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ORIGINAL PAPER

The geometry of continental displacement and its application to Arctic geology: Eugen Wegmann's early approaches published in the *Geologische Rundschau* in 1943

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Abstract Plate tectonics developed around 1965 as a powerful tool to describe the tectonic movements of the Earth's crust. The article demonstrates that basically four already existing theoretical concepts—subduction, seafloor spreading, the application of Euler's theorem and transform faults—had to be combined to arrive at the modern theory. Alfred Wegener, father of the theory of continental displacement, is often credited as the most direct forerunner of plate tectonics. However, none of the aforementioned concepts had been developed by him. The present article deals with the hitherto not duly credited contributions of the Swiss geologist Eugen Wegmann (1896–1982). He developed in a series of highly original papers published between 1943 and 1948 (one of them in the *Geologische Rundschau*), a critical test of the theory of continental displacement based on the regional geology of the Arctic. Furthermore, he gave a very concise account on the geometrical principles of drift movements. As a result, he developed for the first time—25 years before McKenzie and Parker's landmark paper on the Pacific (1967)—the geometrical basis to graphically test plate motion directions. However, his work has not yet received the credit it deserves, neither by scientist nor by historians of science.

Keywords Plate tectonics · Continental drift · Greenland · Spitsbergen · Mercator projection · Geological test

Introduction

Ever since it became accessible to human exploration, the Arctic Ocean and the continental areas which surround it have been of greatest scientific interest (Fig. 1). Apart from numerous attempts to unravel the regional structure and stratigraphy of this remote part of our planet, it has become increasingly clear during the last few decades that the Arctic Ocean basin plays a paramount role in global deep ocean water formation and circulation and thus controls global climate (e.g. Broecker 1987). The likely reduction of sea ice due to global warming shifted the Arctic area also into the focus of international interest as a possible place to find new deposits of fossil fuels (e.g. Pease et al. 2011). The present article focuses on yet another topic related to the Arctic namely the important role it played during early discussions on continental displacement (often somewhat imprecisely called *continental drift*). Here, the original thoughts of the Swiss geologist Eugen Wegmann will be focused on especially. Wegmann, he knew parts of the Arctic from personal experience, published in 1943 in the *Geologische Rundschau*—the precursor of the present journal—a very concise paper on the geometrical properties of continental drift and arrived at basic conclusions which were later discovered again by McKenzie and Parker (1967) during the plate tectonic revolution. Furthermore, Wegmann proposed a geological test in order to check the soundness of his speculations. Unfortunately, his efforts did not get the credit they certainly deserved (with the exception of Schaer 2011). The present article tries to

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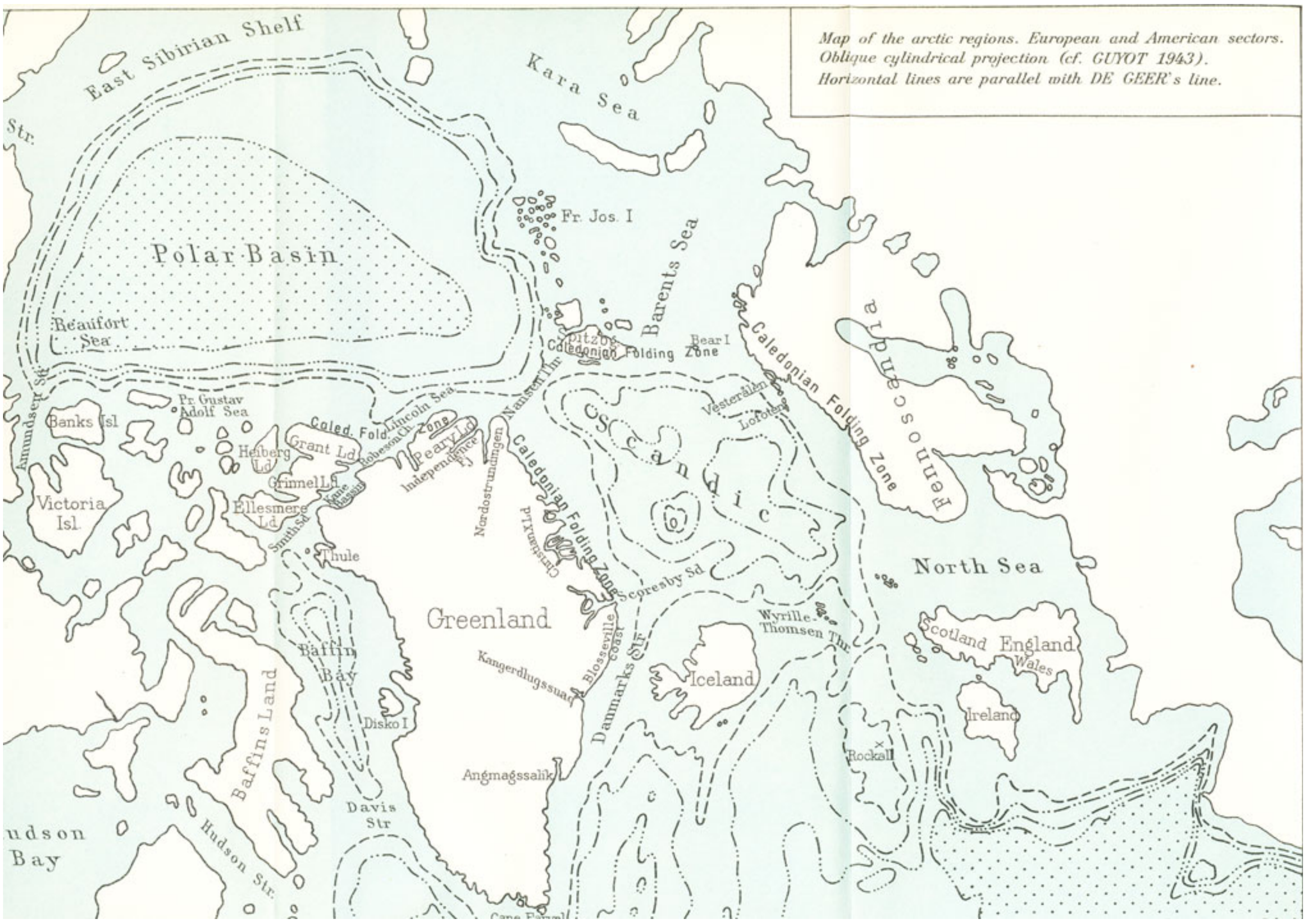

