**A pioneer of Precambrian geology: Boris Choubert's fit of the continents
across the Atlantic (1935) and his insights into the Proterozoic tectonic
structure of the **West** African Craton and adjacent areas**

Dominik Letsch¹

¹Dominik Letsch, Institute for Geochemistry and Petrology, Department of Earth Sciences,

ETH Zurich, Clausiusstrasse 25, CH-8092 Zurich, Switzerland. E-mail: dletsch@erdw.ethz.ch

Abstract

Plate tectonics revolutionized the Earth Sciences during the 1960s and led to a fundamentally new view of tectonic processes inside mountain belts. Application of the new theory to pre-Permian and especially Precambrian orogenic belts developed somewhat reluctantly during the 1970s and 1980s. The present article presents and discusses the ideas of Boris Choubert (1906-1983), a French colonial geologist of Russian origin, which he first developed in 1935. He tried to test Wegener's theory of continental displacement (a forerunner of plate tectonics) by applying it to Paleozoic and Precambrian orogenic belts around the Atlantic (a topic altogether neglected by Wegener). To achieve this, he produced a fit of the continents across the Atlantic which is almost identical to the famous 1965 fit of Bullard et al. Starting from this Paleozoic continental configuration, he presented an inter-continental synthesis of Precambrian geology and discussed problems from a wide array of topics, ranging from regional tectonics of the West African Craton, questionable Precambrian fossils, tillites (and cap carbonates) to the supposed origin of detrital diamonds in Gabon and Brazil. He also provided probably the first Precambrian plate reconstruction *avant la lettre*. After his 1935 paper, Choubert worked for decades in Africa and South America and had opportunity to test and refine his synthesis. His example is a call, addressed to present-day geologists working on Precambrian geology in Africa and other regions, to consult the old colonial literature which contains a wealth of factual information and theoretical inspiration which is still of interest today.

Keywords: Gondwana – Gabon – West African Craton – diamonds – Brazil – continental drift

1. Introduction

When Alfred Wegener first published his groundbreaking paper “On the origin of continents” in 1912, knowledge and awareness of Precambrian geology was only very vague. Wegener based his idea of the lateral mobility of continents, thereby anticipating many aspects of the plate tectonics revolution of the 1960s (e.g. Frankel, 2012a), on many geophysical, geodetic, and geological lines of evidence. However, the latter were exclusively concerned with Permian and younger geological features and it is not clear whether this procedure was only due to methodological reasons (more complete geologic record, see e.g. Köppen and Wegener, 1924), or if Wegener really thought continental displacement was a young and unique event in Earth history (a view heavily criticized by influential critics, e.g. Chamberlin, 1928; Schuchert, 1928, see also Frankel, 2012a and Hoffman, 2014). Be that as it may, some supporters of Wegener’s new theory recognized this serious neglect and hence applied mobilist interpretations to pre-Permian mountain systems (“Variscan” and “Caledonian” systems) especially in the Atlantic area, thereby partly anticipating Wilson’s (1966) proposal of a proto-Atlantic (Argand, 1924; van Waterschoot van der Gracht, 1928; Staub, 1928; Wegmann, 1935). While these isolated attempts of pre-1960s mobilist tectonic approaches to Paleozoic mountain belts are rather well documented by historians of science and geologists (e.g. Frankel, 2012a; Şengör and Okuroğullari, 1991), there seems to be only limited awareness of any pre-1960s tectonicians who applied mobilist models to problems of Precambrian geology.

Possible reasons for this neglect are manifold. First, knowledge of the Precambrian was very sparse (somewhat better developed only in some areas as e.g. the Baltic shield) well into the 1960s and even later until the advent of trustworthy geochronological methods and the fast development of Precambrian (that is Proterozoic) paleontology and biostratigraphy in the 1970s and 1980s (Schopf, 1992). Consequently, only very few of Wegener’s contemporaries

and even less of his sympathizers had firsthand knowledge of the Precambrian, with Eugene Wegmann (1935, see also Letsch, 2013) being an outstanding exception. Second, even after the triumph of tectonic mobilism in its reincarnation as new global or plate tectonics (Frankel, 2012d) during the 1960s, many geologists (with some notable exceptions, e.g. Burke and Dewey, 1973) working on problems of Precambrian tectonics remained skeptical if a direct application of plate tectonic models to their study subjects was appropriate (e.g. Kröner, 1979; Martin, 1983; see Windley, 1984 for a general discussion). Hence, one might argue that they were not as enthusiastic as their colleagues working on Phanerozoic tectonics (as e.g. Schmidt, 1976; Şengör, 1976, White et al., 1970; Şengör and Okuroğullari, 1991), to identify and discuss pre-plate tectonics mobilist forerunners. A third and last, but not the least reason for this neglect might have been the difficult accessibility of some very remarkable pre-1960s geologic syntheses on Precambrian continental displacement, as they were mostly written in French and published in sometimes obscure journals and monographs. The present article tries to fill this gap and highlights a remarkable and insightful article by the French geologist Boris Choubert from 1935. Being concerned with both the more general question of continental displacement and the more regional aspect of Central and Northwest African (Precambrian) geology, Choubert (1935) anticipated not only – at least qualitatively – Bullard et al.’s (1965) iconic fit of the circum-Atlantic continents, but also provided the first and extremely interesting tectonic overview map of the wide Precambrian realms of Africa, South America and adjacent areas. Furthermore, Choubert gave one of the earliest descriptions of the sedimentologic peculiarities of Proterozoic post-glacial dolomite layers (“cap carbonates” in modern parlance) in Central Africa and discussed Precambrian connections between Africa and South America (including the provenance of sediment-hosted diamonds in Brazil). Thus, his life and work is still a source of inspiration for present-day workers and this paper is also a plea for the study of old literature on Precambrian problems, not only from a historical point of view but also a valuable source of local, regional, and even global geological information.

2. The reception of Wegener's theory in France

Contrary to the situation in the German, the Anglo-Saxon (including the then still existing British Empire and associated countries), or the Dutch and Scandinavian world (Carozzi, 1985; Le Grand, 1988; Frankel, 2012a), the reception of Wegener's (1912, 1915) hypothesis of continental displacement is not so well documented in the French world. The situation in the French-speaking part of Switzerland, where Argand's (1924) brilliant continental-scale mobilist tectonic analysis of Asia convinced several other workers to seriously consider continental displacement, is a notable exception and it has been discussed in detail in the literature (Şengör, 1982; Trümpy, 2001; Schaer, 2010, 2011; Frankel, 2012a; Letsch, 2013). The few available accounts on reactions in France itself (Carozzi, 1985; Gaudant, 1995; Durand-Delga, 2009) paint the picture of a general hostility against Wegener's hypothesis, which might indeed have been fueled not least by anti-German feelings in the aftermath of World War I, as Wegener's work only became widely known to a French audience through a translation of the paleontologist Manfred Reichel in 1924 (Schaer, 1991, 2011). Apart from that more chauvinistic aspect, an important factor for many geologists to embrace or reject tectonic mobilism, was whether or not the new theory provided an advantage in explaining the geology of the region the geologist in question was working on. This tendency, variously called *localism* (Le Grand, 1988) or *regionalism* (Frankel, 2012a) is very well expressed by the positive acceptance of Wegener in Dutch and British overseas territories and related countries (India, Australia, South Africa, Dutch East Indies) where either disjunct geologic relics (as in the fragments of Gondwana of the Southern hemisphere) or young subduction-related tectonic and volcanic activity (Dutch East Indies and the Caribbean) served as striking arguments in favour of the new theory. For sure, the exchange with the respective motherlands helped to render continental displacement an acceptable theory in Britain and the Netherlands. France, on the other hand, with her main overseas possessions being represented

by often sand- or jungle-covered, mostly Paleozoic and Precambrian terranes of Western Central and Northwest Africa or French Indochina (Vietnam, Laos, and Cambodia), was in no way in a favorable position to provide colonial geologists with easily recognizable geologic witnesses of continental displacement. Hence, it is perhaps not surprising that only two geologists working in the French colonies or protectorates could be identified who openly declared support for continental displacement. The first, Philibert Russo (1885-1965), an army medical doctor (finally reaching the rank of a major), biologist, and (mostly applied) geologist spent several decades in French Morocco and published a series of books and papers which fully embraced continental displacement (Russo, 1930, 1933, 1936, 1947; see also Médioni, 2008 for a detailed exposé of his life and work). The works based on the acceptance of continental displacement of the second geologist, Boris Choubert, form the core content of the present paper.

