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On the impact of Argand's «*La Tectonique de l'Asie*» on the evolution of Alpine and Mediterranean tectonic concepts

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Abstract

A significant part of the work of as reported by Argand (Comptes rendus de la XIIIe session du Congrès géologique international, Bruxelles 1922, Liège, fascicule, 1924a) «*La tectonique de l'Asie*» concerns the structure and kinematics of the Alps and the Mediterranean. Argand presented some entirely innovative concepts on the kinematics of these areas, showing for the first time, large-scale rotations of microplates and the structure of orogens including both the crust (Sial) and the mantle (Sima). In contrast to his previous alpine works, which were very rapidly accepted and emulated by the scientific community, these new interpretations of the Alpine and peri-Mediterranean chains were partly criticized, but mostly ignored. The scientific community continues to work and publish on these subjects disregarding the new concepts of as reported by Argand (Comptes rendus de la XIIIe session du Congrès géologique international, Bruxelles 1922, Liège, fascicule, 1924a) who presented the very first palinspastic reconstruction of the peri-mediterranean realm in addition to "lithospheric" sections across its chains and basins. Only after the acceptance of Plate Tectonics, geologists and geophysicists discovered on the base of paleomagnetic analyses that the Apennines, Sardinia, and Corsica had undergone anticlockwise rotations throughout the Miocene, thus confirming, the interpretations of Argand, presented in the "*Tectonique de l'Asie*". However, most of these modern studies of the early 1970's did not quote Argand, and still did not propose any lithospheric-scale model, nor paleogeographic reconstructions accounting for the entire western Mediterranean area, half a century after as reported by Argand (Comptes rendus de la XIIIe session du Congrès géologique international, Bruxelles 1922, Liège, fascicule, 1924a).

Keywords Emile Argand, History of Alpine Geology, History of Mediterranean geology

1 Introduction

Emile Argand presented his work « *La Tectonique de l'Asie*» at the XIIth session of the International Geological Congress, held in Brussels in August 1922. He was invited to give the inaugural public lecture of the congress, during which he showed his new tectonic map of Eurasia, which includes the timing of orogenic deformations. This map completely covers the area spacing from Western Europe and North-Africa in the west to Papua New Guinea and the Bearing Sea in the East. Argand received the Spendiaroff prize for this work (Schaer, 1991), which had previously been presented by his colleague and friend De Margerie in 1913 at the XIIth session of the International Geological Congress in

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Toronto, Canada. Hence, Argand had been working at least 10 years on the continental deformation of Eurasia, before giving his public lecture in 1922. However, he did not publish anything on this specific subject in the years preceding the latter conference. The reason may simply be his difficulty and abhor against writing manuscripts. Lugeon (1940) described in detail how Argand retarded the publication of the proceedings of the XIIth session of the International Geological Congress by 2 years, due to his delay in submitting the manuscript of "*La Tectonique de l'Asie*", and which subterfuges were undertaken to eventually force him to terminate his manuscript.

The title of Argand's (1924a) work is somehow misleading, because the latter is not only about Asia. Many other mountain belts and their reciprocal links, including the peri-Mediterranean chains, are also analysed and interpreted in detail. Wegener (1929) stated that[1]:"*…(in) this work on the Tectonics of Asia, Argand also considers the main structures of the entire world surface*". Lugeon (1940) is even more explicit about this[2]: « *The memoir written by Argand carries a title that does not fit to it: Tectonics of Asia. One may imagine that it will only be about this old continent, whereas it embraces the entire Earth*». Indeed, Argand used some of the figures and contents of "*La Tectonique de l'Asie*" for a paper specifically addressing the relationship between Alpine Chain and continental displacements of Africa and Eurasia (Argand, 1924b; see Schaer, 2010, to understand Argand's motivations to rapidly publish this paper).

Argand reconstructed the paleogeography of Eurasia and of the Mediterranean, often quoting the work of Wegener, who was otherwise largely ignored by most geologists working on regional tectonics at that time. In 1922 Wegener's mobilist ideas were not much discussed outside of Germany (Le Vigouroux, 2022), partly because one was not allowed to do so in the years following World War I (Carozzi, 1985), but partly because these ideas were still not accepted, even by scientists having firmly recognized the nappe structure of the Alps (e.g., Termier, 1903). On the other hand, Wegener included several of Argand's ideas and figures in his own publications, to gain additional support on the existence of large, horizontal continental displacements. Indeed, a concept that Argand stressed several times in "*La Tectonique de l'Asie*" is that all vertical displacements are the ultimate result of horizontal ones. Both Wegener and Argand, fought to introduce such innovative concepts in a still reluctant scientific community. Whereas Wegener's starting point was the idea that oceans form where continents drift apart, Argand's mobilistic approach was the consequence of his evolving and profound understanding of the structure of mountain chains (e.g. Schaer, 2010), that starting from 1916, he interpreted as the thrusting of one continental margin on top of the other.