Fig. 1 Map of the Arctic region (from Wegmann 1948: plate 1). This oblique cylindrical (Mercator) map projection has the property that "*horizontal lines*" (i.e. lines parallel to the *lower* and *upper* boundary of the map, see McKenzie and Parker (1967: 1278) on it are parallel to de *Geer's line* which runs from Beaufort Sea over Spitsbergen to Vesteralen at the NW coast of Norway. Areas with water depth deeper than 4,000 m are stippled

highlight Wegmann's remarkable thoughts and to put it into their historical context.

From continental drift to plate tectonics

The triumph of new global tectonics (or plate tectonics) in the years around 1965 as the only generally agreed upon way to describe tectonic activities on the Earth's surface, ranks among the most important achievements in the history of geology. The factual foundation for this revolution was laid down in the two decades following World War II by several mostly British and American teams working in such different fields of research as the magnetic field in continental (e.g. Runcorn 1962) or marine areas (e.g. Mason and Raff 1961), seismology (e.g. Isacks et al. 1968), ocean floor bathymetry (e.g. Menard 1955), the geometrical fit of continental shelves (e.g. Carey 1955) or the petrology of the oceanic lithosphere (e.g. Hess 1962). Generally four initially separate concepts can be distinguished which were brought together around 1965 and provided the theoretical framework within which the huge amount of data gathered during the preceding two decades could be synthesized into the modern concept of plate tectonics (Le Pichon et al. 1973: 1). The oldest concept—subduction in modern terminology—was based on the recognition of shallow to deep lying earthquake epicenters along the west coast of the Americas (Benioff 1954). Somewhat later the second concept—sea-floor spreading—was proposed by Hess (1962) and Dietz (1961) in order to account for ocean basin bathymetry. The third concept—the application of spherical geometry to drift problems—was based upon the recognition of Sir Edward Bullard (1965) that continental displacements on a sphere can be described and calculated using a mathematical vehicle called Euler's theorem (see below). The youngest concept and probably also the most difficult one to envisage was the postulate of transform faults by Wilson (1965). Unifying these concepts and applying them to the spherical surface of the Earth, modern plate tectonics was created by a handful of young geophysicists (McKenzie and Parker 1967; Morgan 1968; Le Pichon 1968) as a basically *geometrical* (and *not a dynamic*) theory (McKenzie 2003: 184; Pilger 2003: V).

