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An Overview of the Present State of Knowledge in the Tectonostratigraphic Evolution of the West Congo Belt in Republic of Congo

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Abstract

The West Congo Belt (WCB) is one of many Proterozoic orogens considered to be mobile belts adjacent to the margins of Archean cratons. This orogen underlies the western margin of the Congo craton in central Africa and outcrops from south-west Gabon to north-west Angola. In the Republic of Congo, the Mayombe Chain in south-west has preserved a geological record of Proterozoic to early Paleozoic rocks that have been investigated to understand the evolution of the West Congo Belt within the regional tectonic context. Investigation into lithostratigraphy and structural architecture of the Mayombe Chain has been done by earlier workers since the 19th century. However, the lack of consistent and diverse geochronological data induced several interpretations of its geodynamic setting. The chain was previously thought to be the result of more than two orogenic cycles, and subsequently to be the result of a single orogenic cycle. Recent petrographic, geochronological, geochemical data and paleogeographic reconstructions allow redefining the tectonic context and the main lithostratigraphic subdivisions of the Mayombe Chain. It is currently recognized that the Mayombe Chain consists of three major tectonostratigraphic domains: Western, Central and Eastern, which are prolongated by the Niari-Nyanga foreland basin. These lithounits seem to have been formed through a complex history that included: (i) Late Paleoproterozoic sedimentation, magmatism and metamorphism between 2110 and 1970 Ma related to the Eburnean tectono-thermal event; (ii) Neoproterozoic rifting magmatism and sedimentation; and (iii) Pan-African tectono-thermal event between 620 and 496 Ma leading to the amalgamation of western Gondwana. In this contribution, we review existing literature on this part of the West Congo Belt and summarize the current knowledge of its geologic setting with a focus on structure, lithostratigraphy and metamorphism. We aim to show how current research, with multidisciplinary approaches, changed the interpretation of the Mayombe with consideration to the Araçuaí-West Congo Orogenic system.

Keywords

Mayombe Chain, Niari-Nyanga Basin, Eburnean, Pan-African,
São Francisco-Congo Cratons

1. Introduction

The evolution of the Earth is characterised by several geodynamic processes. Crustal or continental accretion [1]-[3] is one of the most important Earth structuring processes, leading to the formation of stable continental landmasses (cratons). The Archean-Proterozoic transition is punctuated by many episodes of continentalisation, resulting in orogenic systems of variable configuration and architecture [4]. Archean cratons were involved in the formation of the Proterozoic supercontinents. The present-day African continent was gradually formed by orogenic amalgamation of cratonic blocks such as the Kalahari, Congo, West Africa, East Saharan and Arabian-Nubian Shields [5]. However, it has not always been easy to explain the juxtaposition of orogenic belts and associated cratons as crustal reworking and rejuvenation. The emplacement and reactivation of orogens during recent cycles remains a matter of debate. Several models have been proposed to characterise mobile belts surrounding cratonic landmasses [6].

In central Africa, the West Congo Belt (**Figure 1**) corresponds to the Proterozoic mobile belt surrounding the western margin of the Archean Congo craton. It is currently identified as the counterpart of the Araçuai-West Congo Orogen System (A-WCO) of western Gondwana, which appears in the eastern margin of Brazil and the western margin of central Africa [7]-[13]. In the Republic of Congo, the belt is represented by the Mayombe chain, which outcrops in the southwest of the country (**Figure 2**). This chain consists mainly of meta-plutonic, meta-volcanic and meta-sedimentary rocks, which have been explored since the 19th century [14]. However, previous works in this area were mostly focused on mining exploration and then on structural and petrological points [14]-[28]. Thus, due to its complexity and especially the lack of geochronological data, several models have been proposed to circumscribe the evolutionary context of the chain. Some of the hypotheses and lithostratigraphic subdivisions have been based on petrographic correlation with neighbouring geological units of the Democratic Republic of Congo (DRC) or Angola [21] [23]. Studies combining petro-structural and geochronological approaches have not been widely integrated and have mainly been carried out on restricted units [29]-[32].

Recent studies and mapping of the Mayombe chain [13] [33]-[38] provide additional data that allow redrawing the lithostratigraphic subdivision of the chain based on geochronological and structural data.

The focus of this paper is to share the state of knowledge on the lithostratigraphic evolution of the geodynamic setting of the Mayombe chain, and to highlight current research perspectives in this area.

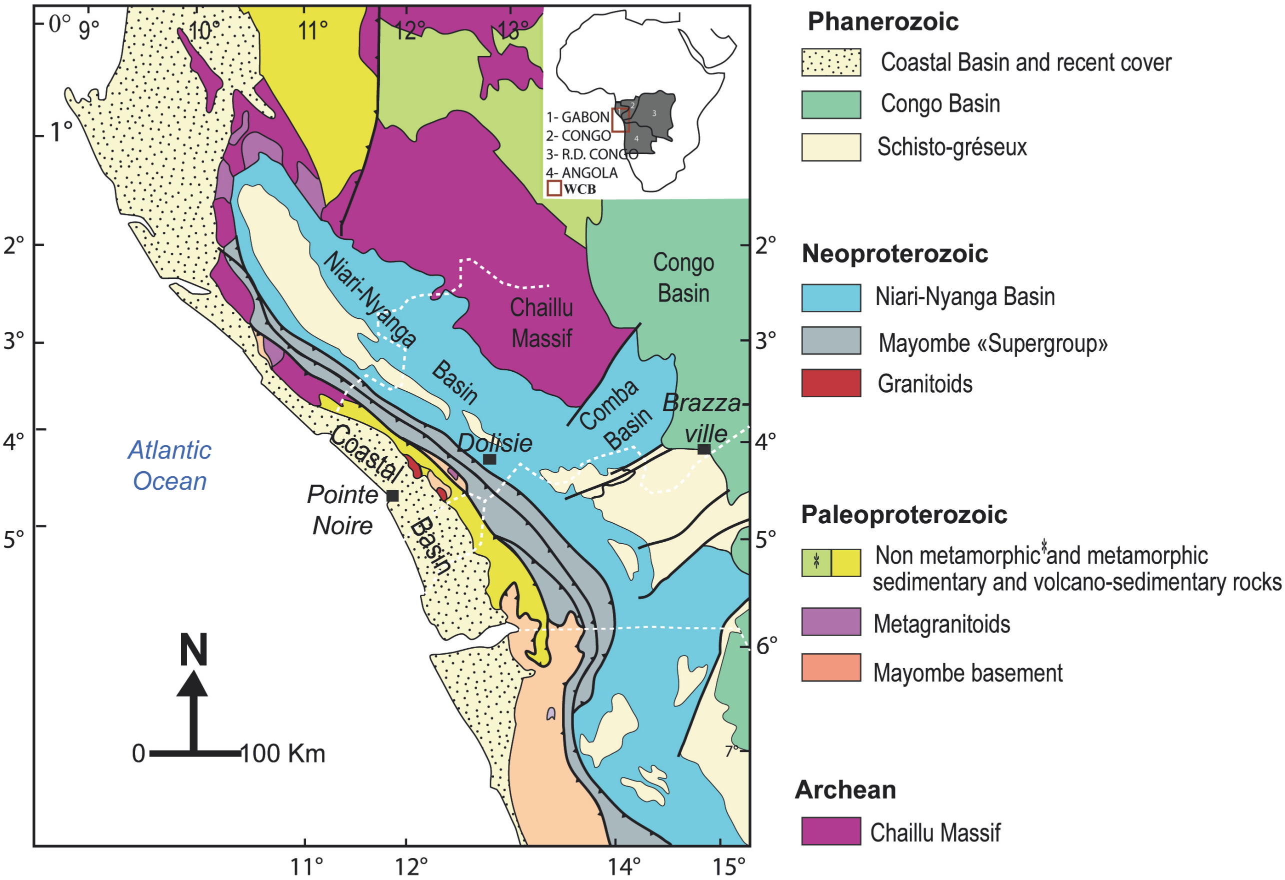

Figure 1. Geological map of the West Congo Belt (WCB) from south-west Gabon to north-west Angola (modified after [39] [40] and redrawn from [41]). The white dashed lines mark the boundaries between countries.