As mentioned by Lugeon (1940), Argand's manuscript is difficult to understand. Several of his conclusions, which are recognized as being still valid today on the base of modern data and concepts, are not entirely explained in his text (Argand, 1924a). The reader is not always provided with all observations and lines of argument that form the base for Argand's interpretations. Hence, a discussion of how Argand could possibly arrive at such modern conclusions, given the scarcity of data existing at his time, is also part of the present paper. After analyzing how in his work Argand interprets the Alps and the Mediterranean kinematics, we will discuss how, and if his discoveries and interpretations impacted geological and geodynamical research in these areas, in the years and decades following the publication of his book.

2 Evolution of Argand's Alpine views from 1909 to «*La Tectonique de l'Asie*»

2.1 Argand's cross sections

Argand's Alpine concepts, and in particular, his western Alpine cross-sections, evolved significantly through time (Fig. 1), and this evolution culminated in "*La Tectonique de l'Asie*" (Argand, 1924a). His first W-Alpine cross section (Argand, 1909; Fig. 1a) strikes across the Matterhorn (Swiss-Italian border) and it is the result of extensive mapping and field work. Argand underlined this in the introduction of his publication (Argand, 1909), stating that he dedicated 500 days of field work to this study, 305 of them between 1905 and 1907. The cross section (Fig. 1a) covers a very large part of the Alpine orogen. Its maximum vertical extension, in the central part of the section (below the Zone du Combin), exceeds 20 km, thus attaining a crustal depth that had never been showed before (Rosenberg, 2024). This section illustrates the pile of basement nappes, sometimes still including their cover, overlying the Helvetic Zone and the External Mont Blanc massif. In 1916, Argand published a second western Alpine cross section (Fig. 1b), this time reaching everywhere the same depth, of approximately 30 km, and imaging the entire Alpine orogen in NW–SE direction, hence adding larger parts of the Helvetic and Adriatic domains that were still missing in the 1909 section. The exact trace of the section is not provided and the topographic surface is not shown, because the section is largely completed by lateral projections, shown in Argand (1911). As a consequence, the section is representative

[1] *"…Argand, der, … in dieser Arbeit über die Tektonik Asiens auch die Hauptzüge des ganzen Erdantlitzes in Betracht zieht "*

[2] *"Le mémoire écrit par Argand porte un titre qui ne lui convient pas: La tectonique de l'Eurasie. On s'imagine qu'il ne parlera que de ce vieux continent alors que c'est toute la terre qui y passe„.*