The idea of moving continents did not come out of a scientific vacuum. The scientific hypothesis of continental displacement had been around for at least 80 years (e.g. Wettstein (1880), see Letsch (2007) for a summary) when Wegener published his famous article *Die Entstehung der Kontinente* (Wegener 1912) in the present journal. And the hypothesis remained heatedly debated throughout the five decades following the publication of Wegener's first papers (see e.g. the summaries and reviews by Lake 1922, Schwinner 1936: 269–287, Willis 1944, Jeffreys 1959: 364–371, Wunderlich 1962, or the historical account by Carozzi 1985). Even though some excellent and highly influential geologists stood behind the theory (notably Argand 1924; Daly 1926; Staub 1928; Holmes 1928, or Du Toit 1937), it could not gain general acceptance, maybe with the notable exception of Switzerland (Carozzi 1985). The explanations for this rejection are manyfold and range from actual geological and geophysical arguments to more sociological ones, as, for example, the ones proposed by Oreskes (1999). Her attempt to explain the rejection of Wegener's theory in the US basically by the different "methodologies" of Wegener and the American geological community is, however, not entirely convincing as she ignores that the factual basis for Wegener's theory was simply too meagre at that time (as pointed out by Şengör 2003) and that Wegener's ideas were indeed still far away from plate tectonics. Judging from today, it is in fact often difficult *not* to agree with Wegener's critics. So did he assume the allegedly rigid continents to "plough" *through* (or sometimes *with*; see e.g. Wegener 1915: 43) their basaltic substratum (*without* implying subduction and sea floor spreading or even the very existence of an oceanic crust[1]) driven by tidal forces that are some orders of magnitude too weak to overcome the enormous resistive forces. Furthermore, he proposed very young dates for the separation of, for example, Greenland and Europe which implied unrealistically fast drift rates of 10–20 m per year (Wegener 1915: 92). And indeed his hypothesis failed this critical test (Lehmann and Haller 1981; Menard 1986). This very short discussion *is not at all* meant as a critique of Wegener's opus which undoubtedly is one of the greatest strokes of genius in the Earth Sciences but is rather intended to demonstrate that his hypothesis was still far away from the modern concept of plate tectonics and that its rejection was—at least partially—justified. It seems even questionable if it can be considered as a forerunner of plate tectonics since it lacked the four basic ingredients of plate tectonics as outlined above. It is thus of interest to search for scientist before 1965 who came closer to the modern concept of new global tectonics. *Close* means in this context that these scientists used or postulated at least one of the four aforementioned basic concepts of plate tectonics, that is, subduction, sea-floor spreading, application of sound geometrical principles or transform faults. Eugen Wegmann belongs to these few and not yet well studied scientists as the following discussion will try to show.

Eugen Wegmann

Eugen (or Eugène, as he spent a considerable part of his life in the French speaking part of Switzerland) Wegmann was born in 1896 in the Kanton of Schaffhausen in the northernmost tip of Switzerland (see Schaer 1967 for a biographical account). After having passed his basic education in his hometown, he joined the University of Neuchâtel in 1915 as one of the few privileged students of the great geologist Emile Argand (Schaer 1991) where he became acquainted with Alpine tectonics and especially with his master's strongly geometrical approach to it. It was probably also in this early stage of Wegmann's mental development that he came into contact with "mobilist" concepts in geology as Argand was one of the most important advocates of continental drift in Europe and applied this hypothesis not only to the Alps and the Mediterranean but also to the enormous and then just barely known mountain belts of Asia in his great opus *La tectonique de l'Asie* (Argand (1924), see Şengörengör and Okuroğullari (1991) for a review).

After obtaining his PhD in Neuchâtel, Wegmann moved to Scandinavia where he broadened his geological horizon considerably by studying the Caledonian mountain belts of Norway (1924–1927) and the old basement areas of Finland (1927–1934), the latter as a pupil of the famous Finnish geologist J.J. Sederholm (who coined the term "migmatite"). The excellent glacially polished exposures of formerly deeply buried lower crustal basement rocks in Finland, and of course Sederholm's influence, led Wegmann to become a keen supporter of the migmatist side in the then burning "Granite controversy" (see Trümpy 2004

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[1] The latter point is of critical importance in order to show the profound differences between Wegener's theory and plate tectonics and has been ignored even by renowned historians of science. Oreskes e.g. (1999: 77–78) misunderstands Wegener's figures (e.g. Wegener 1915: Fig. 8) when she takes the 4.7 km thick layer Wegener drew above the suboceanic Sima as oceanic crust. In fact, it simply represents ocean water! According to Wegener, *there is no oceanic crust at all* and the sea floor represents merely the Earth's uppermost mantle through which the continents plough. It is for this that we do not consider Wegener as a precursor of the sea-floor spreading hypothesis even though Jacoby (1981) has presented evidence in favour of this.

for a concise summary). The fruits of these busy years in Scandinavia were descriptions of regional geology, and especially several more theoretical contributions to the tectonics of the deeper crust which culminated in his famous and still very inspiring paper *Zur Deutung der Migmatite* (1935a) published in this journal.