3. Boris Choubert (1906-1983)

There is not much biographic material available on Boris Choubert (alias Schuberth). The following short biographic account is based on scattered hints in his own papers, oral communications of the Swiss petroleum geologist Walter Ziegler (formerly Exxon Africa) who knew Choubert's brother George personally, and a Russian source in the internet (<http://www.dommuseum.ru/index.php?m=dist&pid=16606>). He was born in 1906 in St. Petersburg, then the capital of the Russian Empire. During the communist takeover in 1917 the family emigrated to Finland and later, in 1927, to Germany, where they lived in Mittelbexbach in the westernmost part of the country just across the border of the French City of Metz. Boris and his younger brother (and later geologist, see below) Georges got the French citizenship in 1929 and Boris subsequently studied engineering geology at the University of Nancy and also spent some time at Brussels University in Belgium (1931-1933?). In 1933, he went for approximately one year to Gabon, then being part of "l'Afrique

Equatoriale Française”, to study and map the old basement rocks there as part of his PhD thesis (submitted to Sorbonne University of Paris) which was published in 1937 (Choubert, 1937). From 1938 to 1945 he was again in Gabon conducting geological exploration and probably also attended the important Brazzaville conference (in today’s Republic of the Congo) in 1944, where Free French and colonial representatives (under the lead of General de Gaulle) promised far-reaching political reforms to the indigenous people living in French colonies in Central and West Africa. Later stages of Choubert’s professional career included some years of geological research (especially mineral exploration) in French Guiana (1947-1961), work for the French national research organization CNRS, the “l’école nationale supérieure des mines de Paris”, and an assignment at the University of Nice. Choubert continued publishing until shortly before his death in 1983 on topics ranging from granite geochemistry/petrology, to regional geology, tropical geomorphology, ore geology, or geochronology.

Boris’ younger brother Georges (1908-1986) also made his career as a geologist and spent several decades in Morocco working in leading position for the “Service géologique du Maroc” (Debrenne, 2014). His main emphasize was on the extended outcrops of Proterozoic and Lower Cambrian rocks in southern Morocco (Anti-Atlas belt) and he published several seminal contributions to Precambrian geology (e.g. Choubert, 1963). Apparently, he was also influenced scientifically by his older brother.

4. Choubert’s continental fit of 1935

Choubert’s earliest and probably also his most outstanding and original contribution to continental displacement and the Precambrian structure of West Africa and adjacent areas was published in 1935 in the bulletin of the institute for physical geography of Paris University (“Revue de géographie physique et de géologie dynamique”). It is convenient to divide his achievements into two parts and to discuss them separately. The first aspect of his 1935

publication (the second one – Precambrian tectonics and regional geology – will be treated in the next paragraph) is his geometrical fit of the continents around the Atlantic into a pre-Mesozoic position. Surprisingly, Wegener himself never produced a geometrically sound and hence convincing reconstruction of his supercontinent Pangea (but see fig. 17 in Wegener, 1915). In fact, he did not even discuss or at least appreciate the geometrical peculiarities of movements of rigid caps on a spherical surface (e.g. Letsch, 2013). One of Wegener's major critics in the US, Charles Schuchert, was the first to conduct geometric reconstructions of continental fit with the help of a plasteline layer moulded onto a physical globe (Schuchert, 1928). Maybe not surprisingly, he arrived at a result which did in no way support Wegener's reconstruction because he did not take into account the counterclockwise rotation of Iberia and treated Europe and Africa as one rigid unit. It is Carey (1955) who is generally credited for being the first one to have performed rigorous continental reconstructions on a sound geometrical base using a hemispheric drawing table (Frankel, 2012b). The breakthrough in this regard was then achieved by Bullard et al.'s (1965) transatlantic reconstruction based on an iterative least-square procedure and using Euler's theorem (Dewey, 2015).

Choubert (1935) based his geometrical fit on a composite bathymetric map of the Atlantic Ocean whose sources he did not indicate. The reconstruction itself (Fig. 1) is surprisingly similar to the Bullard et al. (1965) solution (as pointed out and illustrated by Gaudant, 1995) but deviates considerably both in quality (no continental distortions) and in content from Wegener's schematic sketch (Wegener, 1915: Fig. 17). In line with the – compared to present-day standards – somewhat amateurish style of Choubert's paper (few direct references in the text, almost nothing about methodology etc.), there is no indication of how exactly he carried out the reconstruction. Fortunately, many years later and shortly before his death, Choubert (1981) gave some information on how he worked out his 1935 reconstruction. Thus, he coated a physical globe with a veil which he rendered transparent by means of paraffin and then

shifted continental outlines on that envelope. However, it remains unclear how he proceeded to project the drawings on this envelope onto the map published in Figs. 1 and 2. But how could he come so close to the Bullard et al. fit? There are several operations which he had to conduct to arrive at it. Again, he mentioned or discussed only some of them explicitly in the text. Most importantly and contrary to Schuchert (1928), he treated Europe and Africa as two separate units and thus arrived at a much tighter Atlantic fit but also at a triangular-shaped gap (or ocean) between northern Africa and southern Europe, widening towards the east (in present-day coordinates). The latter bears much resemblance to the pre-Triassic Tethys Ocean (Paleo-Tethys, Şengör, 1979) of later plate-tectonics reconstructions (Smith, 1971), but stood in Choubert's days in stark contrast to contemporary, narrow and parallel-sided reconstructions of Tethys (Argand, 1924: Fig. 6). Additionally, he closed the Gulf of Biscay ("Golfe de Gascogne") without crediting Argand (1924) but with mentioning its considerable depth, its young fill, and the similarity of the older rocks on both sides of it as a justification. Furthermore, he closed Baffin Bay, eliminated substantial parts of the Caribbean and Middle America, and ignored all oceanic islands (notably Iceland) and the Mid-Atlantic rise. The latter neglect is a little bit surprising as even leading mobilists (with the notable exceptions of Wegener, 1912 and Ampferer, 1941) were at that time of the opinion that the Mid-Atlantic rise was composed of an elongated slice of original continental crust ("sial", e.g. Argand, 1924; Daly, 1926) and could thus not simply be ignored in pre-displacement reconstructions. Choubert (1935, p. 6) admitted that there might indeed be some relics of continental crust in the Mid-Atlantic rise (being otherwise composed of "hardened sima"), but he nevertheless explicitly stated that he found it unnecessary to assume a gap between the western and eastern shores of the Atlantic in a pre-drift reconstruction.

After publication of Bullard et al.'s fit in 1965, Choubert had a short correspondence with Sir Edward Bullard in order to draw the latter's attention to his much earlier and very similar fit

(reported in Choubert, 1981). Bullard allegedly declared to Choubert that he did not have much interest in citing old literature. In his personal view on the emergence of plate tectonics, containing a substantial historic discussion on Wegener and the reception of his theory of continental displacement, Bullard (1975) did not mention Choubert at all. In the same year, however, Choubert's work got a nice little tribute by Princeton professor Franklyn Van Houten (Van Houten, 1975) who found it *"a bit said, however, that in recognizing these and other pioneers [Wegener and du Toit], Boris Choubert (1935) was overlooked."* Almost ironically, Van Houten's short note has been overlooked too by geologists and historians of science which might perhaps be due to that his 2-page paper was not listed separately in the table of contents of *Geology* and can thus be easily missed (Paul F. Hoffman, personal communication).

5. Choubert's insights into Precambrian (mainly African) regional tectonics

Apart from its originality as a large-scale continental reconstruction study, Choubert's 1935 paper and especially his plate A (reproduced here as Fig. 2) represent a very remarkable, in certain aspects almost prophetic, synthesis of continental and especially Precambrian geology. We will focus in the present discussion on northwestern Africa and surrounding areas (Fig. 3) for two reasons. First, it is in this area where Choubert's contributions were most original and some of his ideas most perplexing even for present-day workers. The geology of the vast deserts covering what is known today as the central and northern parts of the West African Craton (WAC), was only known in its very broadest outlines around 1930 and the same applies as well to western equatorial Africa with the southern part of the WAC. Second, it was in this area (and in – paleogeographically – adjacent French Guiana and Brazil) where Boris Choubert had the opportunity to test and modify his 1935 proposal.

