural and geological features that place island and surrounding continent structures in context. This provides complimentary information in understanding the evolution of an ocean basin, such as in the fit of adjacent Precambrian shields prior to rifting and separation of the continental fragments.
- The map must also overlay different entities of information in such a way as to not impede an acceptable balance between clarity and detail.

For all these reasons we chose to title this kind of cartography a "structural map", a term not unduly constrained by semantics.

As to the size of the printed map, publishing experience led to the avoidance of large dimensions owing to printing constraints, user convenience, display, clarity and cost. The final scale is chosen as 1:20,000,000 at the Equator and corresponds to that of the Indian Ocean and Atlantic Ocean structural maps in this series. The projection is Mercator using the WGS-84 ellipsoid generally adopted by the offshore sciences community including the International Hydrographic Organization and the Intergovernmental Oceanographic Commission. Consequently the north and south boundaries of the map were limited to 72°N and 72°S in order to avoid too much distortion of the polar regions, while retaining significant detail in the Bering Sea and Southern Ocean.

To maintain legibility within the constraints of an A0 sheet the structural map of the western Pacific Ocean comprises the main structural map accompanied by these "explanatory notes" where we include a geodynamic sketch and a seismic epicentre map.

## PHYSIOGRAPHY

It would have been difficult to include some additional entities of information onto a single structural map without loss of clarity. This applies particularly to the detail involved with physiography/bathymetry. However, geophysical databases do now allow production of high resolution computer generated images of the physiography of the Earth's surface and seafloor bathymetry using colour shaded relief. These displays are derived from elevation and bathymetric data sets and provide increased information and aesthetic value. However, owing to complexity, it was considered necessary to defer the reader to existing publications.

## STRUCTURAL MAP

### INTRODUCTION

This map is a compilation of several different physiographic, geological and geophysical parameters illustrating the structure of the region. Some are complimentary to others, such as magnetic anomalies and ocean age. In order to provide the reader with an accurate and readable set of entities colour coding, shading and various symbols are used consistently and in agreement with previous structural maps in this 1:20M series i.e. the structural maps of the Atlantic and Indian Oceans.

### ONSHORE AREAS

On this map the onshore geology is limited to volcanism related to the ocean margins' formation. It is featured as oceanic island magmatism and ophiolites – sections of oceanic crust that have been uplifted onto continental crust (obduction).

### OFFSHORE AREAS

#### MAGNETIC ANOMALIES AND AGE OF THE OCEANIC CRUST

When seafloor spreading lavas cool they 'fossilize' the vector (normal or reversed) and intensity of the Earth's magnetic field at that geological time to generate linear, and (mostly) identifiable magnetic anomalies. As the lavas were accreted to the seafloor along spreading centres – the principle element in the geological structure of an ocean – they can be dated by using a timescale of the geomagnetic reversal sequence. This has been derived from correlating deep sea drilling ages of oceanic basement, normally the immediate overlying sediments, with the anomalies. Using the identification of a number of characteristic magnetic anomalies it is possible to map the ocean floor

# Structural Map of the Western Pacific Ocean

## Carte structurale de l'océan Pacifique ouest

## Seismic epicentres

Earthquakes epicentres (1993-2013)		Épicentres des séismes (1993-2013)	
Focal depth Profondeur du foyer	Magnitude/Magnitude		
0-35 km	5	6	7
36-70 km	5	6	7
71-300 km	5	6	7
301-700 km	5	6	7

Deep sea drilling site with its number (only sites for which first and/or successive drillings reached the basement are shown)