Between 1935 and the war, Wegmann joined several Danish expeditions to Greenland under the leadership of Lauge Koch. Here, he successfully applied the geometrical approach of Argand combined with his experience of the tectonics of deep crustal sectors gained in Scandinavia to the structure of Eastern and Southern Greenland where he found ample evidence for mountain building of Caledonian age (Wegmann 1935b). Maybe the recognition that the Caledonides of Eastern Greenland represent merely an incomplete fragment of an orogen (Wegmann 1935b: 43, 1948: 30)—comparative tectonics in the best sense of the word—led Wegmann to consider continental displacements as a serious possibility.

Interrupted by the war, Wegmann returned to Switzerland where he soon succeeded his former teacher Argand on the chair of geology at the University of Neuchâtel. This position which he held until his retirement in 1964 seems to have occupied extremely much of his time (Wegmann 1963: 73–74). Nevertheless, he published, during that time, a series of highly inspiring but often somewhat difficult to understand papers on very different topics ranging from his lower crustal tectonic studies to problems of recent crustal movements or the history and philosophy of geology. Apart from that, he was one of the driving forces behind the revival of the *Geologische Rundschau* after the war (together with the two brothers Hans and Ernst Cloos, see Seibold and Seibold 1998). Wegmann died in 1982.

Before we proceed to Wegmann's highly interesting and original views on continental drift, it is of advantage to discuss first some geometrical principles of plate tectonics as developed in the years around 1965 in order to better estimate Wegmann's remarkable early insights.

The geometry of plate motions

The mathematical description of the movement of rigid bodies on a sphere has become general knowledge of the Earth science society trough its application to plate tectonics (see e.g. recent textbooks such as Fowler 2005: 14–15 or Lowrie 2007: 34–36). Generally credit is given to Sir Edward Bullard as the first one to apply an old mathematical principle developed by the Swiss mathematician Leonhard Euler in 1776 to problems of continental displacements (e.g. Bullard 1975: 21). In its most general form, the principle states that "if a rigid body is turned about one of its points taken fixed, the displacement of this body from one given position to another is equivalent to a rotation about some fixed axis going through the fixed point" (Le Pichon et al. 1973: 28). Applied to a lithospheric plate, (which is viewed as a "rigid" spherical cap) the theorem can be simplified to the notion that *any* movement of a plate—be it relative to another plate, the Earth's axis of rotation, the deeper mantle, etc.—on the Earth's surface can be described by *one* simple rotation around an axis of rotation that runs through the centre of the Earth. The intersections of this axis with the Earth's surface are called the Euler poles. Thus, the movement of any plate can be described by three parameters: position (i.e. longitude and latitude) of one Euler pole and the rate of rotation (as expressed in degrees per unit of time) around that pole. Of course, nature is not that simple, and Euler poles and rotation rates are likely to change during the course of time. Therefore, instantaneous and finite rotations have to be distinguished (see e.g. Dewey 1975 for an excellent summary).

It is not the place here to discuss much further about this topic, but it should be noted that the application of Euler's theorem to continental displacements by Bullard et al. (1965) forms one of the very fundaments of the modern plate tectonic theory and paved the way for McKenzie and Parker (1967), Morgan (1968), and Le Pichon (1968). These authors reasoned that the newly defined transform faults (Wilson 1965) should follow small circles around the respective Euler poles and that the segments of the mid-ocean ridges that these transforms connect should stand orthogonal to the former and therefore follow segments of great circles running through the Euler poles. Additionally, relative divergence vectors (i.e. direction and amount of spreading rates at mid-ocean ridges) and convergence vectors (the same at subduction zones) as determined by seismological methods (fault plane solutions) should parallel the transforms and hence the small circles. In order to prove this conjecture, McKenzie and Parker (1967): 1278, see also McKenzie (2003) used a Mercator projection from the Pacific. This kind of cartographical projection has the property that angular relations on the Earth surface are preserved on the projection, that is, the map. Especially if one chooses the inferred Euler pole of a certain plate and its boundaries as the projection pole of the Mercator projection—as McKenzie and Parker (1967) did—the divergence and convergence vectors along the plate boundaries should parallel the lines of latitude of the map. The results of these investigations were compelling (see also Morgan 1968 and Le Pichon 1968) and contributed very much to the gradual global acceptance of the theory in the course of the following years.