Probably the most striking aspect of Choubert's inter-continental Paleozoic and Precambrian tectonic synthesis (Fig. 2) is the high degree of internal tectonic complexity (outlined by

250 tectonic trend lines) which he assumed inside the mainly Precambrian continental interiors of
251 the Baltic Shield, Laurentia (Canada and USA), and Gondwana (South America and Africa).
252 Whereas this assumption was not really new for such well-studied Precambrian areas like the
253 Baltic Shield, Choubert was clearly ahead of his time regarding Gondwana. This gets very
254 clear if one compares his synthesis with du Toit's (1937) Paleozoic Gondwana reassembly
255 and his very faint indications of Gondwana's Precambrian tectonic fabric (Fig. 4), or with
256 Wegener's (1929: Fig. 16) knowledge on West African basement tectonics. Many of these
257 areas had by 1935 only recently become accessible for detailed research by western scientists
258 or had still not yet completed the often bloody process of European (i.e. French, British, or
259 Spanish) conquest. Whereas most sub-Saharan southern parts of the WAC (e.g. Senegal,
260 Ivory Coast, Ghana, or Nigeria) had become European colonies during the final decades of
261 the nineteenth century (with already some good geological overview maps being available in
262 the early 1930s, see e.g. Jessell and Liégeois, 2015), the western part of the Sahara and its
263 rims remained mostly sheltered from substantial European influence until the 1930s. The
264 geologically crucial areas of the Anti-Atlas (Morocco), e.g., had only been completely
265 conquered ("pacified") by the French in 1934, and it took several more years for the Spanish
266 government to get the coastal areas between Agadir and Dakhla (i.e. Western Sahara, the
267 disputed southern provinces of present-day Morocco) under control (Hodges, 1983). This
268 state of political and military affairs was also reflected by the poor knowledge of regional
269 geology: reconnaissance mapping and often only sporadic information from desert
270 expeditions was scattered in the French, Spanish, and British literature. Choubert collected
271 and consulted an impressive amount of literature on the Sahara (see reference list in Choubert,
272 1935) while working at Brussel's University, and he synthesized his reading on large-scale
273 maps during two years (Choubert, 1981). It is against this historical background that his
274 tectonic inferences have to be seen, some of which will be discussed briefly in the following.

275 Starting in the south (Leo or Man shield), he correctly identified the Dahomeyide orogen and
276 its foreland basin (Volta Basin) in Ghana and surrounding countries (Affaton et al., 1991, see
277 also Fig. 3). However, due to a lack of biostratigraphic data, he did not specifically state its
278 Proterozoic age but instead used the vague term “antépermien”. Further west, he almost failed
279 to recognize the coast-parallel Neoproterozoic Rokelide orogenic belt (Villeneuve and
280 Cornée, 1994; Fig. 5) and instead let the bulk of the Paleoproterozoic and Archean tectonic
281 fabric of the WAC run in a rias-coast-like fashion into the Atlantic (he corrected this mistake
282 in later versions of his Atlantic fit, see Choubert, 1967). However, he additionally drew a
283 small North-South trending belt of supposed Precambrian folding (difficult to see on the small
284 scale of Fig. 3) in Sierra Leone which demonstrates that he must have been aware of the
285 presence of a tectonic belt of Neoproterozoic age in that area which only became generally
286 known through the pioneering study of Allen (1969), who also proposed the term Rokelides
287 (Fig. 5). This belt plunges northwards beneath the Paleozoic sedimentary fill of the Bové
288 basin, as correctly drawn by Choubert as well. Northeast of the latter, he assumed a large-
289 scale arcuate belt of folded and metamorphic Precambrian basement running from Guinea in
290 the South to Port-Étienne (Nouadhibou, Mauretania) in the North. In doing this, he anticipated
291 – at least structurally and geometrically – the Mauritanide fold belt (Mauritanides, Fig. 5)
292 which was made popular by Sougy’s influential 1962 GSA Bulletin paper on West African
293 fold belts. Unlike Sougy (1962), who assumed the Mauritanides to be a post-Devonian
294 (Hercynian) orogenic fragment, Choubert (1935) suspected a Precambrian age for the tectonic
295 deformations and metamorphic overprint. More recent work seems to indicate mostly
296 polyphase – Late Neoproterozoic *and* Late Paleozoic – deformation in the Mauritanides
297 (Lécroché et al., 1991). To the East of these folded zones, Choubert clearly recognized the
298 northern part of the WAC – the Reguibat Shield – and identified it as Archean basement.
299 Confined by the Reguibat Shield in the North, the folded zones of coastal northwestern Africa

in the West, and the Man (Leo) Shield in the South, he outlined quite precisely the Paleozoic Taoudenni Basin (Fig. 5).

Most surprising is Choubert's synthesis of the northern and northeastern margins of the WAC. There, two main areas with extensive Precambrian outcrops can be distinguished, the Anti-Atlas of Southern Morocco and the Hoggar Mountains (a purely morphological term encompassing the Neoproterozoic Hoggar Iforas Belt and the Paleoproterozoic to Archean Tuareg Shield) of Algeria, Mali, and Niger. The Precambrian and Early to Middle Cambrian age of vast parts of the Anti-Atlas had only been demonstrated a few years before Choubert finished his synthesis in 1933 by means of Cambrian archaeocyathid fossils (sessile reef-building organisms reminiscent of sponges) found in carbonates covering the Precambrian (see Choubert, 1963 and Debrenne, 2014 for historical accounts). And it was not until the late 1930s and 1940s that the general outlines of Precambrian geology could be unraveled (to a large part due to Boris' brother George). The second area, the remote Hoggar Mountains, was at that time even less known than the Anti-Atlas. Even though **mostly** French military expeditions had reached this mountainous area in the heart of the Sahara by the turn of the century (Porch, 1984), information on the geology was still patchy. Haug (1905) summarized data gathered by the Sahara pioneer Fernand Foureau (**during the monumental, bloody, and suicidal Foureau-Lamy Transsahara Expedition, see Porch, 1984**) and concluded that the Hoggar was composed of a crystalline basement exhibiting strong pre-Devonian ("Caledonian") tectonic deformation with a pronounced north-south strike, which was covered by a gently dipping (but otherwise undeformed) blanket of Silurian and younger sedimentary rocks. This general picture was confirmed and worked out in its details by geologists joining expeditions during the 1920s (Kilian, 1922; Bourcart, 1928). **Kilian (1925), furthermore, was the first to recognize Precambrian tectonic movements in the Hoggar areas. Following this latter author,** Choubert (1935) seems to have been **one of** the first to make a

clear distinction between the older Paleozoic orogens of Europe (“Caledonides”) and the older deformations (“Archean”) in the Hoggar area (the Hoggar Iforas belt of Neoproterozoic age). Furthermore, Choubert assumed a profound boundary (“Precambrian continental outlines”, the thick dashed lines of Figs. 2 and 3) between the Hoggar Iforas belt (albeit with a question mark) and the WAC which he drew running northwest to divide the Anti-Atlas from the northern margin of the WAC and then continuing along the southwestern border of the Appalachians. It would certainly stretch the evidence in an anachronistic way to propose that Choubert anticipated a suture zone in the modern sense of the term along this boundary, but he certainly realized its importance. His boundary almost parallels the commonly accepted western and northern boundary of the WAC which is delineated by HP/LT metamorphic continental and oceanic arc relics in the Hoggar Iforas belt (Berger et al., 2014), the Bou Azzer ophiolite (the first fully described Precambrian ophiolite ever, see Leblanc, 1976, and Fig. 6), and several oceanic arc relics in the Anti-Atlas (Triantafyllou et al., 2016; but see the different interpretation of the northern margin of the WAC by Ennih and Liégeois, 2001 shown on Fig. 5). Even though it is beyond the scope of the present paper, it is worth pointing out that Choubert (1935) also assumed a “suture zone” (his “Precambrian continental outline”) running from the Moine thrust in Scotland to Newfoundland and the northwestern margin of the Appalachians in a manner reminiscent, though different in the details, of later proposals by pioneers of Precambrian and Paleozoic plate tectonics (Wilson, 1966; Dewey, 1969).

6. Inspiration and confirmation: fieldwork in Gabon and French Guiana

Boris Choubert published his mobilist tectonic synthesis in 1935 while working for his PhD in Gabon (Choubert, 1981). However, even though he cited literature as new as the year of publication, he seems to have completed the main outline of his work before coming into direct contact with African geology, and his plate A (Fig. 2) was finished in 1933 in Brussel

350 (as indicated at the base of the map). Hence, one could say that from 1933 onwards, he got the
351 opportunity to test and modify his great early synthesis by means of fieldwork in Precambrian
352 series on both sides of the Atlantic, first in Gabon (1933-1945) and then in French Guinea
353 (1947-1961).