2. Geological Overview

Structural, geochronological and geophysical (paleomagnetic and gravimetric) data from Africa provide strong evidence for the existence of large cratonic continental plates that were later surrounded and overridden by linear mobile belts during the Proterozoic [6]. The Archean Congo craton, located currently in central Africa, was involved in this Proterozoic dynamic which is marked by its amalgamation with other cratons, leading to the formation of several mobile belts such as the West Congo Belt, the Kaoko Belt, the Damara Belt, the Zambezi Belt [5] and the Central African Belt or Oubanguides [42]-[44].

The West Congo Belt (WCB)

The West Congo Belt widely exposed in the western margin of the Congo craton in central Africa, consists of a Proterozoic NW-SE trending fold-and-thrust belt that extends about 1400 km from southwest Gabon to north-west Angola (**Figure 1**), parallel to the Atlantic coast [9] [13] [21] [22] [24] [26] [28] [32] [45]-[47].

The belt is an eastern and external counterpart of the Araçuaí-West Congo Orogenic system (A-WCO), which extends to the east Brazilian margin [48]-[52].

The Mayombe chain, located in the southwestern part of the Republic of Congo (**Figure 2**), is the Congolese portion of the West Congo Belt with a width of 20 to 50 km from north to south and an altitude of 400 to 800 m [14] [36]. The chain is underlain in its southern and western parts by Meso-Cenozoic sedimentary rocks of the Congolese Coastal Basin; it extends towards the northeast with the Niari-Nyanga foreland basin and the overthrust Archean Chaillu Massif (Congo craton).

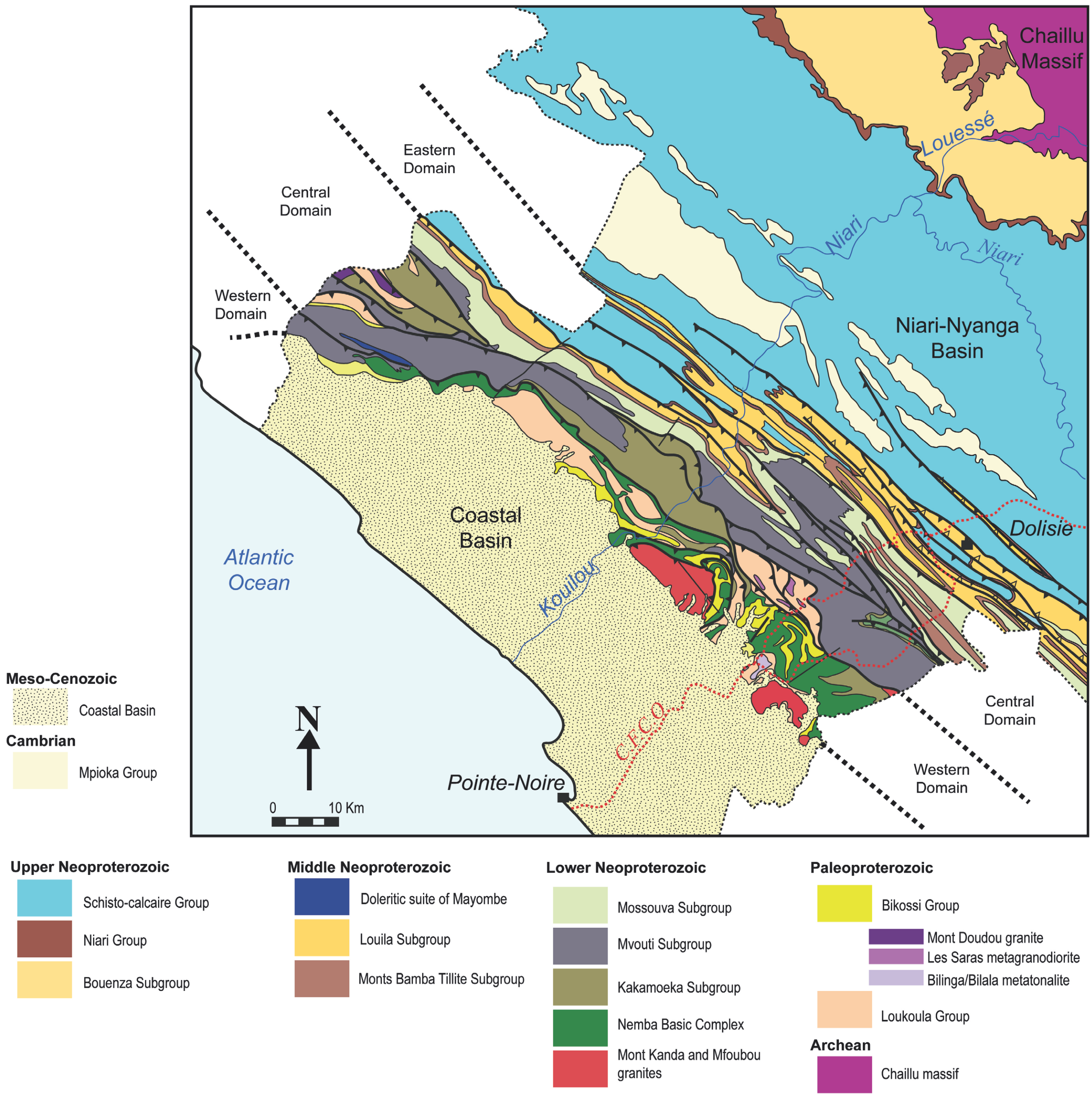

Figure 2. Geological map of the Congolese portion of the West Congo Belt: the Mayombe Chain (modified from [33]).

The Mayombe Chain is made up of para- and ortho-derived metamorphic rocks, which have been the subject of studies by several authors.

3. Lithostratigraphic Subdivisions through Time

The Mayombe Chain currently acknowledged as an important component of the West Congo Belt and its lithounits have been studied since the beginning of the 1900s by different generations of Geoscientists [13]-[37] [39] [41] [46] [53]-[63]. However, stratigraphic complexity and a lack of reliable geochronological data induced divergent interpretations of the Mayombe Chain history. Therefore, the tectonostratigraphic evolution of the Mayombe chain is warmly debated, with diverse models (**Figure 3**) presented below.

3.1. Earlier Observations (1876-1929): Stratigraphic Features

As reported by [14] [20], the geological exploration for the Mayombe region and neighbouring areas of south-western Congo started in 1875 with fieldwork of Peschuel-Loesche. These pioneering efforts have allowed a preliminary view of the geology of the Mayombe region and surrounding areas. According to this author, the Mayombe Chain consists of crystalline schists surrounded by sedimentary rocks of Congolese coastal basin in south, schisto-calcaire rocks of Niari-Nyanga Basin and granitic rocks of Chaillu basement in the north. Since then, other studies have been carried out in the southern part of the Republic of Congo [14] [53]-[57]. These previous works allowed establishing the basic theme of the geology of the Congo in general and of the Mayombe Chain in particular. The construction of the "Chemin de Fer Congo Océan" (CFCO) railway, linking the cities of Brazzaville and Pointe-Noire, allowed access to fresh outcrops and a complete database on the Mayombe Chain [15]-[18] [58], [64] in [14]. In 1929, [17] divided geologic formations of the Mayombe Chain into two series: the crystallophyllian series (supposedly archean) and the quartz-schist or metamorphic series. The first described in the western area of Mayombe in the Bilinga, Bilala and MBoulou areas consists of gneisses and micaschists, which gave way to sericite and chlorite schists. The second outcrops further east, north of MBoulou, near Kakamoéka, Mvouti and up to the Loubomo River (current Niari River) banks.

3.1.1. Models with Multiple Orogenic Cycles

Based on field mapping, many workers proposed that geodynamic setting of the Mayombe Chain could relate to multiple orogenic cycles.

In the following, we present several propositions and various models developed to explain the geodynamic setting of the Mayombe Chain, as related to orogenic cycles.