Early geometrical approaches

Astonishingly, few discussions have been published about earlier approaches of the application of geometrical techniques to problems of continental displacement. As has been pointed out by Bullard (1975: 20), earlier attempts (including Wegener's) to move continents and to unite them to supposed earlier configurations were very inexact and even sloppy. They showed fuzzy continental shapes and were presented on small-scale map projections that of course massively distorted the continental shapes additionally. This seems even to be true for Wilson's famous papers on continental displacement (1963, 1965) as Parker (2003): 198 has suggested. Thus, it was easy to question the reliability of such reconstructions (e.g. Jeffreys 1962). Two exceptions to these early and inexact attempts to bring the continents together were Schuchert's (1928) continental shapes made of plasteline which he moved over a globe and Carey's (1955) careful fit of South America and Africa by means of a spherical drawing table that could be put onto a globe and his meticulous stereographic projections. It is somewhat ironic that both these scientist became later—or already were—critics of Wegener's theory.

Thus, credit is usually given to Bullard (1965) as the first one to have employed Euler's theorem and to have appreciated the fact that drifting continents move along small circles and to Parker (1967) as the first one to have applied Mercator's projection to drift problems (Le Pichon 1968: 217). In the following, it will be shown that both concepts were anticipated by Wegmann 25 years earlier.[2]

Wegmann's discussion of the geometrical principles underlying continental displacement

It seems reasonable to assume that Wegmann received his geological education in an intellectual environmental that was quite sympathetic to the hypothesis of continental drift. Apart from Argand's influence and the generally positive to even euphoric reception of Wegener's thoughts in Switzerland during the 1920s (see e.g. Trümpy 2001; Schaer 2010), the open minded and creative attitude in Scandinavian geology (Carozzi 1985: 134–135) might have been the cause for his displacement studies. The actual occasion to do so was provided by his studies in Eastern Greenland between 1934 and the war. As a by-product of this, he published, during the succeeding decade, three papers in German, French and English (Wegmann 1943a, b, 1948) which were basically concerned with the same question: *Have continental displacements occurred in the Arctic areas and if yes can we check them by geological tests?*

Before Wegmann went into detail, in his papers, he gave some general considerations concerning drift movements. Especially, he presented (to our knowledge for the first time ever) a discussion on the geometrical character of these supposed movements and pointed out that in the existing literature these characters had often been ignored (Wegmann 1943a: 237). He distinguished rotations and translations which at first sight seem strange as every movement on a sphere is a rotation (see above). However, he then proceeded to point out that a translation will generally follow small circles and exceptionally also great circles. The latter remark shows that Wegmann (intuitively?) applied *part* of Euler's theorem. The difference between his translations and rotations (or his parallel and rotational displacements, Wegmann 1948: 17) seems to lie in the distance between the moved unit (continent, block) and its pole of rotation. In the case of a very distant rotation pole, the trajectories of movement will be curved only slightly and resemble translational paths (Dewey 1975: 263). Additionally, the orientation of the continent or block relative to a fixed coordinate grid will not change much, and it gets clear from Wegmann's further discussion that his translations or parallel movements belong to this category of rotations. On the other hand, his rotational movements are rotations around a pole that lies near the unit moved. He distinguished rotations with a "stationary centre" (i.e. Euler pole) inside or outside the unit moved, respectively. So, Wegmann obviously made use of that part of the Euler theorem that *every* movement on a sphere—and also the traces such a movement must inevitably produce in the regional structure of an area which has drifted—follows small or great circles, and he suggested the use of stereographic projections in order to find the trajectories and poles of rotation (Wegmann 1943a: 237, b: 102)—exactly the procedure later applied by Morgan (1968) in his landmark paper on plate tectonics. However, Wegmann failed to recognize (like Carey 1958, see above) that—as stated by Euler's theorem—*any* movement of a given rigid block on a sphere to any new position can be described by *but one* rotation about a suitably chosen axis of rotation. His failure is manifested in his remark that occasionally translational and rotational movements have to be combined (Wegmann 1943a: 237, b: 102, 1948: 17). In this context, it needs to be pointed out, however, that there is a difference between a theoretical finite rotation

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[2] It should be mentioned that also Carey (e.g. 1958: 225) discussed and used intuitively some aspects of Euler's theorem (without reference to Euler) and did this apparently independent of Wegmann as he started his studies in the late 1930s, however, without publishing these attempts before 1955 (Carey 1955, 1988: 95). So did he distinguish between translations along great circles and rotations along small circles (cf. also Carey 1958: fig. 9). However, his discussion of the opening of the Red Sea (1958: 181–183) where he describes the motion of the Arabian peninsula as a combination of a translation parallel to the Dead Sea fault and a rotation around a pivot on the Sinai peninsula shows clearly that he—like Wegmann, see below—did not realize that according to Euler's theorem any movement of a part of the Earth's surface can be described by simply one rotation around a suitably chosen pole of rotation.

that moves a continent to a new position by means of *just one* rotation (e.g. the continental fit of Bullard et al. 1965) and the actual path the continent's movement followed. The latter is likely to be a combination of several sub-rotations about changing poles and need not (and generally does not) coincide with the finite rotation.