354 His PhD thesis entitled “Étude géologique des terrains anciens du Gabon” appeared in 1937
355 and primarily summarized the results of extensive field studies in a tropical country covered
356 either by rain forest or savanna. The last chapter of this thesis, however, was devoted to a
357 regional correlation of the mostly Precambrian basement fringing the much younger Congo
358 Basin and outcropping in a vast territory encompassing parts of the present-day countries of
359 Gabon, Republic of the Congo, Democratic Republic of the Congo, Angola, and Republic of
360 Zambia. Without mentioning his mobilist ideas or even citing his 1935 paper, Choubert also
361 included in this last chapter a discussion of the pre-Permian geology of Brazil and compared it
362 with the geology of the Congo Basin substratum. He justified this inclusion by the lapidary
363 statement: “*According to another order of ideas, it might be interesting to see to what degree*
364 *the African continent, being part of the great Gondwana ensemble, can be compared to*
365 *another of Gondwana’s fragments: Brazil.*” (Choubert, 1937: 185; freely translated).
366 Choubert noted a high degree of similarity among the pre-Permian stratigraphies of these very
367 distant areas but he did not dwell on this topic and never mentioned the possibility of
368 continental displacement. It seems reasonable to assume, that he did this to avoid any troubles
369 with his supervisors who, as almost all contemporary French geologists, were hostile against
370 Wegener’s idea. Choubert returned to Gabon shortly after completion of his thesis and he was
371 lucky to find in 1938 or 1939 Gabon’s first diamonds in alluvial deposits of the Bendolo
372 River (a minor tributary of the Ogooué River) in central Gabon (Choubert, 1946). Years later,
373 Choubert (1981: 42) recalled his great pleasure to recognize that the Gabon diamonds did not
374 resemble the “South African type” but much more the “Minas Gerais type” of Brazil and that

these two diamond-bearing provinces might once have been once close together and were presumably of similar origin. However, again as in 1937 he did not mention this link in his 1946 paper. As potential source rocks for the diamonds, he identified fine-grained olivine-bearing dikes crosscutting the highly metamorphic Precambrian basement of central and south Gabon which he compared with kimberlites (Choubert, 1946). Even though Choubert's "kimberlites" were later identified as Precambrian olivine-phlogopite lamproites (Mitchell, 1989), they contain indeed diamonds and have been the target of active exploration since the early 2000s. Interestingly, even though the source of the sediment-hosted Precambrian diamonds of the Minas Gerais region in Brazil have not yet been identified (Gonzaga et al., 1994; Chaves et al., 2001), the connection to the Gabon lamproites has – to our knowledge – never been made by anybody since Choubert (1946), even though the two diamond provinces were probably close together before the Mesozoic (e.g. Trompette, 1994).

From 1947 onwards, Choubert worked intermittently until the 1960s in French Guiana and published voluminous monographs on the regional geology of this tropical French overseas department and its neighborhoods (e.g. Choubert, 1960). In the volcano-sedimentary Paramaca Group (part of an Archean to Proterozoic greenstone belt) he recognized part of a geosynclinal system whose prolongation he sought – referring to Mesozoic continental separation – in Western Africa (Ivory Coast and Ghana, Choubert, 1969).

7. Supposed fossil algae and the cap carbonates: aberrations in early Precambrian paleontology

Already before his first visit to equatorial Africa, Boris Choubert had the opportunity, while working at Brussels University, to study pieces of carbonate rocks from the eastern parts of then Belgian Congo. The samples were taken by Belgian colonial geologists from a conspicuous pinkish dolomitic carbonate member ("calcaire rose oolithique") of remarkable lateral continuity which they could follow for some 1300 km from eastern to southeastern

400 Belgian Congo (Eastern and Katanga province respectively, eastern margin of the Congo
401 Basin) just above a conspicuous matrix-rich conglomerate (Choubert, 1932a,b, 1937).
402 Choubert was well aware of the existence of at least one Precambrian conglomerate of
403 probable glacial origin (“le grand conglomerat” stratigraphically far below his pinkish
404 dolomite) outcropping around the whole Congo Basin. He even correlated this diamictite with
405 the Macaubas (Jequitai) Formation of western Brazil (Choubert, 1935), a correlation which
406 has become very plausible through modern age datings (Misi et al., 2011). However, he did
407 not take the step to ascribe the same glacial origin to the conglomerate underlying the pinkish
408 carbonate. Later work in the area showed the existence of at least two well defined glacial
409 or glacially influenced sedimentary sequences (Cahen, 1963, Cahen and Lepersonne, 1981),
410 with the upper one (“le petit conglomérat”, firstly interpreted as of glacial origin by Robert,
411 1940) corresponding to the conglomerate below Choubert’s pinkish carbonate. The latter is
412 known today as a so-called cap carbonate deposited in the aftermath of a very severe
413 Neoproterozoic (Marinoan) glaciation ending at around 635 Ma and exhibiting very peculiar
414 (“idiosyncratic”, Hoffman, 2011) sedimentologic and geochemical characteristics (Master and
415 Wendorff, 2011). This was, of course, unknown to Boris Choubert in the early 1930s, but he
416 made some other interesting observations. In thin sections from the oolitic carbonate he
417 observed spherical to highly elliptical objects of some 0.5 to 1 mm longest dimension
418 (Choubert, 1932a). He was impressed by the often very well developed radial segmentation
419 (“des segments longitudinaux”) of many of these objects with the number of segments being
420 mostly around 18 (Fig. 7a). Furthermore, he mentioned fine ornamentations, wavy (wrinkly)
421 laminations, and internal cavities filled with diagenetic calcite and dolomite. By comparison
422 with questionable fossils (charophytes) from the Devonian series of Russia, Choubert (1932a)
423 boldly declared that all the alleged ooids of the “calcaire rose” were in fact the calcified thalli
424 of eukaryote fossil algae and he assigned them to several new species of the genus *Sycidium*.
425 When it later became apparent to him that the “calcaire rose” must be much older than the

Devonian and probably even older than the Cambrian, Choubert (1937) did no longer insist on the identification as *Sycidium* but he still maintained that these grains were most probably algal remains. In doing this, he was in agreement with some other French and Belgian geologists who interpreted similar oolitic carbonates (all from Neoproterozoic cap carbonates) from the wider Congo area as algal limestones (e.g. Cayeux, 1931). It is an interesting side-story and a forgotten episode of early Precambrian sedimentology and/or paleontology that Boris Choubert's brother George, undoubtedly influenced by his elder brother, described very similar carbonate grains from a (?) Mid-Proterozoic carbonate-sandstone succession near Taghdout (Taghdout Formation, Bouougri and Saquaque, 2004; Clausen et al., 2014) in the Anti-Atlas of Morocco and also interpreted them as algae or even sponge-like ancestors of the Cambrian archaeocyathids (Choubert, 1945). In a later publication (together with the paleontologist couple Geneviève and Henri Termier) he described and classified most of the coated grains of the Taghdout formation as microfossils of different taxonomic origins allegedly ranging from algae, over foraminifera to primitive sponges (Choubert et al., 1951). Several new species and even new genera were created and illustrated by thin section pictures and detailed line drawings, such as e.g. *Tubiphyton* (Fig. 8). These very bold claims for complex Precambrian animal and plant life aroused the attention of the famous and very influential German paleontologist Otto Schindewolf (teacher and friend of Adolf Seilacher) who was among the first to propose a dramatic change of Earth's biota across the Precambrian-Cambrian boundary (Schindewolf, 1954). Schindewolf even took the struggle to visit the rather remote Taghdout locality himself under guidance of George Choubert to collect samples. In a rigorous treatment on Precambrian fossils (the title of his publication is somewhat misleading as Schindewolf found that there were hardly any such fossils), Schindewolf described the Taghdout grains and arrived at the conclusion that they represent anything but fossils (i.e. ooids, oncolites, tectonic deformation structures, or intraclasts). Modern specialists mostly agree with Schindewolf's verdict (H. Bouougri and A. Knoll,

written communications January 2016): most Taghdout grains are simply coated grains (ooids, oncoids) which often form composite grains (“oid bags”, Schindewolf, 1956). To use such coated grains for stratigraphic purposes was very much in vogue in the Soviet Union until the 1980s, and they were classified under different terms such as “microphytolites” or “catagraphs” (see Hofmann, 1987). It seems reasonable to assume that the same explanation applies as well for Boris Choubert’s “fossil algae” from Central Africa. Similar “microphytolitic” grainstones seem to have been indeed a fairly common facies type in Neoproterozoic carbonate successions (Swett and Knoll, 1985).