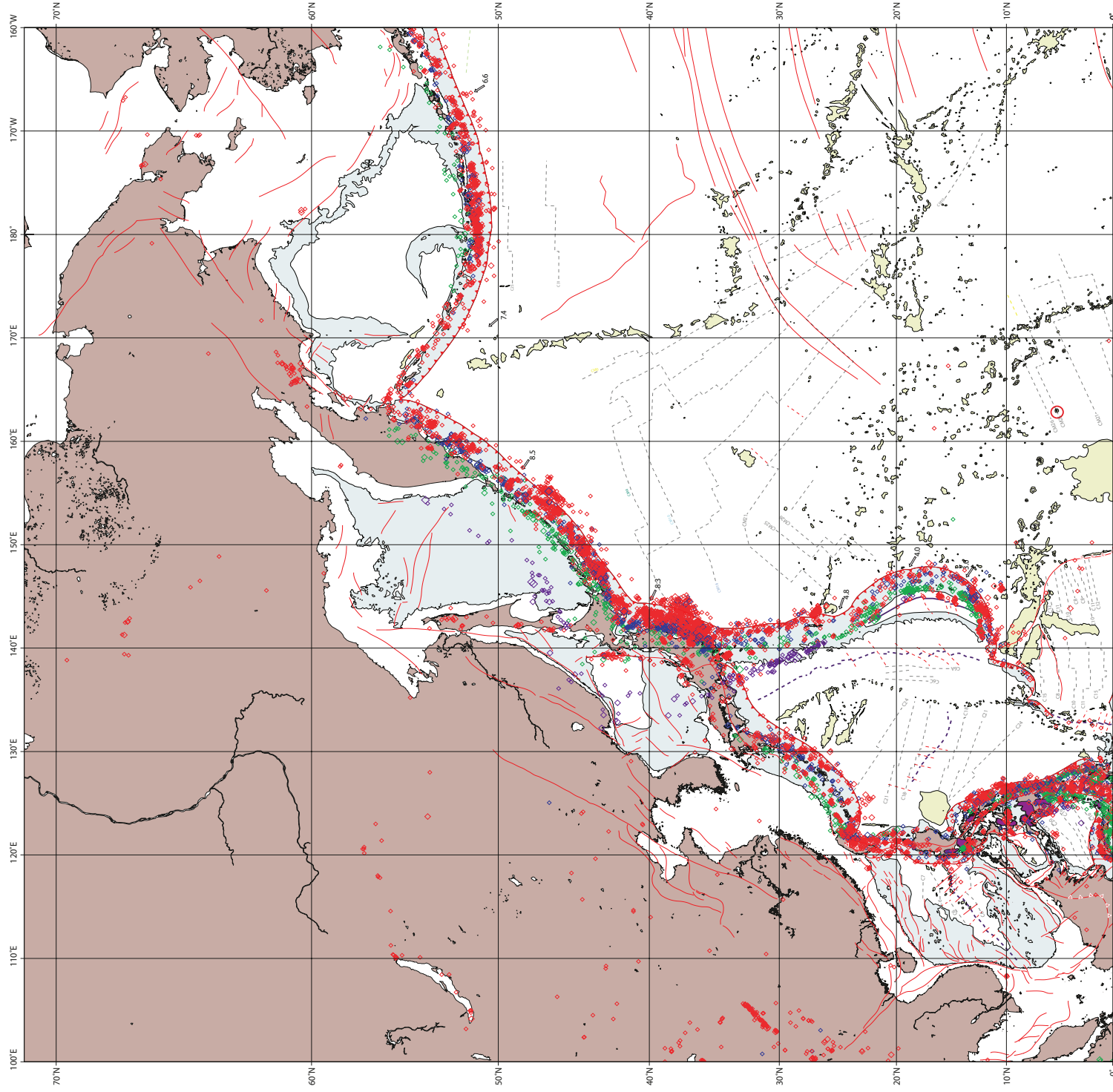
*Site de forage océanique profond avec son numéro (ne sont indiqués que les sites où le premier forage, ou ses reprises, ont atteint le socle)*

Extinct spreading axis  
*Axe d'expansion océanique fossile*

Active subduction zone  
*Zone de subduction*

Fracture zone / Zone de fracture  
Axis of oceanic accretion with  
full spreading rate scaler (cm/yr)  
*Axe d'accrétion océanique et taux  
global d'ouverture (en cm/an)*

Convergent vector with velocity (cm/yr)  
Vecteur de convergence avec taux (cm/an)







age and measure the seafloor spreading processes. Crust of unknown age, or of current different age interpretations, and crust of unknown type (oceanic/thinned continental) is shown in dark grey to differentiate from known thinned or stretched continental crust (mid grey).

The chronostratigraphic ages (epochs, mainly using ICS geological RGB colours) are used here and not the geomagnetic ages (or “chrons” corresponding to the geomagnetic reversal chronology) as often displayed in geophysical texts. This is to maintain consistency with geological events (e.g. the K/T boundary). These chronostratigraphic (geological) ages of the oceanic crust have been obtained by interpolation between digitized magnetic anomaly picks of fixed age (Müller et al., 1997) (Wessel & Müller, 2014) described in Seton et al. (2014). It was also considered valuable to show the location of the principal magnetic anomaly picks used in this age calculation plus other recent lineations that detail seafloor spreading better in some areas. In the legend a table provides the list of each standard anomaly (or chron, ‘C’) with its age, following the geomagnetic timescale of Cande & Kent (1995) from C10 (0.78 Ma) to C33o (79.08 Ma), and after Gradstein et al. (1994) for C34 (83.0 Ma). These picks are shown as small circles colour coded for each chron. As there is no single magnetic pick data set for the whole of the map area the anomalies are shown, consistently, in two regions:

1. South East Indian Ocean lineations are taken from the ‘Structural Map of the Indian Ocean’ compilation of Segoufin et al 2004.
2. Pacific Basin lineation after Müller et al. (1997) and (1999) plus Wessel and Müller (2014).