Application to the Arctic region and the use of a Mercator's projection

Wegmann started his geological test of continental displacement in the Arctic region by pointing out that very different ages had been proposed so far for the Arctic Sea ("Polar Basin" in Fig. 1) and the Northern Atlantic between the coasts of Northeast Greenland and Scandinavia, for which de Geer (1912: 851) coined the term "Scandic". Wegener (1912, 1915, 1929) assumed the latter to be very young (Quaternary), whereas the former was not really discussed by him but according to his figures (e.g. 1929: Abb. 5) probably held to be at least of Palaeozoic age. Most geologists from North America on the other hand considered both ocean basins to be of a much higher age (Wegmann 1943a: 236). Somewhat intermediate was the position of some Scandinavian geologists. So, for example, de Geer (1912, 1919) who assumed that the present day Scandic had been a land mass above sea-level during Mesozoic and Tertiary times and delivered sedimentary detritus to the surrounding areas as, for example, Spitsbergen (cf. Harland 1961: 123). This landmass was supposedly drowned in late Tertiary times. Wegmann now hypothesized that this disappeared landmass possibly did not drown but was just shifted laterally away from the sedimentary basins it once delivered. As a possible candidate for the source area of the huge piles of Cretaceous to Tertiary clastic sediments in sedimentary basins on Spitsbergen, he presented Northern Greenland (Peary Land) and the northern part of Ellesmere Island (Grant Land, see Fig. 1 for locations). Wegmann identified *de Geer's* line as a possible trace of the lateral movement Greenland and Ellesmere Island must have undertaken during the younger Tertiary in order to shift away from the sedimentary basins of Spitsbergen, which they supposedly once delivered, thereby opening the Scandic. *De Geer's line* was the name given by Wegmann to a remarkable geographical alignment. It runs from the northeast coast of Norway near Vesteralen along the western border of the Barents shelf area towards the northwesternmost tip of that shelf and continues along the northern margin of the Arctic Archipelago until it ends at the Alaskan coast at the edge of the Beaufort Sea. In its eastern part, this line separates the relatively shallow Barents Sea to the North from the deeper Scandic to the South. In its western part, this bathymetrical pattern is exactly opposite with the deeper Polar Basin lying north and the shallow shelf area of the Arctic Archipelago south of the line (Wegmann 1943a: 238). Closing the Scandic by kinematically inverting the supposed movement of about 1,400 km (Wegmann 1943b: 102) along de Geer's line brings Grant Land and Peary Land much closer to Spitsbergen and also eliminates the extreme bathymetric relief across de Geer's line (see Fig. 2). Apart from all these remarkable findings, the line follows a great circle (Wegmann 1948: 21; Fig. 3) and Wegmann thus produced—with the help of his mathematically gifted friend Guyot (1943)[3]—a Mercator projection of the Arctic with its equator parallel to de Geer's line (Wegmann 1943a, b: Fig. 1; 1948: Plate 1 and Fig. 1 of the present article). All possible traces of movement of the Greenland block should, therefore, appear parallel to the lower and the upper boundary of this projection which –according to Wegmann– should facilitate their recognition. This was exactly the same procedure McKenzie and Parker (1967) applied 25 years later in their landmark paper on the Pacific (see above). However, Wegmann lacked the critical data (e.g. fault plane solutions) to further exploit the possibilities of his projection.

Wegmann's test and his influence on later workers

Wegmann was very keen to provide the geological community with a critical test to check his speculations of continental displacement in the Arctic region. Because this was the only way to prove or disprove a working hypothesis: "As long as the hypotheses are metaphysic, that is, with as little and as remote a contact with observable phenomena as possible, they can neither be proved nor disproved, and they will have to be trailed along in the baggage of science from year to year." (Wegmann 1948: 36). Thus, he proposed to study the clastic Tertiary sediments of Spitsbergen and the supposed areas of delivery, viz. Grant and Peary Land (Wegmann 1943a: 240, 1948: 23 ff.). Apart from routine stratigraphic work, he also proposed the then relatively new techniques of heavy mineral analysis and geochemical characterisation of peculiar minerals, which still today are the two probably most widely used tools in provenance analysis (e.g. Miller et al. 2006 provides an example of the application of detrital zircon age dating in the Arctic). Thus, if the two

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[3] Edmond Guyot was the director of astronomical observatory of Neuchâtel. In a paper published in 1943, he derived the mathematical formulae to convert the spherical coordinates of a point on the Earth's surface (i.e. longitude and latitude) to the Cartesian coordinates on a Mercator projection (i.e. x and y) with a suitably chosen pole of projection. Using these formulae, he calculated the data and Wegmann needed to draw his maps (Fig. 1).