8. Discussion: was Choubert promoting Precambrian continental displacements?

It has been recently suggested by Hoffman (2014), that it was mainly Wegener’s (and most of his followers’s) neglect to account for pre-Mesozoic tectonics by means of continental displacements which restrained James Tuzo Wilson (one of the fathers of plate tectonics) from embracing tectonic mobilism already much earlier than 1961 (see also Frankel, 2014d). Given Wilson’s great interest in Precambrian geology and his strong preference for uniformitarianism, this suggestion seems very reasonable. Quickly after he worked out – at least qualitatively – the kinematic basics of plate tectonics (Wilson, 1965), he tried to apply the new model to pre-Mesozoic problems (Wilson, 1966), and finally came to the insight that numerous ocean basins must have existed and disappeared during Earth’s history (see also Şengör, 1990). Contrary to the general idea of Mesozoic and younger continental displacement, this extension back into Paleozoic and Precambrian times did not have many forerunners, as pointed out in the introductory remarks to this paper, and the question arises whether Boris Choubert really was one of them. From the historic material discussed in this paper, it is clear that Choubert was very much concerned with Precambrian geology and also that he used disjuncts of Precambrian orogens and stratigraphic systems to substantiate the reality of the Phanerozoic opening of the Atlantic. But did he also apply mobilist concepts to

477 explain pre-Mesozoic and especially Precambrian geology itself? Even though there is no
478 straight-forward answer to this question, there is some evidence to the affirmative. In the final
479 figure of his 1935 paper, Choubert gave a tentative reconstruction of the paleotectonic
480 evolution of the North and Middle Atlantic region during the Paleozoic (Fig. 9). He
481 distinguished four main continental blocks which, by moving forth and back, produced
482 alternately oceanic basins and mountain chains, and whose boundaries (his “Precambrian
483 continental outlines” discussed above) crosscut present-day continental configurations (cf.
484 e.g. Florida belonging to “West-Gondwana” and not to Laurentia). This strongly resembles
485 Wilson’s (1966) arguments in favor of a proto-Atlantic and Choubert also pointed out that the
486 amount of lateral displacement between the continental blocks could not be reconstructed
487 (paleomagnetic techniques had yet to be developed) and might easily have been larger than
488 indicated on his figure. Hence it seems safe to assume that he really did apply continental
489 displacements to explain Paleozoic orogenies (30 years before Wilson), over-regional
490 stratigraphy, and faunal distribution patterns (Choubert, 1935, 23-39). On the other hand, it is
491 difficult to judge whether or not he was also willing to expand this kind of arguments to parts
492 of the Precambrian. He clearly was of the opinion that a thin continental (“sialic”) crust once
493 covered the whole Earth’s surface and subsequently broke apart to form the Precambrian
494 continents Gondwana, Laurentia, and Baltica (Choubert, 1935, 22), but, probably due to the
495 almost total lack of radiometric data at that time, he was not willing to propose paleotectonic
496 reconstructions for the Precambrian. However, even on his Precambrian paleogeographic
497 sketch (Fig. 9) Choubert indicated a separation between western and eastern Gondwana (more
498 or less paralleling the eastern boundary of the WAC), and one might argue whether or not he
499 assumed a former ocean basin there. Be that as it may, Choubert made his point quite clear
500 that he took Precambrian continental drift seriously into consideration: *“It does not seem very*
501 *logic to assume, as Wegener does, that Pangea remained unchanged during the whole*
502 *Primary period before the last separation of the continents which gave rise to their modern*

distribution.” (Choubert, 1935, 10). And in his very last publication he wrote – admittedly in a time when this was no longer an attack on geological orthodoxy – the following reminder: “[...] it is very important for the global knowledge of our planet to try to represent the evolution of the Earth’s crust during all the different ages of Earth’s history, from which Wegener, at his time, only considered one single stage. Pangea, the single continent whose fragmentation he documented for a specific instant in Earth’s history, has been fragmented and re-welded several times, and our present-day continents merely represent the product of its last separation.” (Choubert, 1981, 43).

9. Conclusions

From the historic and geological material presented in this paper, we shall draw some final conclusions concerning not only the history of geology but also addressing the present-day geologist working in Precambrian terrains of ancient Gondwana or elsewhere.

- The striking similarity between Choubert’s (1935) “low-tech” trans-Atlantic continental fit and the sophisticated least-square fit of Bullard et al. (1965), demonstrates that the latter’s mathematical foundation may have been important to convince geophysicists (being otherwise not really susceptible to purely geologic evidence) of the reality of drift, but was not really necessary to arrive at the fit itself. Key points were rather the starting boundary conditions like the rotation of Iberia, which were based on geologic reasoning and altogether already anticipated by Choubert in the early 1930s.
- Wegener’s theory of continental displacement had been heavily criticized for not providing any explanations for global tectonics before the fragmentation of Pangea during the Mesozoic. For James Tuzo Wilson, this neglect was reason enough not to consider continental drift as a viable tectonic theory before 1961. Argand (1924) and especially Choubert (1935), however, provided reasonable mobilist scenarios for

Paleozoic and Precambrian global tectonics and it could be argued that Wilson, had he known these sources, might have become a mobilist already much earlier.

- French contributions to the continental displacement controversy have not yet been fully exploited from a historical point of view, and many interesting ideas (especially concerning pre-Mesozoic drift) still await proper exploration and discussion (e.g. Russo, 1930, 1933). Interestingly, both Choubert and Russo were heavily concerned with continental displacements in pre-Permian times and their works demonstrate that also Precambrian plate tectonics had its forerunners long before Wilson's (1966) landmark paper on the proto-Atlantic.
- Still today, it is worth reading the old European literature on the geology of former colonies mainly in Africa but also in Asia or South America. Though these sources may be sometimes difficult to find and access, or not be written in English, their consultation is highly recommended for geologists interested in these areas for several reasons. First, contrary to present-day academic working practice, colonial geologists like Choubert spent several years in these countries and could thus acquire a very intimate and thorough knowledge of their geology. Second, for many of these areas there are still no modern geological maps or monographs of high quality available, and some of them are not even accessible due to political or security reasons. And finally, even exploration geologists, naturally concerned with very specific questions, can find interesting hints to direct their exploration efforts, as exemplified by Choubert's proposal to look in Gabon for the source rocks of the Minas Gerais diamonds in Brazil.

Acknowledgements

My interest in Boris Choubert was first aroused while doing field work on the Precambrian in Morocco (financed by the Swiss National Science Foundation grant 156244) together with

Wilfried Winkler, where the Taghdout coated grains inspired my imagination and initially led me on an erroneous path already taken by the Choubert brothers during the 1930s. I would like to thank Daniel Bernoulli, El Hafid Bouougri, Tomaso Bontognali, John Grotzinger, Andrew Knoll, and Helmut Weissert for helping me to get back to the right track, and to recognize these grains not as fossils but as a peculiar facies of Proterozoic carbonate systems. I furthermore thank Daniel Kälén and the Swiss Geological Survey for producing the high-quality scan of Fig. 2, and Walter Ziegler for inspiring discussions on African geology and the life and work of the illustrious Choubert brothers. Paul F. Hoffman is to be thanked for providing a very helpful review with some pertinent hints to additional literature and journal editor Randall Parrish for his help to improve the present article. I finally thank the late Rudolf Trümpy for insisting that I had to practice my French skills in order to be able to digest the vast geological literature written in that language.

References

- Affaton, P., Rahaman, M.A., Trompette, R., Sougy, J., 1991. The Dahomeyide Orogen: tectonothermal evolution and relationships with the Volta Basin. In: Dallmeyer, R.D., Lécroché, J.P. (Eds.), The West African orogens and circum-Atlantic correlatives. Springer, Berlin, pp. 107-122.
- Allen, P.M., 1969. The geology of part of an orogenic belt in western Sierra Leone, West Africa. *Geologische Rundschau* 58/2, 588-620.
- Ampferer, O., 1941. Gedanken über das Bewegungsbild des atlantischen Raumes. Aus den Sitzungsberichten der Akademie der Wissenschaften in Wien Mathem.-naturw. Klasse, Abteilung I 150/1+2, 19-35.
- Argand, E., 1924. La tectonique de l'Asie. *Compte-rendu du XIIIe congrès géologique international* 1922, 171-372.

578 Berger, J., Ouzegane, K., Bendaoud, A., Liégeois, J.P., Kiénast, J.R., Bruguier, O., Caby, R.,
579 2014. Continental subduction recorded by Neoproterozoic eclogite and garnet amphibolites
580 from Western Hoggar (Tassendjanet terrane, Tuareg Shield, Algeria). *Precambrian*
581 *Research* 247, 139-158.

