by Philippe Bouysse

The third edition of the Geological Map of the World

at 1:50 000 000 and 1:25 000 000 scales

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The third edition of the *Geological Map of the World* follows the first and second editions published by the CGMW respectively in 1990 and 2000. This bilingual document (English-French) is the result of a highly synthetic compilation given both the small scale of the map and its educational purpose. It is a tentative and (very) simplified representation of the entire solid surface of our planet and includes both continental and oceanic domains.

This new edition is a completely revised concept compared to the map issued in 2000 and takes into account the state of the geologic knowledge at the turn of the century. For the first time, the Map is designed in two sheets of the same size:

- **Sheet 1 (Physiography, Volcanoes, Astroblemes)** revealing the fine-grained texture of the totality of the Earth surface when removing the water of the oceans.
- **Sheet 2 (Geology, Structure)** showing the distribution of the main chronostratigraphic units and the main structural features that make up the mosaic of the present-day surface of our planet, the result of 4.56 billion year of unremitting “resurfacing”. Sheet 2 is the equivalent of the single sheet of the second edition, notably reworked and extended.

Each sheet consists of a main map in Mercator projection, with the 2 polar areas in polar stereographic projections. The drafts have been carried out at the 1:25,000,000 scale (1:25 M) and digitized in vector mode. The circum-polar projections extend to the 60°N and 60°S parallels (instead of 70°N and 60°S for the previous editions), Greenland is now displayed in its entirety and the 2 circum-polar areas have the same surface area. Their scale was slightly enlarged to 1:46 M.

For practical reasons and marketing policy, this 3rd edition is issued in 3 steps:

- An edition at the **1:50 M scale** (issued in November 2009) including **Sheet 1** and **Sheet 2**.
- An edition at the **1:25 M scale** (published in January 2010) corresponding to the original scale of the drafts and including **only the sheet “Geology, Structure”**, but issued in 3 parts due to the larger scale.
- An interactive digital version of the Map is scheduled current 2010.

In the first two editions at 1:25 M scale, the Mercator projection was printed in two parts (20°W-170°W; 170°W-20°W) that allowed adjusting the center of the Map either on the Atlantic (opening of an ocean and fit of the conjugated continents), or on the Pacific (subductions and hotspots tracks). This is also the case for the present 1:25 M scale, but the “western part” of the Mercator projection map (the “Americas”) is bounded by 180° and 20° W, and the “eastern

part” of the Mercator projection map (the “Old World”) by 20° W and 180°.

As regards the present 1:50 M scale, each of the 2 sheets is printed on a single piece of paper preventing the free choice for centering the map. In order to overcome this inconvenience, we decided to center Sheet 1 (Physiography) on the *Pacific* (meridian 0° for E and W sides) and Sheet 2 (Geology) on the *Atlantic* (180° meridian for both sides). This enables the reader to visualize both options of assemblage. Scales and projections being identical, it is easy to superpose the morphological features of the offshore areas (Sheet 1) with the geological structures mapped on Sheet 2 using an illuminated table.

Sheet - 1: Physiography, Volcanoes, Astroblemes

Published for the first time by the CGMW, this Map displays all of the Earth’s morphology and, in particular, the lesser known domains of the submarine areas that represent nearly 71% of its surface. Colour palettes are used to represent the land topography and, ocean bathymetry, the latter including fine black lines to indicate depth contours (isobaths) at every 1000 m. In order to avoid blurring of the physiographic perception of mountain chains, the equivalent for the subaerial areas (isohypses) were not plotted, except for the Greenland and Antarctica ice caps.

On this Sheet are also plotted 1506 active or recent volcanoes or volcanic fields that, *a priori*, cannot be considered as definitively extinct (i.e. having erupted during the last 10,000 years). These volcanic systems exist in 1436 subaerial edifices (red triangles) and 70 submarine volcanoes (blue triangles) that are extracted from the *Global Volcanism Program* of the *Smithsonian Institution*. All triangles are bordered by a fine white line that allows differentiation between each volcano in very active regions, such as in the island arcs or in arc cordilleras. The fissure volcanism that characterizes the active mid-oceanic ridges (where the divergence of the lithospheric plates takes place) is not included here. It is however represented by the axis of active accretionary ridge drawn in Sheet 2 of the Map.