## STRUCTURAL FEATURES

The following structural features have been mapped: axes of oceanic accretion (mid-ocean ridges) with full present day spreading rate scalers in cm y<sup>-1</sup>; extinct spreading axes in the Tasman Sea, South China Sea and the Philippine Sea. Principal selected transform faults, with their fracture zone extensions, are mapped from satellite gravity and published texts. Extensions to, inferred and other FZs can be seen from magnetic anomaly pick sequences. Some faults related to continental margin structure are also shown in grey.

## ANOMALOUS SUBMARINE PLATEAUX

Bathymetric highs associated with anomalous volcanic basement (seamounts, ‘aseismic’ ridges, oceanic plateaux, features of uncertain or disputed origin and selected significant buried basement features) are shown in a pale yellow hue. Notable features include the Ontong Java plateau, the Manihiki plateau plus the Chatham Rise and Lord Howe Rise among others.

## SUBDUCTION ZONES

Several subduction zones exist in the western Pacific region both active and ‘fossil’. The under-thrusting and relatively cold oceanic crust in these localities is progressively heated as it is forced down into the plastic asthenospheric mantle beneath the over-riding plates. It becomes dehydrated and triggers partial melting of the overlying mantle material to provide the source of the magma that generates the island arc volcanoes. The active sedimentary deformation fronts of these subduction zones are marked by a red line with solid red triangles. Subduction vectors show the orientation and convergence rate. Fossil subduction is shown with a blue line.

## DEEP-SEA DRILLING SITES

The deep-sea drilling sites occupied by the international scientific consortia of DSDP, IPOD, ODP and IODP are shown as black stars with their site identification number. Only those holes that reached basaltic basement or marginal thinned continental crust are shown. These drill-holes are important because the basalt sampled can be dated using radiometric techniques. Sediment sampled immediately above the basement can be dated from their microfauna. In the latter case the age of the oceanic crust predates the sediment age. As referred to above, these samples permit control on the age of the oceanic crust and calibration of the magnetic anomaly timescale reversal sequences. However, Sibuet et al, 2007 showed that the serpentinization process in some regions can also result in the formation of magnetic grains which produce magnetic anomalies similar to those of typical oceanic crust.

## SEDIMENT THICKNESS

Compilations of sediment thickness, principally from seismic reflection measurements, can be rare and often generalized. However the western Pacific Ocean has coverage from the NGDC world sediment thickness grid. This has been used to construct 1km isopachs (lines of equal thickness) shown as dashed lines with an overprinted grey hue whose intensity increases between 1 and 15km. The thickest sediments occur along the continental margins and thick sediment fans extending seaward of the large river deltas.

## ZONE OF OCEANIC CRUST DEFORMATION

South of the Tasman Sea, and coincident three seafloor spreading ridges is a region of deformation caused by adjacent compressional and tensional forces. These areas are shown overprinted with hatching. They are associated with diffuse seismicity and may also be zones of future rupture between the Antarctic, Pacific and Australian Plates.

## CONTINENTAL MARGINS

The delineations used in this map between continental shelf, slope and oceanic crust should not be confused with the legal term 'extended continental shelf' used in the United Nations Convention on the Law of the Sea (UNCLOS). The latter is a political boundary constructed by the application of parameters laid down by the UNCLOS Article 76 which applies morphological and geological factors in specific contexts not used here.

The continental margin represents that part of the continent situated at depth beneath sea level. It extends from the outer continental shelf – more or less arbitrarily bounded by the 200m isobath – to a continental slope and rise that meets oceanic crust at an average water depth of about 3000m. In this map the slope is not always shown to include its full morphology *sensu stricto*, but as a representation of its location bounding the shelf edge and deep water or outer banks. Sediment fans and extended continental rises are not included as slope where they would obscure sediment thickness contours. The continent-ocean boundary may also lie beneath the lower slope and extended continental rises.