1. Cosson (1955): Three cycles

Tectonostratigraphic events were integrated into the lithostratigraphic subdivisions of the Mayombe region during the survey of the Pointe-Noire-Brazzaville sheet at a scale of 1:500,000 carried out by [19] who have distinguished three main systems, corresponding each to an orogenic cycle. These are, from the oldest to the most recent: (i) the Lower Mayombe system, including the Loémé, Bikossi and

Loukoula series; (ii) the Bambas Mountains system, including the Mvouti and Mossouva series; (iii) the West Congo system, made up of the Lower Tillite, Louila or Bouenza, Schisto-calcaire and Schisto-gréseux series of the Niari-Nyanga foreland basin. According to Cosson, these different systems are separated by major tectonostratigraphic unconformities.

2. Dévigne (1959): Four cycles

In his study of the Precambrian of Gabon and neighbouring regions (including Congo), [20] added a major discordance between the Bikossi series and the Loukoula series compared to the subdivision of [19].

3. Vincent (1961); Scolari and Van Daalhoff (1965): Two cycles

Between 1961 and 1965, [65] [66] and other authors [67] updated the lithostratigraphic subdivision of Proterozoic strata in the Mayombe Chain by distinguishing the intermediate black series and the upper series instead of the lower and upper Loukoula series and the Mvouti and Moussouva series of [19]. Vincent recognised the existence of two cycles: a pre-Bambian and a Bambian which correspond to two metasedimentary sequences, named Mayombe and West Congo respectively. Furthermore, [67] underlines the discordance between the Bikossi series and the Loukoula series proposed by [20]. Then, the Loukoula series is associated with the Mvouti and Mossouva series to form the Bambian or Mayombian system.

3.1.2. Models with a Single Orogenic System: Dadet (1969); Hossié (1980); Boudzoumou (1986) and Boudzoumou and Trompette (1988)

Previous reconstructions that consider the Mayombe Chain as resulting from multiple orogenic cycles were refuted by some workers who have suggested that Mayombe Chain originated from a single orogenic system based on field observations [14] [21]. In facts, [14] presented the Mayombe units as having developed within a single system, which he described as a geosyncline forming the West Congo Belt. In this model, all the orogenic systems or cycles described previously correspond to a single cycle linked to the Pan-African orogeny [21]. It reached the same conclusion as [14]. He confirmed that, except for a part of the polycyclic Guéna basement (Loémé series), the whole Mayombe Chain shows only a Pan-African style of deformation, to which he associated a regional metamorphism characterised by a grade evolving from east to west from the anchizone to the amphibolite facies. He also distinguished three main tectono-metamorphic domains from south-west to north-east: the internal, intermediate and external domains. Towards the eastern part of external domain, [21] recognised the Niari-Nyanga foreland basin. Based on petro-structural analyses of rock exposures in the Mayombe Chain, the existence of the only Pan-African cycle with an intra-cratonic geodynamic setting was admitted by [24]. He also identified a third deformation phase related to the Pan-African tectono-thermal event, whereas previous studies only mentioned two phases [21].

3.2. Contribution of Available Geochronological Data

Earlier lithostratigraphic schemes and arguments presented above have been focused upon outcrop observations, but did not integrate geochronological data.

This lack of geochronological data has maintained uncertainty in the interpretation of the evolutionary context of the Congolese part of the West Congo Belt. However, geological works carried out from the early 1980s to the late 1990s resulted in the acquisition of diverse geochronological data, which provided first constraints to the revision of lithostratigraphy framework and to revisit the tectonic history of this part of the West Congo Belt.

The first available age of Mayombe formation was given in [68] from the Les Saras granodiorite. Age of 1376 ± 14 Ma was found based on the Pb/α on zircons method. This Mesoproterozoic age helped [23] to suggest that Les Saras calc-alkaline granitoid was evidence of plutonism related to subduction that occurred before the collision of western Archean cratonic blocks (Chaillu and Kasaï) and eastern Paleoproterozoic crustal landmass (Guéna, Doussa, Kimezian and basement Complex respectively located in Congo, Gabon, DRC and Angola) at 1 Ga time. Therefore, the Mayombe Chain was interpreted as formed by the closure of an oceanic basin through subduction processes with the emplacement of ophiolitic complexes. Two main tectonic phases have been described as accommodating West Congolian deformations:

(i) Bambian or Mayumbian phase at 1 Ga (Kibarian)

(ii) Tchibanguian or West congolian phase at 0.6 Ga (Pan-African)

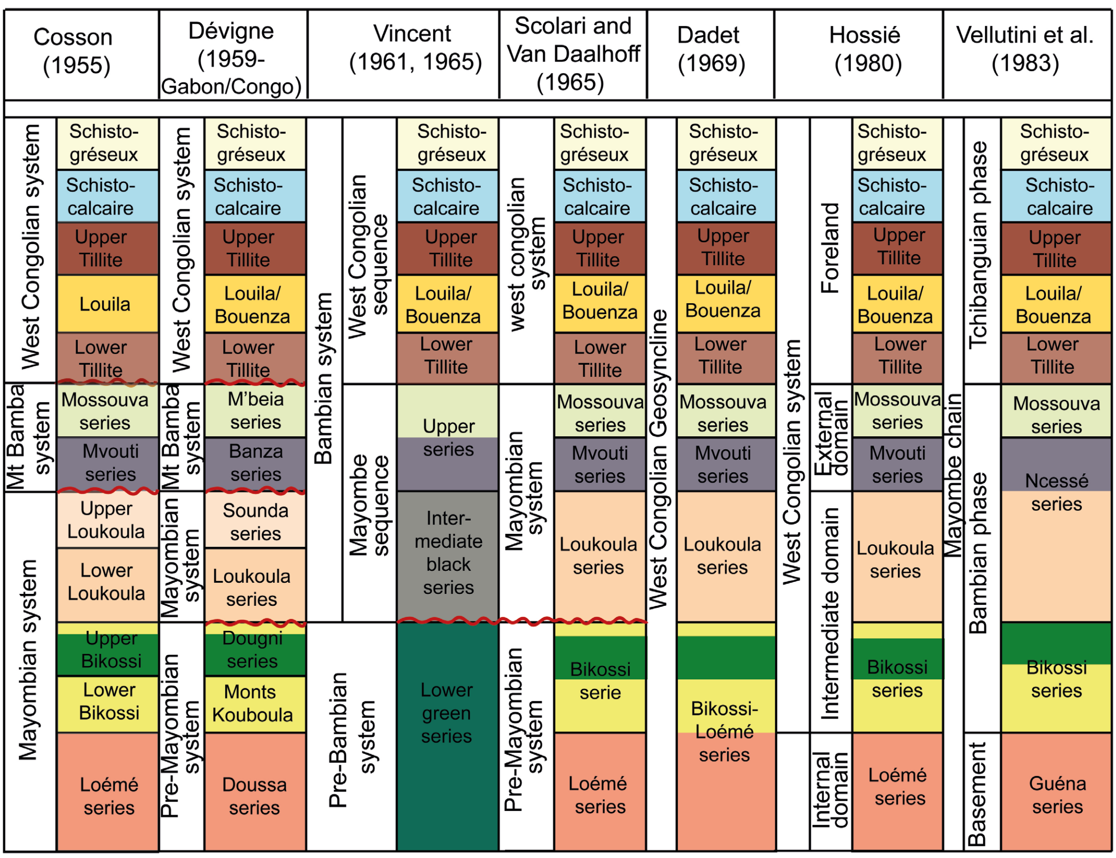

Figure 3. Lithostratigraphic subdivisions of the Mayombe chain, with different orogenic systems marked by a major unconformity (red wavy line) modified after [24] [30] (redraw from [41]).

At this stage, the lithostratigraphy of the Mayombe Chain (**Figure 3**) is almost fixed based on the correlation of lithologies and structures with the neighbouring regions where geochronological analyses have been involved [68]-[72]. However, the age of 1376 Ma, on which [23] based their geodynamic model of the chain, was obtained using the Pb/α method [73], which was very popular in the 1950s but has since proved obsolete.