Except for one site adjacent to Chesapeake Bay, 198 onshore astroblemes, or meteoritic impact craters (black asterisk), are plotted on the Map. They are divided into 2 categories of crater diameter: < 10 km and ≥ 10 km. Even though it is not an impact crater *stricto sensu*, the location of the Tunguska (Central Siberia) airblast of an asteroid in 1908 was also plotted.

This Sheet also includes information concerning the elevation of some specific locations.

Sheet 1. Physiography, volcanoes, astroblemes. Main map. Mercator projection. Published at the scale of 1:50,000,000 (November, 2009).

Sheet 1. Physiography, volcanoes, astrophysical features. Arctic and Antarctic areas limited respectively by 60° N and 60° S. Polar stereographic projection. Published at the scale of 1:46,000,000 (November, 2009).

Sheet - 2: Geology, Structure

The legend of the map is organized in 3 sections: onshore areas, offshore areas, hotspots.

Onshore areas

Chronostratigraphic units

The onshore areas (29,2% of our planet's surface) correspond mainly to the rock formations of continental origin (or continentalized in the case of island arcs). They are classified using 8 broad *chronostratigraphic units*: 1 = *Cenozoic*; 2 = *Mesozoic*; 3 = *Upper Paleozoic*; 4 = *Lower Paleozoic*; 5 = *Neoproterozoic*; 6 = *Mesoproterozoic*; 7 = *Paleoproterozoic*; 8 = *Archean*. A number of regroupings were made when necessary by the geological or cartographic contexts. In comparison with the previous edition, and for the sake of coherence, the Quaternary and the Triassic Periods within the Cenozoic and Mesozoic eras respectively have not been shown individually. Also the 3 eras of the Proterozoic Eon have been introduced as units 5, 6 and 7.

Within these time units 3 main lithological facies ensembles were distinguished: • *sedimentary formations* or those of an undifferentiated nature (uneasy to define); • *extrusive volcanic formations* (V); • *endogenous formations* (P). The last two rock categories are illustrated by a scattering of superimposed dots (blue for extrusive, red for the endogenous). One exception was made for the Cenozoic volcanism (V1) that is identified by a uniform strong blue hue. Actually, the volcanism of this era (which includes Quaternary and Present times) is, in many cases (e.g. subduction volcanism), the consequence of on-going geodynamic activity. It is therefore important that this volcanism be seen in relation to the "active" volcanoes of Sheet 1. Another exception was also made for the oldest formations, the Archean, as here they are not differentiated for the sake of simplification.

Ophiolites

The ophiolites plotted on this map are restricted to the Meso-Cenozoic times.

Large igneous provinces: the Traps

During some periods in the history of our planet, large eruptive pulses of a relatively short duration (in some cases less than 1 million years) occurred in the Earth at mantle depth. These magmatic "crises" led to the vast and voluminous outpouring of basalts at the surface of the continents (*traps*) as well as on the ocean floor (*oceanic plateaus*). These huge lava flows are interpreted as the consequence of the ascent of a large mantle plume up to the base of the lithosphere to produce the head of a strong "*hotspot*", during the first phases of its life. These surface features are labelled "*Large Igneous Provinces*" (abbreviation *LIP*).

In the former editions of this map the traps were merged into the too large time slices used to corresponding to the chronostratigraphic units of the legend (e.g. the Upper Paleozoic for the *Siberian* traps, or the Mesozoic for the *Deccan* ones in India). On the other hand, a number of traps straddle the large main stratigraphic boundaries of these units, e.g. Upper Paleozoic/Mesozoic (250 Ma) in Siberia; Mesozoic/Cenozoic (65.5 Ma) for the Deccan event. In order to deal with these issues, we chose for this new edition to assign the same

color (bright red-orange) to all the traps, with an indication in black of their average age in Ma. The other traps mapped are those of *Columbia River/Snake River*, of *Parana* and *Etendeka*, of *Karoo* and *Ferrar* (Antarctica), of *Ethiopian* and *Yemen*, of *Rajmahal* and *Sylhet* (India), and of *Emeishan* (China).