582 Bouougri, H., Saquaque, A., 2004. Lithostratigraphic framework and correlation of the
583 Neoproterozoic northern West African Craton passive margin sequence (Siroua-Zenaga-
584 Bouazzar El Graara inliers, central Anti-Atlas, Morocco): an integrated approach. *Journal*
585 *of African Earth Sciences* 39, 227-238.

586 Bourcart, J., 1928. Une carte de reconnaissance du sommet de l'Ahaggar (Sahara Central).
587 *Revue de Géographie Physique et de Géologie Dynamique* I/2, 121-139.

588 Bullard, E., The emergence of plate tectonics: a personal view. *Annual Reviews of Earth and*
589 *Planetary Sciences* 3: 1-30.

590 Bullard, E., Everett, J.E., Smith, A.G., 1965. The fit of the continents around the Atlantic.
591 *Philosophical Transactions of the Royal Society A* 1088, 41-51.

592 Burke, K., Dewey, J.F., 1973. An outline of Precambrian plate development. In: Tarling,
593 D.H., Runcorn, S.K. (Eds.), *Implications of continental drift to the Earth Sciences* –
594 volume 2. Academic Press, London, pp. 1035-1045.

595 Cahen, L., 1963. Glaciations anciennes et derive des continents. *Annales de la Société*
596 *Géologique de Belgique* 86/1, 19-84.

597 Cahen, L., Lepersonne, J., 1981. Proterozoic diamictites of Lower Zaïre. In: Hambrey, M.J.,
598 Harland, W.B. (Eds.), *Earth's pre-Pleistocene glacial record*. Cambridge University Press,
599 pp. 153-166.

600 Carey, W.S., 1955. Wegener's South America-Africa assembly, fit or misfit? *Geological*
601 *Magazine* 92, 196-200.

602 Carozzi, A.V., 1985. The reaction in continental Europe to Wegener's theory of continental
603 drift. *Earth Science History* 4, 122-137.

604 Cayeux, L., 1931. Existence de restes organiques et notamment d'algues siphonnées
605 verticillées dans le système schisto-calcaire du Congo belge. *Comptes rendus de*
606 *l'académie des sciences Paris* 193: 11-14.

- 607 Chamberlin, R.T., 1928. Some of the objections to Wegener's theory. In: Van Waterschoot
608 van der Gracht, W.A.J.M. (Ed.), Theory of continental drift. The University of Chicago
609 Press, Chicago, pp. 83-87.
- 610 Chaves, M.L.S.C., Karfunkel, J., Hoppe, A., Hoover, D.B., 2001. Diamonds from the
611 Espinhaço Range (Minas Gerais, Brazil) and their redistribution through the geologic
612 record. Journal of South American Earth Sciences 14, 277-289.
- 613 Choubert, B., 1932a. Sur la présence d'algues dévoniennes dans le niveau du « Calcaire rose »
614 du système du Kundelungu du Katanga. Bulletin de la classe des sciences de l'académie
615 royale de Belgique 18, 1421-1431.
- 616 Choubert, B., 1932b. Nouvelles recherches sur les algues du niveau du « Calcaire rose
617 oolithique » du Kundelungu supérieur du Congo belge (Province Orientale et Katanga).
618 Société Belge de Géologie, de Paléontologie et Hydrologie XLII, 63-70.
- 619 Choubert, B., 1935. Recherches sur la genèse des chaînes paléozoïques et antécambriennes.
620 Revue de Géographie Physique et de Géologie Dynamique VIII/1, 5-50.
- 621 Choubert, B., 1937. Étude géologique des terrains anciens du Gabon. Thèses présentées à la
622 faculté des sciences de Paris pour obtenir le titre d'ingénieur-docteur. p. 209.
- 623 Choubert, B., 1946. Sur la présence du diamant au Gabon (A.E.F.), en relation avec des
624 kimberlites et des roches carbonatées métamorphiques. Comptes rendus de l'académie des
625 sciences Paris 223, 638-640.
- 626 Choubert, B., 1960. Les granites précambriens des Guyanes et leur origine probable.
627 Mémoires pour servir à l'explication de la carte géologique détaillée de la France :
628 Département de la Guyane française. Imprimerie nationale, Paris, p. 176.
- 629 Choubert, B., 1967. Réflexions sur la finalité des mesures géochronologiques (périodicité des
630 événements du Précambrien et dérives des continents). Bulletin société géologique de
631 France 7 (IX), 809-819.
- 632 Choubert, B., 1969. Les Guyano-éburneides de l'Amérique du Sud et de l'Afrique
633 occidentale. Bulletin du B.R.G.M. (deuxième série) IV/4, 39-68.
- 634 Choubert, B., 1981. Aperçu de l'évolution des idées concernant la formation de la croûte
635 terrestre d'Alfred Wegener à nos jours. Geologische Rundschau 70/1, 40-49.

- 636 Choubert, G., 1945. Découverte d'organismes calcaires dans le Précambrien de l'Anti-Atlas.
637 Comptes rendus de l'académie des sciences Paris 220, 561-563. 1945.
- 638 Choubert, G., 1963. Histoire géologique du Précambrien de l'Anti-Atlas. Notes et Mémoires
639 du Service géologique du Maroc 162, 1-352.
- 640 Choubert, G., Termier, H., Termier, G., 1951. Les calcaires précambriens de Taghdout et
641 leurs organismes problématiques. Notes et Mémoires du Service géologique du Maroc 85
642 (5), 9-34.
- 643 Choubert, G., Faure-Muret, A., 1969. International tectonic map of Africa (1/5'000'000).
644 Unesco-Asga, Paris.
- 645 Clausen, S., Alvaro, J.J., Zamora, S., 2014. Replacement of benthic communities in two
646 Neoproterozoic-Cambrian subtropical-to-temperate rift basins, High Atlas and Anti-Atlas,
647 Morocco. Journal of African Earth Sciences 98, 72-93.
- 648 Daly, R.A., 1926. Our mobile Earth. Charles Scribner's sons, New York, p. 342.
- 649 Debrenne, F., 2014. Research on the Ediacaran and Cambrian of the Anti-Atlas and High
650 Atlas Mountains Morocco: a historical overview. Journal of African Earth Sciences 98, 11-
651 18.
- 652 Dewey, J., 1969. Evolution of the Appalachian/Caledonian orogen. Nature 222, 124-129.
- 653 Dewey, J., 2015. A harbinger of plate tectonics: a commentary on Bullard, Everett and Smith
654 (1965) "The fit of the continents around the Atlantic". Philosophical Transactions of the
655 Royal Society A 373, 20140227.
- 656 Durand-Delga, M., 2009. Trois essais de tectonique globale avant la lettre, par Élie de
657 Beaumont, Suess et Wegener. In: Gaudant, J. (Ed.), L'essor de la géologie française –
658 essais. Presses des mines, Paris, pp. 43-79.
- 659 Du Toit, A., 1937. Our wandering continents. A hypothesis of continental drifting. Oliver and
660 Boyd, Edinburgh, p. 366.
- 661 Ennih, N., Liégeois, J.-P., 2001. The Moroccan Anti-Atlas : the West African craton passive
662 margin with limited Pan-African activity. Implications for the northern limit of the craton.
663 Precambrian Research 112, 289-302.

- 664 Frankel, H.R., 2012a. The continental drift controversy – Wegener and the early debate.
665 Cambridge University Press, Cambridge, p. 604.
- 666 Frankel, H.R., 2012b. The continental drift controversy – Paleomagnetism and confirmation
667 of drift. Cambridge University Press, Cambridge, p. 525.
- 668 Frankel, H.R., 2012c. The continental drift controversy – Introduction of seafloor spreading.
669 Cambridge University Press, Cambridge, p. 476.
- 670 Frankel, H.R., 2012d. The continental drift controversy – Evolution into plate tectonics.
671 Cambridge University Press, Cambridge, p. 675.
- 672 Gaudant, J., 1995. La réception de l'idée de dérive des continents en France et en Suisse
673 Romande: les enseignements d'une enquête. Mém. Soc. géol. France 168, 129-138.
- 674 Gonzaga, G.M., Teixeira, N.A., Gaspar, J.C., 1994. The origin of diamonds in western Minas
675 Gerais, Brazil. Mineralium Deposita 29, 414-421.
- 676 Haug, E., 1905. Sur la structure géologique du Sahara central. Comptes rendus de l'académie
677 des sciences Paris 141, 374-376.
- 678 Hodges, T., 1983. Western Sahara – The roots of a desert war. Lawrence Hill & Co.,
679 Connecticut, p. 377.
- 680 Hoffman, P.F., 2011. Strange bedfellows: glacial diamictite and cap carbonate from the
681 Marinoan (635 Ma) glaciation in Namibia. Sedimentology 58, 57-119.
- 682 Hoffman, P.F., 2014. Tuzo Wilson and the acceptance of pre-Mesozoic continental drift. Can.
683 J. Earth Sci. 51, 197-207.
- 684 Hofmann, H.J., 1987. Precambrian biostratigraphy. Geoscience Canada 14/3, 135-154.
- 685 Jessell, M.W., Liégeois, J.-P., 2015. Editorial – 100 years of research on the West African
686 Craton. Journal of African Earth Sciences 112, 377-381.
- 687 Kilian, C., 1922. Aperçu général de la structure des Tassilis des Ajjer. Comptes rendus de
688 l'académie des sciences Paris 175, 825-827.
- 689 Kilian, C., 1925. Au Hoggar – Mission de 1922. Société d'éditions géographiques, maritimes
690 et coloniales, Paris, p. 186.