Fig. 2 Reconstruction of the Arctic region in Early Tertiary and Mesozoic times according to Wegmann (from Wegmann 1943a: Abb. 2). This figure was constructed by kinematically inverting the supposed movement along de *Geer's line*. The numbers in the legend are as follows: *1* Caledonian zone, *2* "Old red" graben structures, *3* Variscan zone, *4* directions of important post-Variscan transgressions, *5* basalts and other young volcanic rocks. The abbreviations are as follows: *RI* Rejkjavik-Iceland swell, *R*, Rockfall swell, *P*: Porcupine swell

provinces mentioned do show a high degree of similarity—that is, if one can be considered the source area of the sedimentary rocks of the other—continental displacement would be very probable.

Wegmann did not get the opportunity to test his working hypothesis himself (Schaer 2011), and to our knowledge, no one else did this—at least before the plate tectonic revolution 25 years later. However, Wegmann's ideas on the de Geer's line have been repeatedly cited—not always correctly and sometimes surprisingly wrong—by later worker as, for example, Carey (1958), Harland (1961, 1965) or Wilson (1965). Carey (1958: 206–207), for example, even understood a totally different line (one that fitted into his tectonic model of the Arctic) under the term de Geer's line even though he made explicit reference to Wegmann (1948). Furthermore, it is surprising that Harland obviously was of the opinion that Wegmann either rejected his own test (1965: 60) or at least was very sceptical about the theory of continental displacement (1961: 126). Close reading of all three of Wegmann's papers that are concerned with the problem reveals an opposite picture (cf. also the remarks by Aldinger 1937: 125): Wegmann was remarkably open-minded and even argued that a negative result of his test—that is, the two provinces do not correspond to each other—would not disprove continental displacement as a general theory but rather the specific application to de Geer's line (Wegmann 1943a: 240). On the other hand, it has been pointed out by Wegmann's former pupil Schaer (2011) that his teacher was, at least in his later years, of a rather conservative and even anxious nature.

Compared to more recent plate reconstructions of the Arctic (e.g. Bullard et al. 1965; Rowley and Lottes 1988; Johansson et al. 2005, or Pease et al. 2011), it seems likely that Wegmann overestimated the shift along de Geer's line: it is today more likely to assume that Spitsbergen (and the whole Svalbard archipelago) was much closer to Peary Land than to Ellesmere Island (Johansson et al. 2005: Fig. 5) before the opening of the eastern Polar basin and the Scandic started in early Tertiary times (Rowley and Lottes 1988). Apart from that, it has become clear that the portion of de Geer's line lying between the Lomonosov ridge (which was not yet discovered when Wegmann published his papers) and Beaufort Sea is seismically inactive (cf. the very instructive Fig. 8 in Sandwell et al. 2005) and probably merely represents a geographical "coincidence". Only that portion of de Geer's line which lies between the polar part of the North Atlantic ridge (the Gakkel ridge, which lays halfway between the Lomonosov ridge and the margin of the Barents shelf) and the northern tip of Norway is actually a fault plane—a ridge–ridge transform as already drawn by Wilson (1965: fig. 5).

Some final thoughts

After this short discussion of Wegmann's thoughts, it seems worth to point out that he added a hitherto unknown degree of quantification—apart from the geodetic measurements, which are, however, not of a geological nature—to the heated debate on continental displacement. It is exactly this high predictive power of modern plate tectonics that is considered as one of its greatest assets that guided geology from a descriptive to a predictive science (see e.g. Menard 1986: 293, Le Grand 1988: 238). Figure 3 demonstrates this quite well: from a regional tectonic problem, the de Geer's line, Wegmann deduced tectonic consequences which concerned areas as distant as