Finally, a large *red dashed line* figures the boundary (that one can follow from the east of North America and the NE of South America to the west of Africa and Europe), of a sole large magmatic province. This boundary outlines the traps of the CAMP (*Central Atlantic Magmatic Province*) generated by a hotspot 200 million years ago (limit Triassic/Jurassic) shortly before the opening of the Central Atlantic dislocated this ensemble. Although the erosion caused the disappearance of piling-up of lava flows, the CAMP was reconstructed thanks to the occurrence of related sills and dykes that underlaid the surface outpourings.

Glaciers, inlandsis

Glaciers of some importance were mapped in the far south of the Andes, along with those covering islands of the far North Canada and Eurasia. They were assigned the same color as the Greenland and Antarctica *ice caps*. For the latter *inlandsis*, the *zero meter level contour* (sea level) was drawn.

Structural features

The onshore areas show only two structural features: the large *normal faults* or those of *undertermined nature*, and the large *thrust fronts* curving round the large orogenic belts.

The Iceland case

The entirely volcanic island of Iceland covers a significant area (103 000 km²) and has an exclusively oceanic origin. It was built on a substratum of oceanic crust modified by a powerful hotspot linked to the opening of the North Atlantic. The axis of the *Mid-Atlantic (spreading) Ridge* runs across the island to separate two distinct geodynamic domains; the Eurasian plate to the east, and the North American plate to the west. Instead of mapping this island in the same way as the rest of the onshore areas (i.e. in "V1"), as in the former editions, it was decided to represent it as a surface of oceanic crust where Plio-Quaternary and Miocene basalts are distinguished from each side of the spreading axis.

Offshore areas

The world ocean represents more than two thirds of our planet's surface (70,8%). It covers, on one hand, the submerged edges of the continents, the *continental margins*, and also the deep seafloor whose substratum consists of *oceanic crust* "produced" at the axes of the *spreading ridges*, also called "*Mid-Oceanic Ridges*". The drawing of the offshore part of Sheet 2 was constructed, for some elements (spreading axes, transform faults/fracture zones, subduction zone axes, oceanic plateaus, hotspot tracks and other *anomalous reliefs*), by superposing the tracing draft of this sheet over the "Physiography" sheet.

Continental margin

Continent/Ocean Boundary (COB)

The boundary between the continental crust and the oceanic crust

(*COB*) is shown by a **blue line**. This outlines the *passive continental margins* generated by the rifting of two separating continental blocks to form an ocean. Actually, this boundary is not that precise and one should include a transitional zone between a well identified continental crust and a “normal” oceanic crust characterized by well identified magnetic anomalies.

On this Sheet, some tiny « rafts » of continental crust are shown isolated within an oceanic basin. They are named *microcontinents* and result from the complex history of the continental break-up and seafloor spreading in the formation of an ocean. This is in particular the case for the Seychelles platform in the Indian Ocean; or of the Jan Mayen microcontinent in the far North Atlantic.

Island arcs

The island arcs follow the same mapping principle used for the continents and are bounded by the same **blue line**. It is known that they are the product of magmatic processes peculiar to the *subduction* events that lead to the formation of a “*continentalized*” crust.

Continental shelf

The *continental shelves* (or “continental platforms”, or “continental terraces”) represent the innermost part of the continental margins. They extend from the coastline to the shelf break which tops the *continental slope*. The external limit of this shelf has an average depth of –132 m. For practical reasons, and given the scale of the Map, the commonly assigned –200 m *isobath* is used here to delineate the continental shelf since this depth is generally close to the shelf break. On this Sheet, and from a mapping point of view, the continental shelf was considered only from a morphologic point of view (a terrace) and conceals all other cartographic units it might overlay. Thus, the “continental” shelf of the Niger delta obliterates the oceanic nature of the underlying oceanic crust upon which the sedimentary fan of this large African river is prograding.