- 691 Köppen, W., Wegener, A., 1924. Die Klimate der geologischen Vorzeit. Borntraeger, Berlin,
692 p. 255.
- 693 Kröner, A., 1979. Pan African plate tectonics and its repercussions on the crust of northeast
694 Africa. *Geologische Rundschau* 68/2, 565-583.
- 695 Leblanc, M., 1976. Proterozoic oceanic crust at Bou Azzer. *Nature* 261, 34-35.
- 696 Lécorché, J.P., Bronner, G., Dallmeyer, R.D., Rocci, G., Roussel, J., 1991. The Mauritanide
697 Orogen and its northern extensions (Western Sahara and Zemmour), West Africa. In:
698 Dallmeyer, R.D., Lécorché, J.P. (Eds.), *The West African orogens and circum-Atlantic*
699 *correlatives*. Springer, Berlin, pp. 187-227.
- 700 Le Grand, H.E., 1988. *Drifting continents and shifting theories*. Cambridge University Press,
701 Cambridge, p. 313.
- 702 Letsch, D., 2013. The geometry of continental displacement and its application to Arctic
703 geology: Eugen Wegmann's early approaches published in the *Geologische Rundschau* in
704 1943. *Int. J. Earth Sci. (Geologische Rundschau)* 102, 1171-1180.
- 705 Martin, H., 1983. Alternative geodynamic models for the Damara orogeny. A critical
706 discussion. In: Martin, H., Eder, F.W. (Eds.), *Intracontinental fold belts – case studies in*
707 *the Variscan Belt of Europe and the Damara Belt in Namibia*. Springer, Berlin, pp. 913-
708 945.
- 709 Master, S., Wendorff, M., 2011. Neoproterozoic glaciogenic diamictites of the Katanga
710 Supergroup, Central Africa. In: Arnaud, E., Halverson, G.P., Shields-Zhou, G. (Eds.), *The*
711 *geological record of Neoproterozoic glaciations*. Geological Society, London, *Memoirs* 36,
712 pp. 173-184.
- 713 Médioni, R., 2008. Philibert Russo (1885-1965), pionnier de l'exploration géologique du
714 Maroc. *Travaux du comité français d'histoire de la géologie*. 3/XXII, 1-19.
- 715 Misi, A., Kaufman, A.J., Azmy, K., Dardenne, M.A., Sial, A.N., De Oliveira, T.F., 2011.
716 Neoproterozoic successions of the São Francisco Craton, Brazil: the Bambui, Una, Vazante
717 and Vaza Barris/Miaba groups and their glaciogenic deposits. In: Arnaud, E., Halverson,
718 G.P., Shields-Zhou, G. (Eds.), *The geological record of Neoproterozoic glaciations*.
719 Geological Society, London, *Memoirs* 36, pp. 509-522.

- 720 Mitchell, R.H., 1986. Kimberlites, Geochemistry, and Petrology. Springer, Berlin, p. 442.
- 721 Porch, D., 1984. The conquest of the Sahara. Farrar, Straus and Giroux, New York, p. 332.
- 722 Robert, M., 1940. La glaciation du Kundelungu au Katanga (Congo Belge). Report of the
723 XVII Session (Moscow 1940), International Geological Congress 6, 100-113.
- 724 Russo, P., 1930. Recherches sur les déplacements tectoniques des aires continentales.
725 Mémoires de la société des sciences naturelles du Maroc XXV, 5-65.
- 726 Russo, P., 1933. Les déplacements des continents. Ch. Béranger, Paris & Liège, p. 104.
- 727 Russo, P., 1936. Remarques sur l'orogénèse des Alpes et ses rapports avec les plissements
728 tertiaires du Maroc. Bulletin de la société des sciences naturelles du Maroc XVI, 266-272.
- 729 Russo, P., 1947. Contribution à l'étude tectonique de la Méditerranée occidentale. Bulletin
730 société géologique de France (5) XVII, 81-95.
- 731 Schaer, J-P., 1991. Emile Argand 1879-1940. Life and portrait of an inspired geologist.
732 Eclogae geologicae Helvetiae 84/3, 511-534.
- 733 Schaer, J.-P., 2010. Swiss and Alpine geologists between two tectonic revolutions. Part 1:
734 from the discovery of nappes to the hypothesis of continental drift. Swiss J. Geosci 103,
735 503-522.
- 736 Schaer, J.-P., 2011. Swiss and Alpine geologists between two tectonic revolutions. Part 2:
737 From drifting continents towards plate tectonics. Swiss J Geosci 104, 507-536.
- 738 Schindewolf, O., 1954. Über die Faunenwende vom Paläozoikum zum Mesozoikum.
739 Zeitschrift der deutschen geologischen Gesellschaft 105/II, 153-182.
- 740 Schindewolf, O., 1956. Über präkambrische Fossilien. In: Lotze, F. (Ed.), Geotektonisches
741 Symposium zu Ehren von Hans Stille. Ferdinand Enke, Stuttgart, pp. 455-480.
- 742 Schmidt, K., 1976. "Subfluenz" und "Subduktion" in den Alpen. Zeitschrift der deutschen
743 geologischen Gesellschaft 127, 53-72.
- 744 Schopf, J.W., 1992. Historical development of Proterozoic micropaleontology. In: Schopf,
745 J.W., Klein, C. (Eds.), The Proterozoic biosphere – a multidisciplinary study par tone.
746 Cambridge University Press, Cambridge, pp. 179-183.

747 Schuchert, C., 1928. The hypothesis of continental displacement. Annual report of the
748 Smithsonian Institution 1928, 249-282.

749 Şengör, A.M.C., 1976. New historical data on crustal subduction. *Journal of Geology* 85, 631-
750 634.

751 Şengör, A.M.C., 1979. Mid-Mesozoic closure of Permo-Triassic Tethys and its implications.
752 *Nature* 279, 590-593.

753 Şengör, A.M.C., 1982. A note on a late revision of the theory of embryotectonics by Argand
754 himself. *Eclogae geologicae Helvetiae* 75, 177-188.

755 Şengör, A.M.C., 1990. Plate tectonics and orogenic research after 25 years: a Tethyan
756 perspective. *Earth-Science Reviews* 27, 1-201.

757 Şengör and Okuroğullari, 1991. The role of accretionary wedges in the growth of continents:
758 Asiatic examples from Argand to plate tectonics. *Eclogae geologicae Helvetiae* 84 (3),
759 535-597.

760 Smith, A.G., 1971. Alpine deformation and the oceanic areas of the Tethys, Mediterranean,
761 and Atlantic. *Geological Society of America Bulletin* 82, 2039-2070.

762 Sougy, J., 1962. West African fold belt. *Geological Society of America Bulletin* 73, 871-876.

763 Staub, R., 1928. *Der Bewegungsmechanismus der Erde – dargelegt am Bau der irdischen*
764 *Gebirgssysteme*. Borntraeger, Berlin, p. 270.

765 Swett, K., Knoll, A.H., 1985. Stromatolitic bioherms and microphytolites from the Late
766 Proterozoic Draken Conglomerate Formation, Spitsbergen. *Precambrian Research* 28, 327-
767 347.

768 Triantafyllou, A., Berger, J., Baele, J.M., Diot, H., Ennih, N., Plissart, G., Monnier, C.,
769 Watlet, A., Bruguier, O., Spagna, P., Vandycke, S., 2016. The Tachakoucht-Iriri-Tourtiti
770 arc complex (Moroccan Anti-Atlas): Neoproterozoic records of polyphased subduction-
771 accretion dynamics during the Pan-African orogeny. *Journal of Geodynamics* 96, 81-103.