3.3. A Growing Body of Isotopic Data: Controversy over the Vellutini *et al.* (1983) Model

The development of new techniques for the analysis of samples by mass spectrometry [74]-[76] and the integration of cathodoluminescence (CL) or backscattered electron (BSE) imaging have made it possible to significantly improve age calculation methods with a certain degree of precision. For example, the isotope dilution analysis method (ID-TIMS) was used by [29] to date the Guéna orthogneiss and the Mfoubou granite. Geochronological data brought out by [29] [32] on Guéna gneiss and Mfoubou granite gave respectively ages of 2014 ± 56 Ma and 1050 ± 25 Ma for these lithounits. The first one confirmed Paleoproterozoic emplacement of Guéna basement as assumed by [23]. However, the second one was a matter of discussion because Mfoubou granite displays the same petrographic features as Mont Kanda granite, which has been considered equivalent to Les Saras granodiorite [23]. The alkaline composition of this granite allowed [29] to suggest that there was no collisional setting in the Mayombe chain area at the end of the Mesoproterozoic period (1 Ga). Alkaline magmatism was evidence of an extensive dynamic during this time and attested that Mfoubou granite and Mont Kanda are anorogenic. Moreover, the redating of Les Saras granodiorite [30] brought the age of 2000 ± 80 Ma for this calc-alkaline granitoid, which was considered as Paleoproterozoic and older than its country rocks represented by Loukoula series or Ncessé series (=Loukoula + Moute series; [23]).

Additionally, [31] proposed, based on the new age of the Les Saras granodiorite, that the inner part of the West Congo Belt may correspond to an Eburnean laminar belt with a marginal basin where the Bikossi and Ncessé formations were deposited. Also, [39] made a synthetic structural approach and identified the presence of an Eburnean cycle (2 Ga), pre-Pan-African within-plate magmatism (1 Ga), and Neoproterozoic Pan-African orogeny (0.6 Ga). Thus, the Following lithostratigraphic subdivision was proposed for the West Congo Belt in the Republic of Congo, including from the base to the top: i) the polycyclic tonalitic gneiss of Guéna; ii) the leptyno-amphibolitic Group of the Bikossi; iii) the schists and greywackes of the Loukoula Group; iv) the schists of the Mvouti Group; v) the conglomeratic Group of the Mossouva; vi) the Louila Group with the Lower and Upper diamictite; and vii) the Schisto-calcaire Group and the Mpioka molasse.

An assessment of the available outcrop and geochronological data by [77] has led to the geological map of Congo, which presented the Mayombe Chain and significant revision of previous interpretations, as shown in **Figure 4A**.

[46] gave additional structural data and lithostratigraphic constraints for geologic record of the Mayombe Chain (**Figure 4B**) which he divided into tree structural domains named internal, central and eastern domains. Finally, in the light of the available vintage and sparse geochronological data, this author has suggested reassessment of the existing interpretations for the tectonic evolution of the West Congo belt. Therefore, two orogenic events have been identified in the Mayombe Chain: i) a Paleoproterozoic event (c. 2000 Ma), evidenced by the Guéna basement and Les Saras granodiorite, and ii) a Pan-African event (c. 600 Ma).

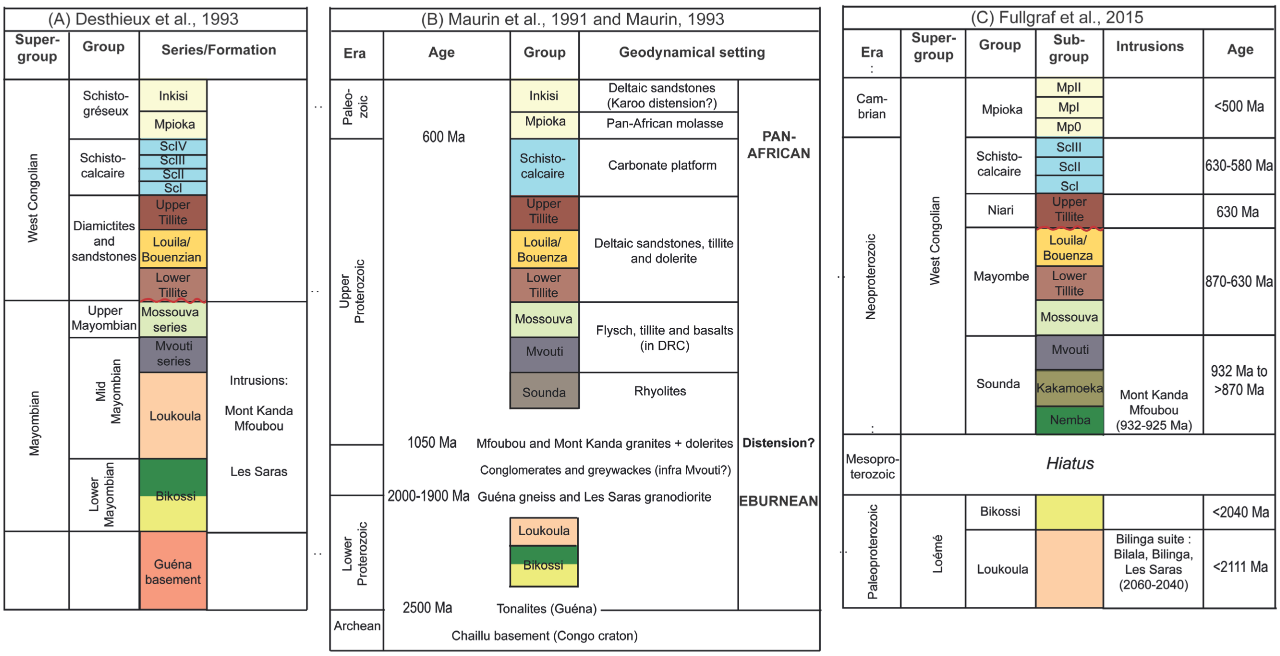

Figure 4. Mayombe Chain lithostratigraphic subdivisions including geochronological data according: A) [77], B) [39] [46] and C) [36] showing important reorganisation for the basal units (ante-Mvouti) and underline the main Mesoproterozoic hiatus.

3.4. New Lithostratigraphic Subdivisions

In 2015, as part of geological mapping program of Congo initiated by the "Ministère de la Géologie et des Mines" in partnership with Total E&P, French geological survey (BRGM) teams [33]-[38] presented new useful geological and geochronological constraints on the geology of the Mayombe Chain and Niari-Nyanga Basin; These recent data provided insight into the structure of Congolese part of West Congo Belt and permitted better understanding of its lithostratigraphy and metamorphic evolution. They have recently published efficient bedrock maps of the Mayombe Chain and Niari-Nyanga Basin with structural interpretations and refined lithostratigraphy. As noted by [46], these authors confirmed that the Congolese part of the West Congo Belt is structurally subdivided into four tectono-metamorphic domains, separated by crustal-scale structures, including (from west to east): the Western (WMC), Eastern (EMC), Central (CMC) Mayombe Chain and the Niari Basin (NB), which are characterized by distinct rock suites. Furthermore, In the light of new isotopic constraints, these authors have in fact presented a revised stratigraphic column for this part of West Congo Belt, comprising two temporarily distinct stratigraphic Supergroups, named Loémé and West Congolian Supergroups placed between the Archean- and Paleoproterozoic and the Neoproterozoic and lowermost Cambrian respectively, which in turn are subdivided into different stratigraphic units (**Figure 4C**), as described below by age range.

The **western domain**, corresponding to the **internal domain** of the chain [21], is complexly structured and comprises Paleoproterozoic basement terranes of the Loémé Supergroup stacked with Early Neoproterozoic rocks belonging to West Congolian Supergroup. The Paleoproterozoic basement terranes consisting of the Loémé Supergroup have been divided into three groups named the Loukoula Group, the Bilinga metatonalitic suite and the Bikossi Group.

The **Loukoula Group** is composed of schists, amphibolites, quartzites and gneisses that were intruded by the Bilinga suite. Detrital zircons reveal a maximum deposition age of 2111 ± 14 Ma [36] [38].