The mapping of the continental shelf is one of the innovations of this third edition of the Map. It is an important element when considering the Quaternary palaeogeography of the world. It allows us to consider the withdrawal of sea level that occurred during the *great Würm regression*, the Last Glacial Maximum during which the sea level dropped by about 130 m.

Continental slope

The part of the continental margin located seaward of the shelf break and extending down to the contact with the oceanic crust is called *continental slope*. This term applies also to the island arc margins.

The Antarctic margin

The continental margin of Antarctica presents specific morphological characteristics owing to the isostatic loading exerted on the continental lithosphere for some 30 Ma by its huge ice cap. Therefore the continental shelf and continental slope have been merged into a single map unit to differentiate it from that of the continental slope.

Ice-shelf

For glaciologists, an *ice-shelf* is a thick volume of ice creeping from the ice cap to well beyond the coast and has the form of a glacial sheet floating above a continental terrace. The ice-shelves of Greenland

and Canadian Arctic Islands, too small at the scale of the Map, were not plotted.

Oceanic basins

Oceanic basins are that part of the seafloor whose basaltic substratum is made up of oceanic crust. They are overlain by sediments, except in the axial zones of the mid-oceanic ridges. Their history and structure differ drastically from that of the continents. Oceanic basins cover about 59% of the planet surface. Five main types of morphostructures are to be distinguished: abyssal plains; mid-oceanic ridges; large fracture zones; subduction trenches; “anomalous” oceanic features.

Age of the oceanic crust

The mapping of the age of the oceanic crust was made by interpolation of the position of the magnetic anomalies generated by the effect of periodic inversion of the Earth magnetic field on newly formed crust (cf. Müller *et al.*, 1997) in order to display only the limits of the chronostratigraphic units shown: *Plio-Quaternary* – *Miocene* – *Oligocene* – *Eocene* – *Paleocene* – *Upper Cretaceous* – *Lower Cretaceous* – *Upper Jurassic* – *Middle Jurassic* (cf. the relevant legend). The colours for the different oceanic units are those currently used for CGMW seafloor maps.

Finally, shown in *grey* are a number of oceanic areas where the *age of the crust remains undetermined*.

Abyssal plains

The abyssal plains are characterized by a very flat sea bed with a sometimes quite thick sedimentary cover that extends to both sides of the mid-oceanic ridges. Their depth (blue hues on the physiography of Sheet 1) increases imperceptibly from some 4000 m to a little over 6000 m.

Mid-oceanic ridges

The *mid-oceanic ridges* (or *oceanic accretionary ridges*) form the largest mountain range in the world with a total length of nearly 80 000 km that extends through the four oceans. With a width varying from 1 000 to 3 000 km, the oceanic ridges rise 2 500 to 3 000 m above the abyssal plains. The mean depth of the crest of these ridges is about 2 500 m beneath the sea level. They occupy nearly a third of the surface of the seafloor.

Axis of mid-oceanic ridges

The axis of active mid-oceanic ridges marks the *boundary between two divergent lithospheric plates*. Depending on whether the *divergence rate* is low or high, the morphology of the ridge differs. At low spreading rates (2 to 3 cm/year), as in the Atlantic, the topography is rough and shows a deep axial valley (rift). At high spreading velocities (about 15 cm/year), as in the East-Pacific Rise, the topography is smoother without deep axial valleys. This contrast is strikingly noticeable on Sheet 1 (Physiography).

Concerning the *back-arc basins* (or “marginal basins”) that open “behind” an island arc, a micro-ocean forms and therefore the oceanic accretionary axis is represented by the *same red line* as for the oceans.

The *extinct axes of oceanic accretion* are figured like the active axes by way of a *red dashed line*, as in the Tasman Sea east of Australia.

Transform faults and fracture zones

One of the salient characteristics of the morphology of the oceanic

Sheet 2. Geology, structure. Main map. Mercator projection. Published at the scales of 1:50,000,000 (November, 2009) and 1:25,000,000 (January, 2010).