772 Trompette, R., 1994. *Geology of Western Gondwana (2000-500 Ma)*. Balkema, Rotterdam, p.
773 350.

774 Trümpy, R., 2001. Why plate tectonics was not invented in the Alps. *International Journal of*
775 *Earth Sciences* 90, 477-483.

776 **Van Houten, F.B., 1975. A precocious Atlantic reconstruction. *Geology* 3, 194-195.**

777 Van Waterschoot van der Gracht, W.A.J.M., 1928. The problem of continental drift. In: Van
778 Waterschoot van der Gracht, W.A.J.M. (Ed.), *Theory of continental drift*. The University
779 of Chicago Press, Chicago, pp. 1-75.

780 Villeneuve, M., Cornée, J.J., 1994. Structure, evolution and palaeogeography of the West
781 African Craton and bordering belts during the Neoproterozoic. *Precambrian Research* 69,
782 307-326.

783 Wegener, A., 1912. Die Entstehung der Kontinente. *Geologische Rundschau* 3, 276-292.

784 Wegener, A., 1915. *Die Entstehung der Kontinente und Ozeane*. Vieweg & Sohn,
785 Braunschweig, p. 94.

786 Wegmann, C. E., 1935. Preliminary report on the Caledonian orogeny in Christian X's Land
787 (North-east Greenland). *Meddelelser om Gronland* 103/3, 1-59.

788 White, D.A., Roeder, D.H., Nelson, T.H., Crowell, J.C., 1970. Subduction. *Geological*
789 *Society of America Bulletin* 81, 3431-3432.

790 Wilson, J.T., 1965. A new class of faults and their bearing on continental drift. *Nature* 207,
791 343-347.

792 Wilson, J.T., 1966. Did the Atlantic close and then re-open? *Nature* 211, 676-681.

793 Windley, B., 1984. *The evolving continents – 2nd edition*. John Wiley & Sons, Chichester, p.
794 399.

795

796 **Figure captions:**

797 Figure 1. Pre-Permian (“Hercynian”) reconstruction of the circum-Atlantic continents relative
798 to Europe (i.e. Europe taken as fixed relative to present-day coordinates). Reproduced from
799 Choubert (1935: Fig. 2). Although not explicitly stated by Choubert, the reconstruction

seems to be based on the 1000 m depth contour which roughly corresponds to the 50 fathoms contour used by Bullard et al. (1965) as a proxy for the edge of the continental shelf.

Figure 2. Pre-Permian (“Hercynian”) fit of the circum-Atlantic continents with the superimposed geology of the Paleozoic and Precambrian orogens (“terrains plissés”) and non-folded areas (“terrains non plissés”). Reproduced from Choubert (1935: plate A).

Figure 3. Detail of Choubert’s synthetic map (Fig. 2) centering on the West African Craton (WAC). Modern tectonic units are indicated with red letters. Abbreviations: AA: Anti-Atlas, Bas: Bassarides; BB: Bové Basin; Dah: Dahomeyide Orogen; HIB: Hoggar Iforas Belt; Ma: Mauretanides; Rok: Rokelides; VB: Volta Basin.

Figure 4. Gondwana reassembly for the Paleozoic according to Alexander Du Toit (1937: Fig. 7). Note the poor knowledge of Precambrian tectonic trend lines (“tectonic grain”) in Northwest Africa (indicated by short lines).

Figure 5. Tectonic overview map of the northern part of the West African Craton (WAC) and surrounding Neoproterozoic and Paleozoic orogenic belts. Base map redrawn after Choubert and Faure-Muret (1969) and slightly modified according to Affaton et al. (1991), Ennih and Liégeois (2001), Lécroché et al. (2001), and Villeneuve and Cornée (1994). Localities of Bou Azzer ophiolite and Taghdout village in southern Morocco (see text) are indicated by asterisks.

Figure 6. The Proterozoic ophiolite of Bou-Azzer (South Morocco): one of the few outcrops of well-developed sheeted dykes composed of metabasalt. Picture was taken in the Jebel Oumarou region south of the village Ait Hamane (central Anti-Atlas, for approximate location see Fig. 5).

Figure 7. Choubert's alleged fossil algae from the Neoproterozoic Calcaire Rose Formation (Kundelungu Group), the cap carbonate succeeding the Marinoan glaciation (Master and Wendorff, 2011). Katanga province, Democratic Republic of the Congo (from Choubert, 1937). a: spherical oolite facies; b: elongated coated grains reminiscent of *Tubiphyton* (see text for explanation).

Figure 8. Questionable ooids and other coated grains from the Proterozoic Taghdout Formation of Southern Morocco (Taghdout village in the Anti-Atlas, for locality see Fig. 5). Note the wrinkly laminations and the irregular shape of the grains (e.g. the elongated *Tubiphyton*-type grain on the right). Standard petrographic thin section photograph (plane light).

Figure 9. Probably the first “plate reconstruction” for the Paleozoic (copied from Choubert, 1935, Fig. 3). Geological epoch names and continental designations have been added according to Choubert's original descriptions but using modern epoch names. Outlines of present-day geography are indicated on the lower right picture for the sake of orientation. Precambrian continental blocks (cratons) are shown stippled. Active mountain belts are shown in black. Abbreviations: Bal: Baltica; Fl: Florida; GE: East Gondwana; GW: West Gondwana; Lau: Laurentia.

Fig. 2. — Assemblage des continents d'après les données de la carte bathymétrique.

Relations
des
CONTINENTS ATLANTIQUES
À LA FIN DE
L'ÉPOQUE HERCYNienne

PAR
B. CHOUBERT.

ÉCHELLE 1:30000000

TERRAINS PLISSÉS

Plis hercyniens de la couverture paléozoïque des massifs antécambriens

Chaîne Hercynienne

Plis Carbonifères, Permians et Triasiques
avec des enclaves Calédoniennes et plus anciennes et des intrusions de roches éruptives.
Raccourcissements hypothétiques

Chaîne Acadienne

Plis Dévonien
avec des enclaves Calédoniennes et plus anciennes et des intrusions de roches éruptives
Chaîne Calédonienne et Vaconique
Plis Siluriens
avec des enclaves plus anciennes et des roches éruptives.

Chânes d'âge inconnu (antépermian)

Chânes Précambriennes
Terrains pour la plupart fortement métamorphiques

Chânes Archéennes
Terrains cristallophyliens et granitiques des socles continentaux antécambriens.

LÉGENDE

Contours géographiques des régions inchangées depuis l'époque Hercynienne
Contours géographiques des régions de formation récente.

Contours des plates-formes continentales

Contours présumés des masses continentales figées avant le Cambrien

TERRAINS NON PLISSÉS

Principaux affleurements de roches volcaniques post-hercyniennes
Régions polaires inexplorées couvertes de formations récentes (glace)

Terrains post hercyniens des régions plissées avant l'époque Hercynienne.

Roches volcaniques du Harroo.

Permien et Perm-Trias (Harroo)

Carbonifère.

Dévonien.

Gothlandien.

Ordovicien.

Cambrien.

Complexe sédimentaire d'âge inconnu (antépermien) du continent de Gondwana et d'origine non séparée de l'A.O.F. et du Sahara Oriental.

Ordovicien ou Précambrien (Sparagmites et Grès de Varanger)
Précambrien.

FIG. 7.—Reassembly of Gondwana during the Palaeozoic Era. The space between the various portions was then mostly land. Short lines indicate the pre-Cambrian or early Cambrian “grain.” Diagonal ruling shows the “Samfrau” Geosyncline of the late Palaeozoic. Stippling marks out regions of late Cretaceous and Tertiary compression. (Lambert’s Equal Area Polar Projection.)

L'un des individus de la photo ci-dessous,
Gross. environ $\times 90$,

Calcaire oolithique de la région des Monts Koni,
Katanga méridional. Gross. environ $\times 90$,

Calcaire oolithique de la région des Monts Koni du
Katanga méridional. Gross. environ $\times 25$.

Calcaire oolithique de la région de la Lufira, Katanga
méridional. Gross. environ $\times 25$.

FIG. 62. — Calcaire oolithique de la région des Monts Koni, Katanga méridional. Gross : environ $\times 90$.
Algues au milieu d'oolithes.

(Echantillons recueillis par M. Dubois (Comité Spécial du Katanga).

0.2 mm

Fig. 3.

Fig. 3.