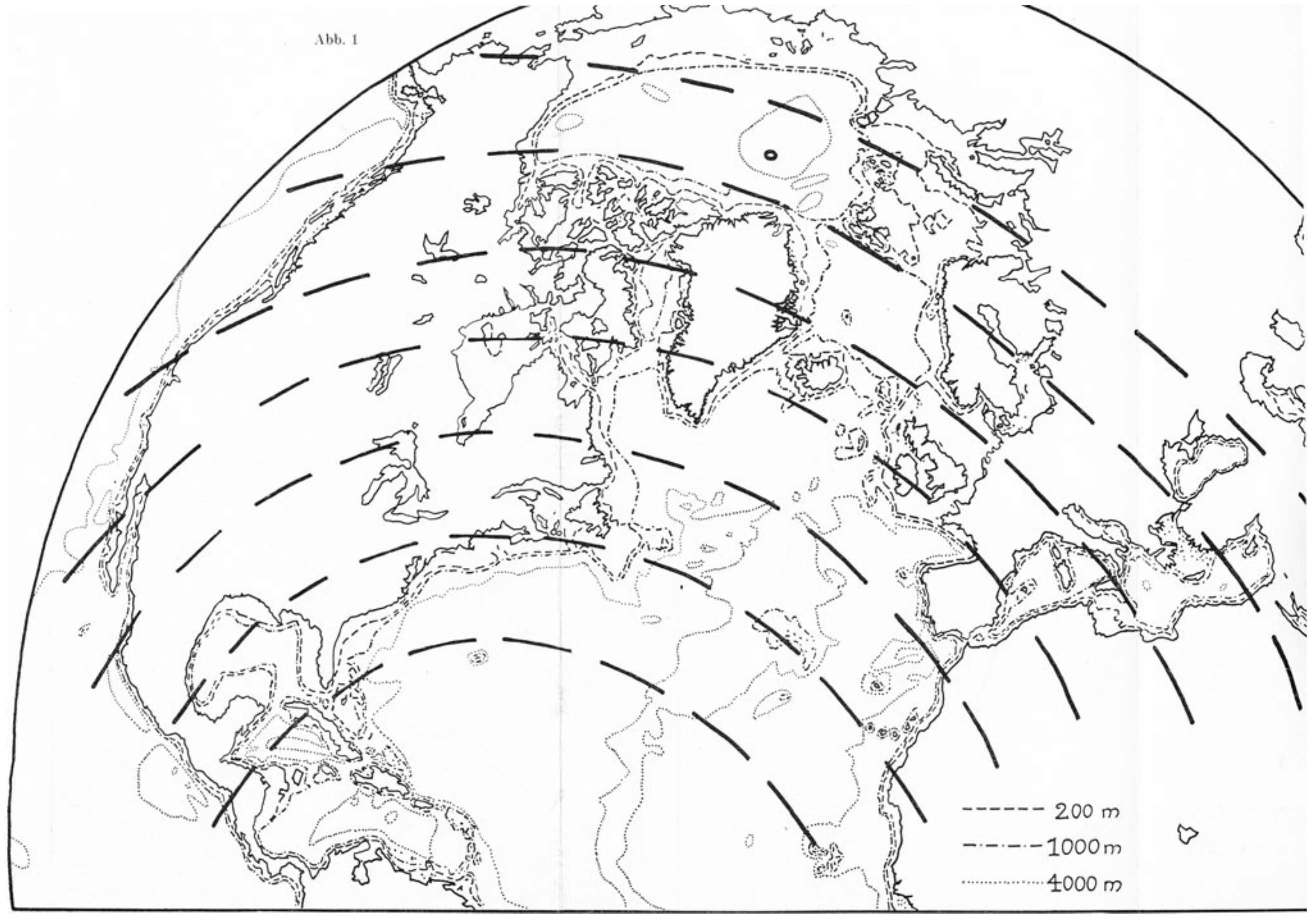

Fig. 3 Sketch of all parallels to de *Geer's line* (from Wegmann 1943a: Abb. 1). In modern parlance, these parallels are *small circles* around an Euler pole situated in the Western South Atlantic

California (Wegmann 1943a: 241), where he pointed out the importance of the San Andreas fault and the fact that the latter runs approximately along a great circle parallel to his de Geer's line (see also his plate 2 in Wegmann 1948). These two fault zones were maybe contemporaneous and due to the same cause: "Die Verschiebungen in Kalifornien […] werden in diesem Falle mehr oder weniger parallel mit der angenommenen Bewegung im arktischen Sektor. Man ist daher versucht, einen gewissen Zusammenhang anzunehmen, der sich auf die einfachste Art dadurch ergibt, dass man den ganzen Kontinent [i.e. North America] in der Richtung der Parallelen verschiebt. Ein solcher Versuch ist in mancher Hinsicht vielversprechend, da er die zeitlichen Episoden besser fixieren helfen kann." (Wegmann 1943a: 241). Even though Wegmann did not join the camp of the drifters" (cf. e.g. his sober discussion of the theory of continental displacement in Wegmann 1963), he seems to have been quite open-minded—at least until maybe the 1950s—and supplied the geological community with a lucid discussion on the geometry of continental displacement and highly predictive means to test this hypothesis. For this, he deserves full credit.

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