Sheet 2. Geology, structure. Arctic area limited by 60° N. Polar stereographic projection. Published at the scales of 1:46,000,000 (November, 2009) and 1:23,000,000 (January, 2010).

basins is their sectioning, or slicing, by a set of long faults (black lines on the Map) that cut perpendicular to the mid-oceanic ridges. This kind of feature corresponds to the pair *transform fault* (active)-*fracture zone* (inactive) the latter representing the “scar” of the former. This type of complex fault frequently reaches a length of several thousands of kilometres. On the map, 22 examples of movements of large *transform faults* (or simply large wrench faults) are plotted (double half black arrows in opposite directions) either in oceanic or continental domains.

Subduction zones, subduction trenches and other trenches

The subduction zones indicate the boundary between converging lithospheric plates. Their total length is approximately 55 000 km, a size comparable to that of the mid-oceanic ridges. The *active*

subduction zones are shown by a green line with solid triangles whose tops are situated on the leading (overlying) plate to indicate the direction of the subduction. On the concave side of an island arcs, a back-arc basin opens by separating itself either from a continent, or from another island arc that has become a *remnant arc*, i.e. extinct.

The convergence zones are generally characterized in the submarine morphology by a *subduction trench*. Trenches are not always visible because, in some areas, voluminous sedimentary input are released into the ocean by large river systems that fill up the trench with an *accretionary sedimentary prism*, the *deformation front* of which is indicated on the map by a **symbol** similar to that of the subduction, but colored light blue with open triangles. In the region between this thrust front and the axis of the filled part of the subduction

Sheet 2. Geology, structure. Antarctic area limited by 60° S. Polar stereographic projection. Published at the scales of 1:46,000,000 (November, 2009) and 1:23,000,000 (January, 2010).

trench it was decided to show the age of the underlying oceanic crust, as yet to be subducted but, concealed by the sedimentary prism that would have otherwise been shown as part of the arc margin (e.g., as in front of the Lesser Antilles arc).

There are very few places where an *incipient subduction* presently occurs. It is represented on the map by the *symbol* of active subduction (but with *green open triangles*). This also occurs to the north of the Lesser Sunda island arc (subducting southwards) in order to accommodate the docking of the Australian continental margin as a result of its northward convergence toward the Sunda arc.

It is worth noting a case of *extinct subduction* (represented by a similar *symbol*, but in *purple dashed/dotted line*) in the Vitiaz Trench stretching from the Solomon Archipelago to the northern tip of the Tonga arc.

“Anomalous” submarine features (seamounts, oceanic plateaus, hotspots tracks)

These constitute a large ensemble of all sized reliefs that affects the oceans and is represented by the same *orange-brown hue* recalling, in a subdued way, the colour of the traps on continent. Actually, all these features result from a generally powerful magmatic activity postdating the age of the “normal” oceanic crust. All these features, thus being of volcanic origin, are generated by the activity of a hotspot (whatever the signification attached to this concept) having, with some exceptions, a relatively stationary position. They are of three types: *submarine seamounts*, relatively small, mainly covered by sediments; *oceanic plateaus*; *hotspots tracks (or trails)*, formerly denominated “*aseismic ridges*” because these ridges lack of seismic activity compared to the mid-oceanic ridges located at plate boundaries.

Geologically speaking, an *oceanic plateau* is generally built up during a short period of time from a pulse of intense hotspot activity (plume). The average age of the plateau is given in red. The age, sometimes quite approximate, is given only for 10 oceanic plateaus: in the Indian Ocean, the *Maud Rise*, the *Kerguelen Plateau*, the *Broken Ridge Plateau*; in the Pacific Ocean: the *Shatsky Rise*, the *Hess Rise*, the *Manihiki Plateau*, the *Ontong Java Plateau*, the *Hikurangi Plateau*; in the Atlantic Ocean, the *Caribbean Plateau*, and the *Sierra Leone Rise*.