The Bilinga suite consists of three Eburnean-aged gneissic meta-plutonic massifs: Bilala metatonalite dated at 2014 ± 56 Ma (U-Pb on zircon, ID-TIMS, [29] [32] and 2048 ± 12 Ma (U/Pb on zircon, SIMS, [36] [38]; Bilinga metatonalite with emplacement age of 2028 ± 12 Ma and Les Saras granodiorite dated at 2000 ± 80 Ma (ID-TIMS, [30] [31]) and 2038 ± 10 Ma (SIMS, [36] [38]).

The **Bikossi Group**, previously known as the Bikossi series [14] [19] [21] [23] [24] [29] [30] [39], was defined by [23] as comprising of two parts: (i) a strongly deformed set mostly composed of biotite and garnet gneisses, micaceous quartzites, metagabbroic rocks and graphitic schists, and (ii) a group mainly composed of basic rocks and some intercalations of chloritic mica schists with garnet. Recent works carried out by the French geological survey teams [36] [38] have led to the splitting of the Bikossi series into two different lithostratigraphic units (**Figure 4C** and **Figure 5**). These authors have shown that the Bikossi Group corresponds to the metapelitic and meta-quartzitic sequence of the ancient Bikossi series, while the **Nemba Basic Complex** corresponds to a metabasic sequence made of amphibolites, epidotites, gabbros and chlorite-schists. U-Pb dating detrital zircon from the metasedimentary rocks of Bikossi Group by SHRIMP method yields an age of sources ranging between 3.08 and 2.04 Ga [36] [38] and 2.20 to 2.00 Ga [13], indicating a maximum age of deposition at about 2 Ga. However, zircons from a metagabbro attributed to the Nemba Basic Complex have provided a Neoproterozoic age (915 ± 8 Ma, [36] [38]) which has been interpreted as a syn-rift emplacement of gabbro. This Neoproterozoic age allows linking the Nemba Basic Complex to the West Congolian Supergroup.

Numerous large **granitic intrusions**, including the better known the Mfoubou and Mont Kanda granites [14] [19] [28], are identified as cutting across the Paleoproterozoic basement rocks of Loémé Supergroup. The Mfoubou Granite was dated at 1050 ± 25 Ma (U-Pb zircon, ID-TIMS: [29] [32]) whereas the Mont Kanda Granite has provided ages of 928 to 932 Ma (U-Pb zircon, LA-ICP-MS: [36]). Similar granites are known southeastwards in the Democratic Republic of Congo (e.g.

Noqui Granite: [9] [71] [78]).

The central and eastern domains are characterised by northern verging thrust-folded deformations formed at the end of the late Ediacaran phase of deformations. They correspond to a fold-and-thrust belt overthrusting the foreland basin and are essentially constituted of Neoproterozoic generally weakly to moderately metamorphic, deformed rocks of the West Congolian Supergroup, including two key marker horizons, namely the Lower and Upper Tillite [13] [36]. The Neoproterozoic metasedimentary rocks have been interpreted as deposited in a rift [26] and/or a passive margin [36].

The **syn-rift sequences** [36] are represented by the **Sounda Group** which contains from bottom to top, the Nemba Basic Complex, the Kakamoeka and Mvouti Subgroups. The Nemba Basic Complex comprises metagabbros, metabasalts, amphibolites, and greenschists. The Kakamoeka Subgroup is made up of conglomerates, quartzites, graphitic schists, ignimbrites, rhyolites, tuffs, metabasic rocks, whose equivalent is dated between 920 ± 8 Ma and 917 ± 14 Ma in the DRC [9]. The Mvouti Subgroup comprised chlorite-schists, black schists, quartzites, meta-sandstones and meta-arkoses.

The **post-rift sequences** are represented by the **Mayombe Group** which contains, from bottom to top, the Mossouva Subgroup, the Lower Tillite Formation and the Louila Subgroup. The Mossouva Subgroup is made up of quartzites and schists. The Lower Tillite is a glaciogenic or a mudflow deposit constituted by black calcareous shale matrix containing heterogeneous, heterometric and heteromorphic pebbles and boulders. The Louila Subgroup is made up of meta-sandstones, locally conglomeratic, quartzites, quartzo-schists and schists with intercalation of limestones and calcschists [14] [19] [26].

In the **Niari-Nyanga basin**, the Lower Tillite is overlain by the Louila subgroup which in turn is overlaid in regional unconformity by the glaciogenic deposits of the **Niari Group**, also known as the Niari Tillite, which consist mainly of gravity deposits. These deposits are associated with the Marinoan glaciation that developed at the end of the Cryogenian [79] [80]. They are covered by calcareous-dolomitic carbonate deposits of the **Schisto-calcaire Group**, deposited in a shallow environment favourable to the development of gypsum-type evaporites [81] and in an extensive context [36] [82]. The whole has been involved in Pan-African compressional dynamics.

Structurally, the Neoproterozoic sequences are deformed by open, upright folds (**Figure 5**) whose NW-SE trending axes can be followed along strike for more than one hundred km. A few NE-verging thrusts are also recognised, and this association of structures defines the frontal fold-and-thrust belt of the Pan-African Mayombe orogen [21] [26]. In the innermost portions of this sequence, a penetrating schistosity, which is axial-plane to the large-scale folds, can be observed in the less competent layers. The more competent layers, like the quartzite formations, exhibit flexural slip, and lack penetrative schistosity. The metamorphic grade is consistently very low (chlorite grade, or lower), with a grading to anchizonal in the adjacent Niari-Nyanga basin [36] [41].

The **Mpioka Group**, which comprises the last terms of the West Congolian Supergroup, was previously described as a flysch [14] and it is currently considered to be the molasse of the chain [9]. It consists of silico-clastic conglomeratic sediments at the base and sandstone-pelitic sediments at the top. The detrital micas in this group have been dated between 580 - 500 Ma [36]. Similarly, the detrital zircons have given major age peaks between 500 - 800 Ma and 900 - 1200 Ma [13], testifying to an almost Cambrian evolution.

In addition to the refinement of lithostratigraphy subdivisions, French geological survey teams have added important information on tectono-metamorphic history