The shelf (<200m) is shown in white, generally without any other information other than margin faulting. The slope is in a light blue/grey and can contain some structural information relevant to the adjacent ocean structure or rifting. It is also extended onto deeper shelf areas to highlight channels. As island arcs are built-up seafloor features, their submarine areas are treated as slope.

An addition to this map is 'thinned or stretched continental crust'. This is to show, where possible, the relationship of continental crust thinned during rifting and full seafloor spreading to oceanic crust. Thinned continental crust is shown as continental slope but with the sediment thickness shading included.

Also seaward dipping reflector sequences (SDRs) have been mapped from various sources. They are indicated by a pale red hue and are shown only where they exist beyond the shelf edge off western Australia.

## EXHUMED MANTLE

There is one example of exhumed mantle crust shown in dark green – The Godzilla Mega mullion complex (Looke et. al.,2013).

## THE SEAFLOOR SPREADING RIDGES

This map shows only one small section of the Pacific spreading ridges in the south east. The principle spreading axis seen is the south east Indian ridge. These plate boundaries were created from evolving phases of spreading during the Mesozoic and Cenozoic Eras, at different times and at different rates. This can be seen on the map by the width of the coloured strips located on either side of the

ridge. These represent the area of oceanic floor generated by the ridge during the time of a geological stratigraphic Series or time Epoch (i.e. Late Cretaceous) since early in the Jurassic Period. The thin black arrows that overprint the ridge axes give the (combined) spreading rate scalar.

## HOTSPOTS

The different types of «hotspots» were plotted in the 3rd edition of the Geological Map of the World (2010). For the present western Pacific map, only three typical oceanic and quite well defined hotspots were selected in order of importance of today's activity: The Tasman Sea and southern Lord How Rise, and the south eastern Pacific Basin. All three are no longer related to active seafloor spreading.

## SEISMICITY

Seismicity is an important parameter in the study of current regional geodynamics. It underlines the limits of the current lithospheric plates (spreading axes, transform faults and subduction zones) and active intra-plate rifting. Earthquake epicentres are symbolized with open diamonds and are shown for both on and off-shore occurrences in the figure here. The time interval used for the occurrences is from 1993 to 2013 in order to both represent activity and maintain clarity. Also to this end only 4 categories of earthquake magnitude have been selected for display, the symbol size increasing for magnitude ranges 5.0-5.9; 6.0-6.9; 7.0-7.9; 8.0 and greater. The 4 categories of focal depths are shown as colour coding of the diamonds for depths 0-35 km; 36-70 km; 71-300 km and 301-700 km.

As explained, these earthquakes are not distributed randomly, rather they define the plate boundaries, transform faults and Benioff zones (below). On spreading ridges the seismicity is generated by tensional stress exerted by the plate divergence and injection of magma at the axis of the ridge (oceanic accretion). At transform faults the shear stress is caused from opposite movements along the fault between the offset ridge axes either side of the fault. Both these causes of earthquakes are generally shallow and of low magnitude.

Owing to the density of these events, the epicentres are shown separately in a figure here to maintain clarity on the main map.

## BENIOFF ZONE

Benioff zones are created at the sloping interface between the two convergent plates at a subduction zone producing the stresses that generate seismicity. The subducting lithospheric slab is revealed by the distribution of earthquakes in location and depth. Some have been mapped but here they are mainly illustrated schematically from the earthquake epicentre distribution using colour coded dashed lines and are an approximation.

## OVERVIEW OF THE OPENING OF THE WESTERN PACIFIC OCEAN AND ADJACENT OCEAN BASINS

The Panthalassic ocean surrounded the supercontinent of Pangaea from the late Palaeozoic. It included the palaeo-Pacific Ocean and the Tethys Ocean. With the break-up of Pangaea the Tethys Ocean closed and the separating continental blocks formed the Indian, Atlantic and Pacific Oceans.

For the most part the original Panthalassic oceanic crust has been subducted beneath the North American and Eurasian Plates. The plate beneath the present-day Pacific has been formed since the breakup of Pangaea and consists of post early Jurassic oceanic crust. Remnants of the Panthalassic oceanic plate may exist as the Juan de Fuca, Gorda, Cocos and the Nazca plates, all of which were part of the Farallon Plate.

Seafloor spreading has evolved several marginal basins in the western Pacific region. Examples include the Sea of Japan, the West Philippine Basin, the Parace Vela & Shikoku Basins, the Mariana Trough, the Woodlark Basin, the Fiji and Lau Basins. Other small basins exist and these all derive from complex arc/back-arc systems which the structural map attempts to define without loss of clarity.