After dissipation of the plume, only the “tail” of the hotspot remains active, evidently at a lower rate but for a much more extended period of time. This activity is recorded in the moving overlying plate by a chain of volcanoes that drift away from the feeding hotspot, first as an active volcanic center, then extinct, and finally subsiding below the ocean surface.

The *age of selected progression steps* for 6 hotspot trails is indicated in the map: *Hawaii* (the most illustrative example), *La Réunion*, *Kerguelen*, *Louisville*, *Tristan da Cunha*, and *Easter Island*.

Distributed or diffuse plate boundaries

A *grey hatching* covers some oceanic areas where the transform boundary (strike-slip motion) between two lithospheric plates is ill-defined. It is distributed over an area of variable width, e.g. between the North America and South America plates. The largest region displaying this kind of diffuse boundary is located in the middle of the Indian Ocean where it crosses the whole width of the so-called Indian-Australian plate. Actually, it is not yet a true boundary showing a clear separation between an Indian plate and an Australian plate, but a zone where the basaltic substratum is deformed by a compressive stress.

Submarine volcanism related to the opening of the North and South Atlantic Ocean

In the North Atlantic, a *red hatching* overprint shows the presence of *SDRs* (Seaward Dipping Reflector sequences), located from seismic reflection surveys, or *submarine basalt* bodies. The latter can be both outcropping or buried and all provide evidence of an extensive volcanic province related to the opening of the North Atlantic Ocean during the Paleogene and to the activity of the powerful *Iceland hotspot*.

In the South Atlantic, oil exploration has more recently located *SDRs* (*blue hatching*) on the conjugated continental margins of Argentina and Namibia-South Africa. The presence of these reflectors

is related to the opening of the South Atlantic Ocean during the Early Cretaceous and the presence of the *Tristan da Cunha hotspot*.

Hotspots

The hotspot theory was proposed by Tuzo Wilson in 1963. This attractive theory had enormous success in consistently explaining the distribution of specific volcanism generally seen outside the plate boundaries (hence its name of *intraplate volcanism*) and is particularly evident in the oceanic domain. The initial hotspot list included a score of cases, but its number rapidly expanded to 130 units, even more indeed. Today, the list has been brought down to a more reasonable number varying between 40 and 50 hotspots. But not all of them meet the basic criteria of the original model, and particularly a deep origin for the mantle plume and a long duration of the activity (several tens of million years) which determines the progression of a volcanic track in surface. Those cases, disagreeing with the classic model, are labelled *shallow*, *weak hotspots* or *hotlines*, etc. The latter is exemplified by the NE-SW Cameroon volcanic line where the age of the volcanism is not distributed according to a regular migration throughout time, and shows a more or less random mode. The polemics around the hotspot concept has been hardening since the early 2000s, when some researchers denied the existence of a number of plumes. They proposed an explanation for the origin of *LIP* (Large Igneous Provinces, cf. *supra*) mainly attributed to dynamics related only to the plate tectonics *sensu stricto*, which induce shear stress in the lithosphere favoured by pre-existing lines of weakness such as fracture zones.

Whatever it might be, it was considered of informative interest to plot the exact or inferred *position* of 45 hotspots on the Sheet 2 (list given in the **inset** placed in the bottom of the Map). They are categorized in 4 types of hotspots, taking into consideration the criteria of Vincent Courtillot and co-workers (2003) in particular: 1) “primary” hotspots interpreted to correspond to a powerful plume, deeply rooted in the lower mantle and with a long duration, marked HA to HG; 2) hotspots that might be considered as primary, shown Hh to Hi; 3) less characteristic, problematic or controversial hotspots, noted H1 to H34; 4) hotspots supposed to have been extinct since much over 1 Ma, but which would have left traces in the seafloor morphology (eH1) and (eH2).

The full text of the explanatory notes (English and French versions) is downloadable at <www.ccg.org>.

Philippe Bouysse is former Secretary General of the CGMW and main author of the 2nd and 3rd editions of the Geological Map of the World at the scale of 1:25,000,000 and 1:50,000,000.

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