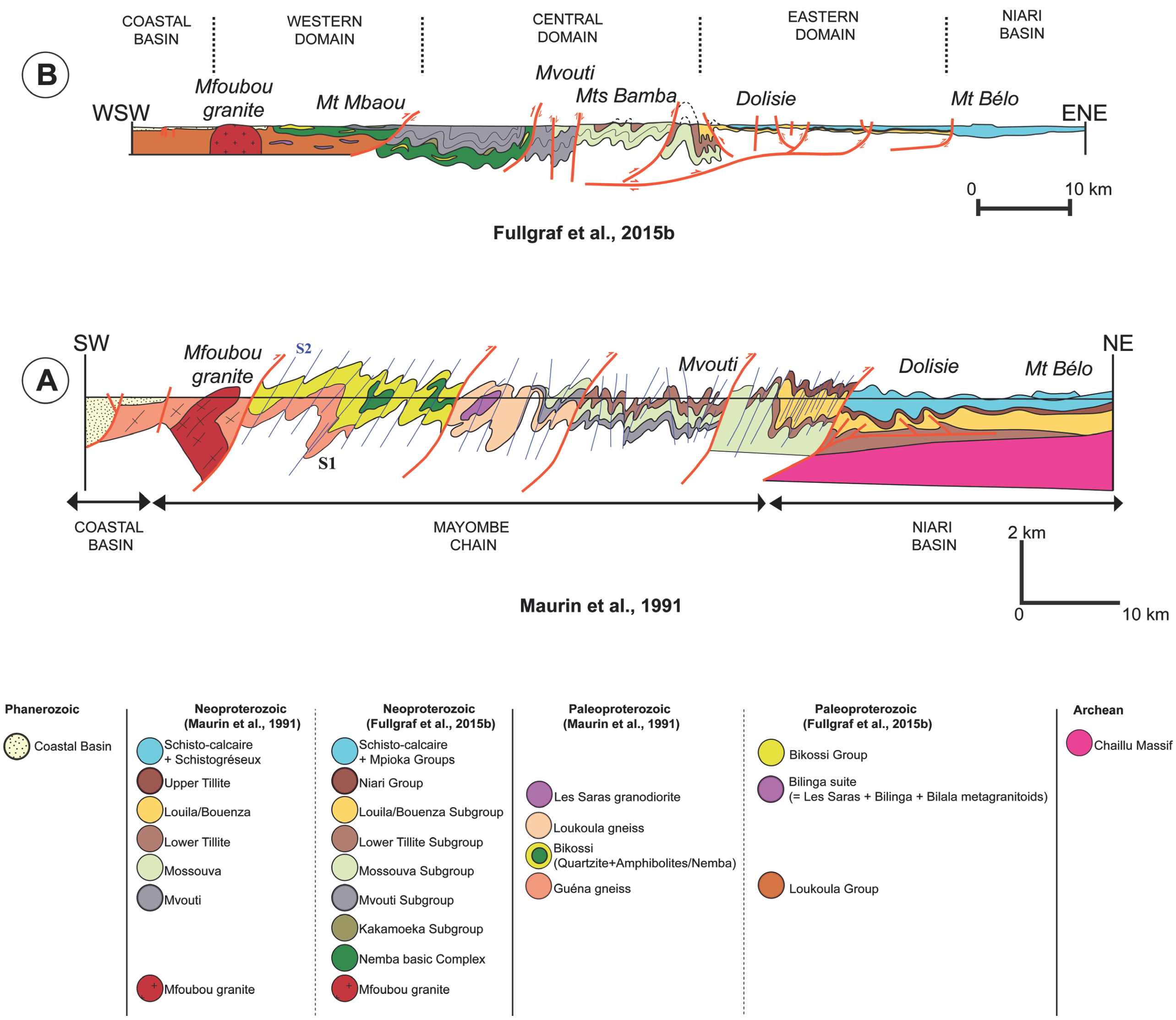

Figure 5. Cross sections represented structural architecture of Mayombe Chain with variance in style of deformation and lithostratigraphy in the Paleoproterozoic and Neoproterozoic units according to A) [39]: The Paleoproterozoic and Neoproterozoic units accommodate Pan-African fold style as a result of NE-SW compressive constrains. S1 and S2 correspond to two main phases of schistosity related to the Pan-African event. Red lines correspond to faults mainly represented by thrusts within the chain and B) [36]: Foliation in the Paleoproterozoic Loukoula Group is flat and Neoproterozoic Mfoubou granite seems not to accommodate the Pan-African global style of the chain. Main difference occurs also on the constitution of Bikossi Group (yellow) and Nemba Basic Complex (green).

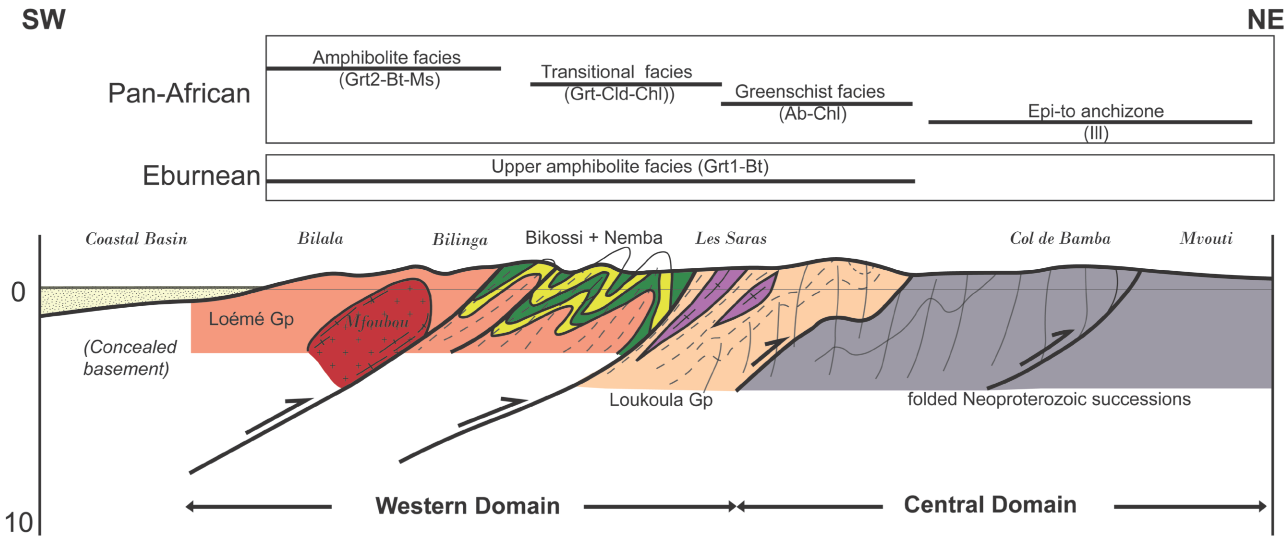

Figure 6. Simplified cross-section of the Mayombe Chain (modified from [63]) showing structural architecture and metamorphic evolution of mineral assemblages from the western domain to the central domain depending on the Eburnean and Pan-African tectono-themal events. Paleoproterozoic units (Loémé Group, Loukoula Group and Les Saras metagranodiorite) are affected by both events while only Pan-African style of deformation is recorded in Bikossi Group (yellow) + Nemba Basic Complex (green), Mfoubou granite and the folded Neoproterozoic successions (grey) marked by northeast verging folds with axial plane schistosity. Abbreviation meaning: Gp—Group, Grt—Garnet (1 & 2 = first and second generation of garnets), Bt—Biotite, Ms—Muscovite, Cld—Chloritoid, Chl—Chlorite, Ab—Albite, Ill—Illite.

of the Mayombe Chain and Niari-Nyanga basin. They revise and better constrain the timing of tectonic events that affected the Neoproterozoic and Early Paleozoic rocks of the West Congo Belt in the Republic of Congo. As stated by earlier workers [21] [24] [39], French geological survey teams have confirmed that the grade of metamorphism in the West Congo Belt decreases towards Northeastern. These authors also supported the commonly accepted interpretation of the Neoproterozoic geological units of the Mayombe Chain and Niari-Nyanga basin as being subjected to regional deformation and low-grade metamorphism related to the Late Neoproterozoic to Cambrian Pan-African orogenic event at 590 - 570 Ma (M1) and at 520 - 500 Ma (M2). However, they stated that a complex structural and stratigraphic history evolved in the Western domain of the Mayombe with multiphases of superimposed orogenies. In fact, the Paleoproterozoic basement rocks within the Western domain of the Mayombe Chain have been demonstrated to be affected by the Eburnean Orogeny ca. 2091 ± 18 Ma and partly reworked by the Pan-African orogenic event.

In addition to the work of the French Geological Survey, an effort has recently been made to investigate the metamorphic history of the Paleoproterozoic terranes within the Western domain of the Mayombe Chain [41] [63]. [63] have constructed a structural cross-section (**Figure 6**). Thus, considering the garnet chemical zoning, grade of metamorphism and structural features, the Paleoproterozoic Metasedimentary rocks of the Loukoula Group defined by [36] can be separated into two main parts from north to south, named respectively the Loukoula and Loémé Groups, which preserves evidence for the long-standing polycyclic metamorphic history presumably linked to the Eburnean and Pan-African-aged orogeneses. Ancient Eburnean metamorphic assemblages seem identical from south to north, and rocks display an upper amphibolite facies characteristic [63]. However, Pan-African overprinted Paleoproterozoic rocks have been recorded differently in these two parts (**Figure 6**). Conversely, these authors have assumed that the metasedimentary rocks of the Bikossi Group, previously interpreted as part of Eburnean terranes [36] [38], underwent medium pressure-temperature (MP-MT) conditions (4 - 6 kbar; 500˚C - 600˚C) related to transitional even amphibolite facies during Pan-African Orogeny and appear not to have been subjected to the Eburnean orogenic effects. However, it is pointed out that these observations are not supported by the available U-Pb radiometric age data, and so the previous model of interpretations cannot yet be replaced.