Owing to the complexity of the geological history in this region the reader is referred to Neall & Trewick (2008) for an overview.

## GEODYNAMIC SKETCH

The Geodynamic sketch gives an overview of the configuration of the plate boundaries in the map area at the present time. The main bathymetric features, including principal fracture zones, are included in the toponomy. It also identifies the major oceanic plateaux and significant seamount chains. The regions associated with each tectonic plate are colour coded and include a detail inset of the complex microplate structure in the southwest Pacific. Isolated micro-continents, outer banks and thinned continental crust are shown in their continental context.

P.R. Miles, CCGM, Paris.

April 2016

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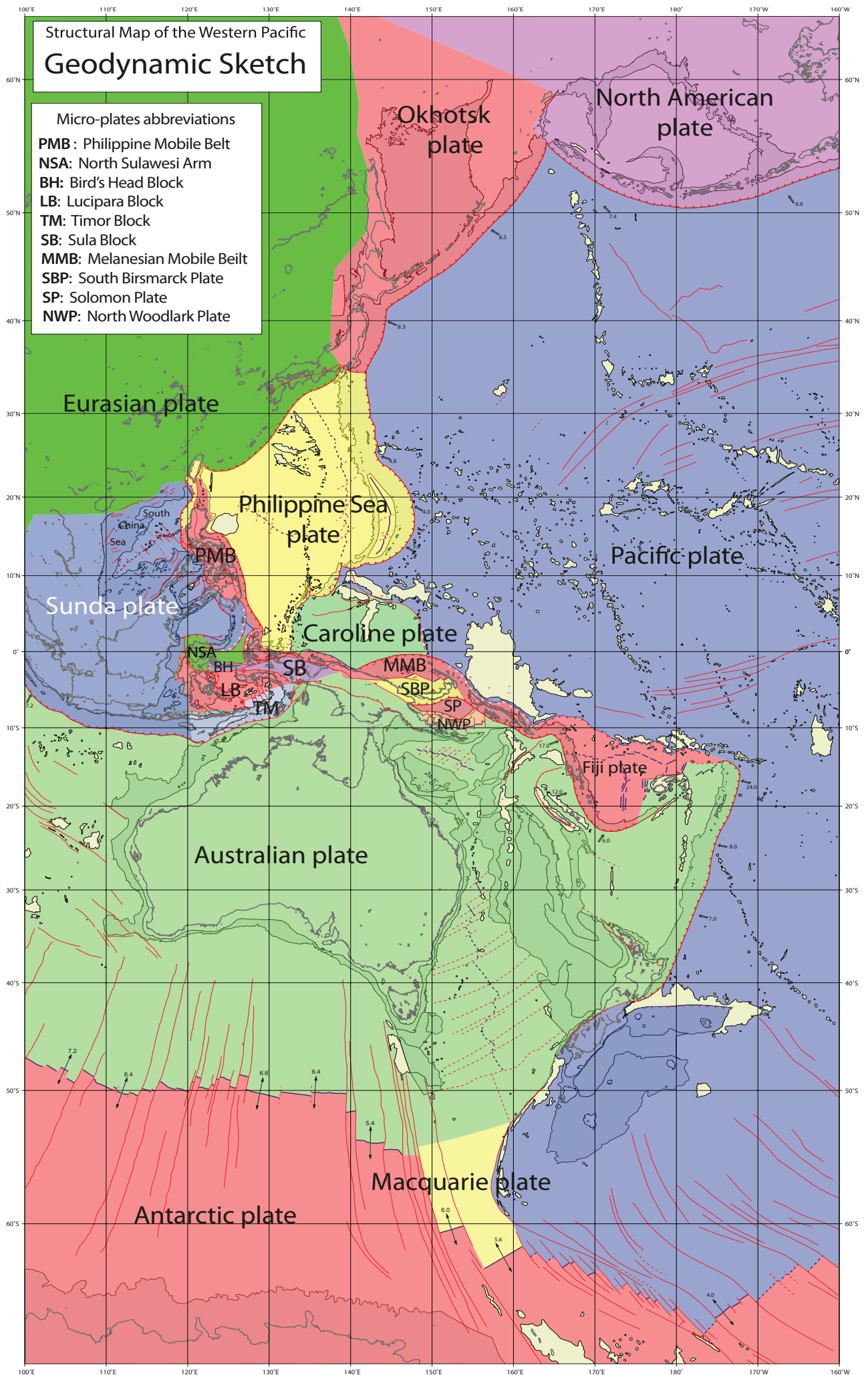
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