4. Discussion

A wide range of published literature [13] [14] [21]-[23] [28]-[32] [36] [38] [39] [41] [46] [59]-[63] [82]-[84] is available describing the geological setting of the Mayombe Chain and Niari-Nyanga basin which are collectively referred to as the portion of the West Congo Belt developed along the western margin of the Congo craton. In fact, over time, the Mayombe Chain and its foreland basin Niari-Nyanga have revealed a dual interest: i) their lithological assemblages host diverse mineralisation with economic implications, and ii) the chain represents a piece of the grand puzzle that allows the reconstruction and understanding of Precambrian lithospheric plate dynamics. The first phase of exploration in this part of the West Congo Belt was motivated by mineral exploitation and opened a window for mapping and petrographic description. The second phase, which is still ongoing, has focused on the scientific aspects of its formation and evolution through geological time.

By the 1980s, the concept of plate tectonics was established, and some questions were raised to better understand the evolutionary dynamics of the Earth. Questions arose about the formation of the Earth's inner mantle, mountain ranges and the absorption of former oceanic areas. The West Congo Belt and its Counterparts in Brazil proved to be an ideal case study to answer these questions. The synthesis of various studies carried out in these belts pointed to many contradictory opinions in the literature about the extent and age, tectonic environment, geological meaning of rock units composing this part of the west Congo. Therefore, contradictory stratigraphic subdivision schemes exist and are often based on geological fieldworks and little long-distance geochronological constraints.

4.1. An Updated Lithostratigraphic Framework

There is general agreement that the Congolese portion of the West Congo Belt is constituted of Paleoproterozoic and Neoproterozoic to Cambrian terranes showing various degrees of metamorphism from upper amphibolite to greenschist facies even anchizone, which occur in four major structural domains known as the

Niari-Nyanga Basin (NB), Eastern (EMC), Central (CMC) and Western (WMC) Mayombe Chain [13] [24] [26] [27] [31] [36] [38] [63]. However, the tectonostratigraphic reconstruction of the geological record of this part of the west Congo Belt has historically been very problematic and variously defined in terms of lithostratigraphic subdivision and associated nomenclature of rock units. Amongst existing lithostratigraphic subdivisions, the arguments have largely been based on field-based geological observations, but rarely chronostratigraphic data. For this reason, the stratigraphic positions and ages of rock units have been much debated.

Initially, the earliest workers [19] [20] [66] [67] presented different reconstructions of the lithostratigraphy of Congolese part of composing four, three or two distinct lithostratigraphic systems, separated by major unconformities, each of which was thought to represent an orogenic cycle which was poorly age-constrained. Other authors [14] [21] [23] proposed contrasting lithostratigraphic subdivisions. Contrary to earlier lithostratigraphic reconstructions, in their stratigraphic reconstructions, the entirety of rocks recorded in Mayombe Chain and Niari-Nyanga basin, except the Guéna basement, is assumed to be considered as one main tectonostratigraphic system, defined as West Congolian Geosyncline by [14], or as the West Congolian system by [21] or as the Mayombe Chain by [23]. Gross differences between these previous lithostratigraphy subdivisions are likely the result of lacking radiometric age constraints. As a result, these previous subdivisions into several or single lithostratigraphic systems are inconsistent or less reliable. Some of the hypotheses and lithostratigraphic subdivisions have been based on petrographic correlation with neighbouring geological units of the Democratic Republic of Congo (DRC) or Angola [21] [23]. Studies combining petro-structural and geochronological approaches have not been widely integrated and have mainly been carried out on restricted units [29]-[32].

Over the last 10 years, however, new field observations and modern absolute dating have raised in Mayombe Chain and Niari-Nyanga basin [13] [33] [35]-[38] [41]. A growing body of isotopic data has led to redrawing the lithostratigraphic subdivision and associated nomenclature of the chain based on geochronological and structural data and allowed clear regional correlations to be produced between this part of the West Congo Belt and neighbouring countries (Gabon, Democratic Republic of Congo and Angola). In fact, [36] has published a robust and age-constrained Tectono-Stratigraphy scheme for this part of the West Congo Belt **that has been the definition of new rock units and a revision of formation age, and nomenclature for many**. One of significant advances with this new lithostratigraphy has been the recognition of younger detrital zircons of c. 2111 Ma that facilitates the definition of maximum depositional ages of the oldest basement rocks in the Mayombe chain older than the age of magmatism of its intruding orthogneiss of the Bilinga Suite dated at 2065 ± 13 Ma and 2028 ± 12 Ma, which constrain the minimum age in these basement rocks [36] [38] [41]. Based on these additional age constraints, [36] proposed to include all Paleoproterozoic polycyclic metasedimentary rocks outcropping in the Western domain, previously documented as Guéna basement [14] [21] [23] [24] [32] [59] into the **Loukoula Group** [36] [38]. They also supported the commonly accepted interpretation of these basement rocks as a relic of the Eburnean context.

Another significant advance has been the better definition of lithostratigraphic status of metasedimentary rock and metabasites overlying the basement rocks of the Loukoula (former Guéna) which was controversial due to the absence of geochronological data. Historically, these metasedimentary rocks and metabasites have been grouped within the Bikossi Group [39] [46] or the Bikossi Series [14] [19]-[21] [23] [67]. Some earlier workers consider these rock units to be part of the Pre-Mayombian system [14] [19]-[21] [23] [67], whereas others have assigned them to the Eburnean basement [39] [46]. However, new geochronological data have improved age constraint of stratigraphic units. In fact, reliable ages for the siliciclastic metasedimentary rock of the Bikossi and their overlying metabasites have recently been determined [13] [36] [38] [41]. Thus, the maximum depositional age of siliciclastic metasedimentary rocks belonging to the Bikossi Group is now constrained by detrital zircon geochronology dated at 1971 ± 40 Ma (Paleoproterozoic). This date is significantly older than U-Pb crystallization age of 915 ± 8 Ma obtained from zircons of the overlying metabasites, suggesting that it postdates the Eburnean event and pre-dates Tonian rift magmatism [38]. These new geochronological constraints clearly show that the Bikossi Group and Nemba Basic Complex belong to two distinct tectonostratigraphic units. Thus, the Bikossi Group is assumed to be part of the Paleopoterzoic Loémé Supergroup while Nemba Basic Complex is assigned to the lower part of the West Congolian Supergroup [36] [38]. Moreover, according to [36]-[38], the Paleoproterozoic allochthonous supracrustal metasedimentary rock of the Bikossi Group can be correlated with the rocks of the Paleoproterozoic Francevillian Group of the eastern Gabon.

Additionally, the newly acquired geochronological data, combined with field observations, enabled mapping of metavolcanics and granitoids which are coeval with U-Pb metabasite ages discussed above, linked to the early Neoproterozoic rifting phase. [36] [38] generated U-Pb zircon ages at 912 ± 7 Ma from bimodal metavolcanic rocks assigned to the Kakamoéka Subgroup. In turn, age constraints of the coeval granitoids have been refined through U-Pb isotopic dating of zircon yielding an age of 932 ± 8.3 Ma. These additional age constraints allowed the modification of the lithostratigraphic subdivision of the Proterozoic geological record of the Mayombe Chain. These newly documented Early Neoproterozoic metavolcanics and coeval metabasite of the Nemba Basic Complex and granitoid intrusions are grouped into a single lithostratigraphic units named the Sounda Group which is considered as the equivalent, in composition and age, of the Gangila meta-basalts from the Zadinian and the Mayumbian Group at DRC part of the West Congo Belt [45] [71]. Furthermore, a comparison of previous lithostratigraphic reconstructions revealed that the lithostratigraphic subdivision from the Mossouva subgroup to the Mpioka Group has remained almost unchanged for decades.

More generally, recent works have clearly shown that the stratigraphic record of the Congolese portion of the West Congo Belt can be divided into two main tectono-lithostratigraphic intervals known as the Loémé and West Congolian Supergroups of Paleoproterozoic and Neoproterozoic to Cambrian in age, respectively [36] [38]. The tectono-stratigraphy of the West Congolian Supergroup is relatively well known. This Supergroup comprises a succession of igneous, clastic rocks and carbonates that is formally divided into five tectono-lithostratigraphic units defined as groups, including the Sounda, Mayombe, Niari, Schisto-calcaire and Mpioka groups. Comparatively, little is known about the lithostratigraphy and associated structure of the Paleoproterozoic autochthonous basement terranes overlain by the Bikossi Group formations made up of allochthonous supracrustal rocks belonging to the **Loémé Supergroup**.

Besides, there is generally well-defined boundary between the stratigraphic units, and this new toctono-lithstratigraphic reconstruction is limited by the sparsity of available geochronological data.

4.2. Tectonic History: Single Orogeny versus Multiple Orogeny

Amongst existing research concerning the geology of the West Congo Belt has focused on its structure and lithostratigraphy, but rarely on its geodynamic history. Nonetheless, it is known that the present configuration of the West Congo Belt is the result of a complex succession of tectonic processes involving rifting, subduction, and collision phases. There is general agreement that the intensity of the deformation and metamorphism grade in the West Congo Belt decreases northwards. However, there is no consensus on the interpretation and dating of deformation and metamorphic events that affected the Congolese part of the West Congo Belt. Therefore, different geodynamic models have been proposed to depict the number or sequence of orogenic events that have affected the geological record in the Congolese part of the West Congo Belt, and the different scenarios of the tectono-metamorphic history. Some earlier workers argued for a scenario of multiple orogenies [19] [20] [65]-[67]. These authors differentiated at least three orogenies in the evolution of West Congo Belt. Contrary to predictions of the multiple orogeny Hypothesis, subsequent authors [14] [21] [23] [24] point to late Neoproterozoic to early Paleozoic collision during the Pan-African orogeny as the single tectonic event recorded in the entire West Congo Belt, expect in the Guéna basement. However, recent works done in Congo provided new contexts for understanding the tectono-thermal events in the West Congo Belt. These works gave increasing credence to the scenario of multiple orogenies. These authors claimed that the West Congo Belt was developed by a sequence of superposed regional orogenic events linked to the Eburnean and Pan-African collisions, which influenced its structural (**Figure 5**), stratigraphic, and metamorphic evolutions. A similar scenario of multi-phases of superimposed two orogenic events has been proposed to explain the geodynamic evolution of Araçuaí Mobile Belt in

Southeastern Brazil [85] [86].

In summary, two main tectonic pulses influenced the formation of the West Congo Belt. U-Pb ages on zircon and Ar-Ar ages on biotite, muscovite and amphibole in the Loémé, Loukoula and Bikossi groups show that the Paleoproterozoic units of the Mayombe Chain have been affected by both the Eburnian orogeny (c. 2000 Ma) and the Pan-African orogeny (c. 640 - 496 Ma) [36] [38] [41]. Eburnian metamorphism is recorded in the upper amphibolite facies with garnet-biotite-oligoclase assemblage in the metapelites and plagioclase-brown hornblende in the metabasites of the Loémé Supergroup. These Eburnian units were subsequently involved in the rifting process associated with the break-up of Rodinia around 1 Ga [36], giving rise to the West Congolian Basin, in which the magmatic and sedimentary rocks of the West Congolian Supergroup were emplaced and deposited. These rocks were subsequently metamorphosed and deformed at the end of the Neoproterozoic-Early Paleozoic during the Pan-African Orogeny, leading to the assembly of western Gondwana [8] [36] [38]. The Pan-African Orogeny affected the pre-existing Eburnian units and induced metamorphism characterised by a gradient perpendicular to the chain, increasing towards the west-southwest and recorded differently in the Loémé and Loukoula Groups [63]. In the former, the mineralogical assemblages are garnet-biotite-oligoclase with an overgrowth of new generations of garnet (Grt1) on old ones (Grt2), while in the latter, the Pan-African paragenesis is of low-grade made of chlorite-albite-epidote. The Bikossi Group shows garnet-chloritoid-chlorite-muscovite assemblages in a monocyclic evolutionary context, taking into account garnet growth zoning [63]. All the constituent units of the West Congolian Basin (Sounda Group, Mayombe Group, Niari Group and Schisto-calcaire Group) were only affected by the Pan-African orogeny [36] [38] [41]. The deposition of the siliciclastic formations of the Mpioka Group marks the breakdown of the chain in early Paleozoic time [9] [36].

5. Conclusions

The Congolese portion of the West Congo Belt has a long history of geological investigations dating back to the 1950s that provided the essential basis for understanding its geologic setting. According to these previous works, this part of the West Congo is composed of four major tectono-metamorphic domains from west to east, including the Western (WMC), Eastern (EMC) and Central (CMC) Mayombe Chain, and Niari-Nyanga Basin (NB), that are characterized by distinct rock suites. Although the structural, lithostratigraphic and metamorphic characteristics of this part of the West Congo are becoming better constrained with more precise isotopic ages, its historical setting has been told in many ways and is evolving with recent work in geologic mapping and academic research. This contribution provides a review of the existing literature on the geology of the West Congo Belt in Congo and provides summaries and syntheses for its structural and lithostratigraphy framework and metamorphic evolution. It led to the following conclusions:

i) the geological record in the West Congo Belt consists of a variety of igneous, volcanic, and sedimentary rocks, ranging from Proterozoic to early Paleozoic in age, which have been deformed and metamorphosed to different degrees. The Mesoproterozoic strata, however, was not observed within the Congolese part of the West Congo.

ii) In the context of recent knowledge, the geological record of the West Congo Belt can be divided into two Supergroups: 1) the Loémé Supergroup comprising Paleoproterozoic polycyclic basement terranes of the Loukoula Group and supracrustal metasedimentary rock of the Bikossi Group, and 2) the West Congolian Supergroup including both Neoproterozoic and Cambrian rock units.

iii) The internal or Western domain of the Mayombe chain is a structurally complex area comprising an assemblage of different terrains, including relics of Paleoproterozoic Eburnean basement that records an older polyphase tectono-metamorphic history comprising at least two stages separated from each other by the emplacement of calk-alkaline Eburnean intrusions between 2060 and 2020 Ma.

iv) At present, it is accepted that the Western Congo Belt is the result of the collision between the São Francisco (Brazil) and Congo (Africa) cratons during two main orogenic events: the Paleoproterozoic Transamazonian/Eburnean orogeny and the Neoproterozoic/Early Paleozoic Brasiliano/Pan-African orogeny. The latter led to the assembly of western Gondwana with the formation of a major mountain belt: Araçuaí-West Congo Orogen (A-WCO), of which the West Congo Belt is the outer or external part. Separating the effects of the Paleoproterozoic Transamazonian/Eburnean orogeny from the Neoproterozoic/Early Paleozoic Brasiliano/Pan-African orogeny is difficult and is the subject of scientific debates which are not definitively closed.

Despite knowledge gained from the recent research, there are still some fundamental questions remaining related to the chain's structuring and evolution, particularly i) the age of Eburnean metamorphism, ii) the relationship between the Bikossi Group and the Nemba Basic Complex, which has always constituted the unique Bikossi series of ancient authors, and which as we see on the map of [33] (**Figure 2**) are folded together. This question leads to that of the great Mesoproterozoic hiatus in the West Congo Belt from Gabon to the DRC. The Bikossi Group and the Nemba Basic Complex were differentiated based on the ages obtained from detrital zircons and an intrusive gabbro, respectively. The nature of these samples provides several possibilities for considering these ages.

The interpretation of structural characteristics of the Western domain is more complex due to the Pan-African overprint of Eburnean units. The complexity of its deformation has left numerous questions regarding its tectonic and metamorphic evolution unresolved, providing rich avenues for future research. One of these issues concerns the spatial distribution of rock units in this domain, their internal stratigraphy, geochemistry, and geochronology, which remain ambiguous and need to be addressed to create a more comprehensive view of West Congo Belt evolution. The influence of the Pan-African tectono-metamorphic overprinting Eburnean basement structures needs to be better defined through more efficient mapping with detailed structural, stratigraphic and geochronological analyses.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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