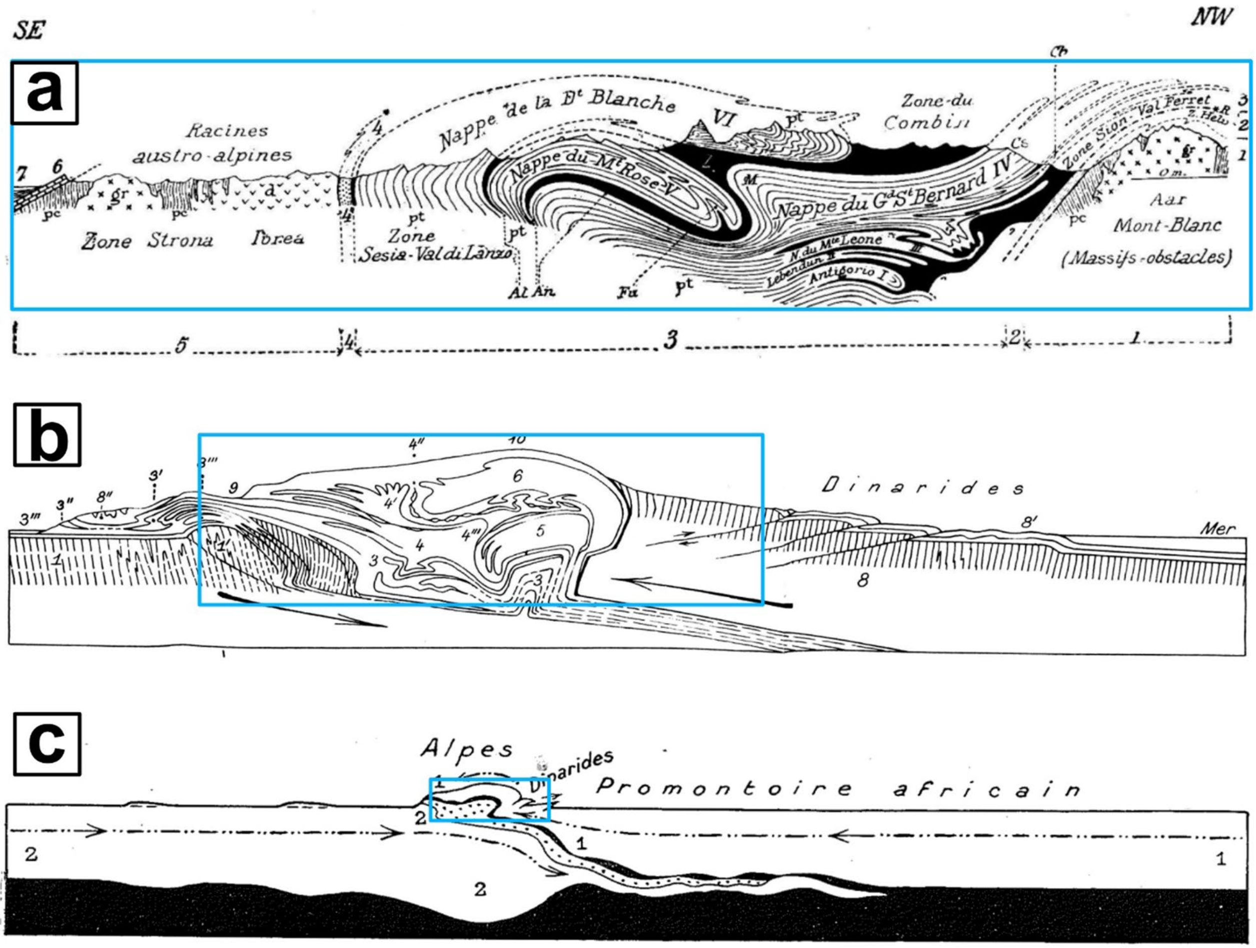

Fig. 1 Alpine cross sections of Argand, showing how his interpretation evolved through time, including progressively deeper structural levels, and progressively larger space. **a** Argand (1909). This section shows most of the northwestern Alps and most of the alpine crust, namely down to a depth of ca. 20 km. **b** Orogenic-scale section of the northwestern Alps (Argand, 1916), showing the entire orogen down to the base of the crust and both foreland and backland. This section does not show a topographic surface, because it results from extensive lateral, fold-axes parallel projections, hence this same section is representative of a wide area of the NW Alps and not of a single specific vertical plane. It bears a higher degree of abstraction compared to figure a). The blue rectangle shows the approximate surface represented in the section of Fig. 2a. **c** "Lithospheric"-cross section of Argand (1924a). The rectangle shows the approximate surface represented in the section of Fig. 2a, b. The Alps only form a small part of the "lithospheric"-scale representation of Argand (1924a)

of a wider area, and does not illustrate a specific trace in map view (Argand, 1916); (Fig. 1b). Hence, it is a «synthetic» section, which allows one to visualize the Alps form a more distant perspective, less attached to the very specific structures outcropping along a given trace. Both of these cross sections had an immediate and enormous impact on the community of Alpine geologists. In the years following their publication, other large-scale cross sections showing Argand-style nappe stacks over vertical extensions of several 10's of km were performed in the Central and Eastern Alps (Staub, 1917; 1924, for the eastern Central Alps; Heim, 1921; Jenny, 1924, for the Central Alps; Kober 1923 for the southern and eastern Alps; Fig. 2) and Argand's sections themselves were widely reproduced (e.g., Wilckens, 1911; Blanchard, 1915; Kober, 1921; 1923; Heim, 1921; Jenny, 1924; Collet, 1926; 1927; Staub, 1928a; Bucher, 1933). Before the 1909 cross-section of Argand the Alpine nappe stack was never depicted down to depths exceeding a few km (e.g. ca.7 km in Schardt, 1906 and Heim, 1908), and basement nappes were only starting to be identified and represented in their correct geometries (Lugeon, 1902; Schardt, 1904; Schardt, 1906). Argand's numbering of these «fold-nappes», from the lowest (nappe I; Antigorio) to the uppermost one (nappe VI; Dent Blanche) was also adopted by several authors (e.g., Jenny, 1924).

The innovating character of Argand's Alpine sections culminated in « *La Tectonique de l'Asie*», with two new types of representations of the orogen structure in section: one (Fig. 3) is a modified version of his 1916 section

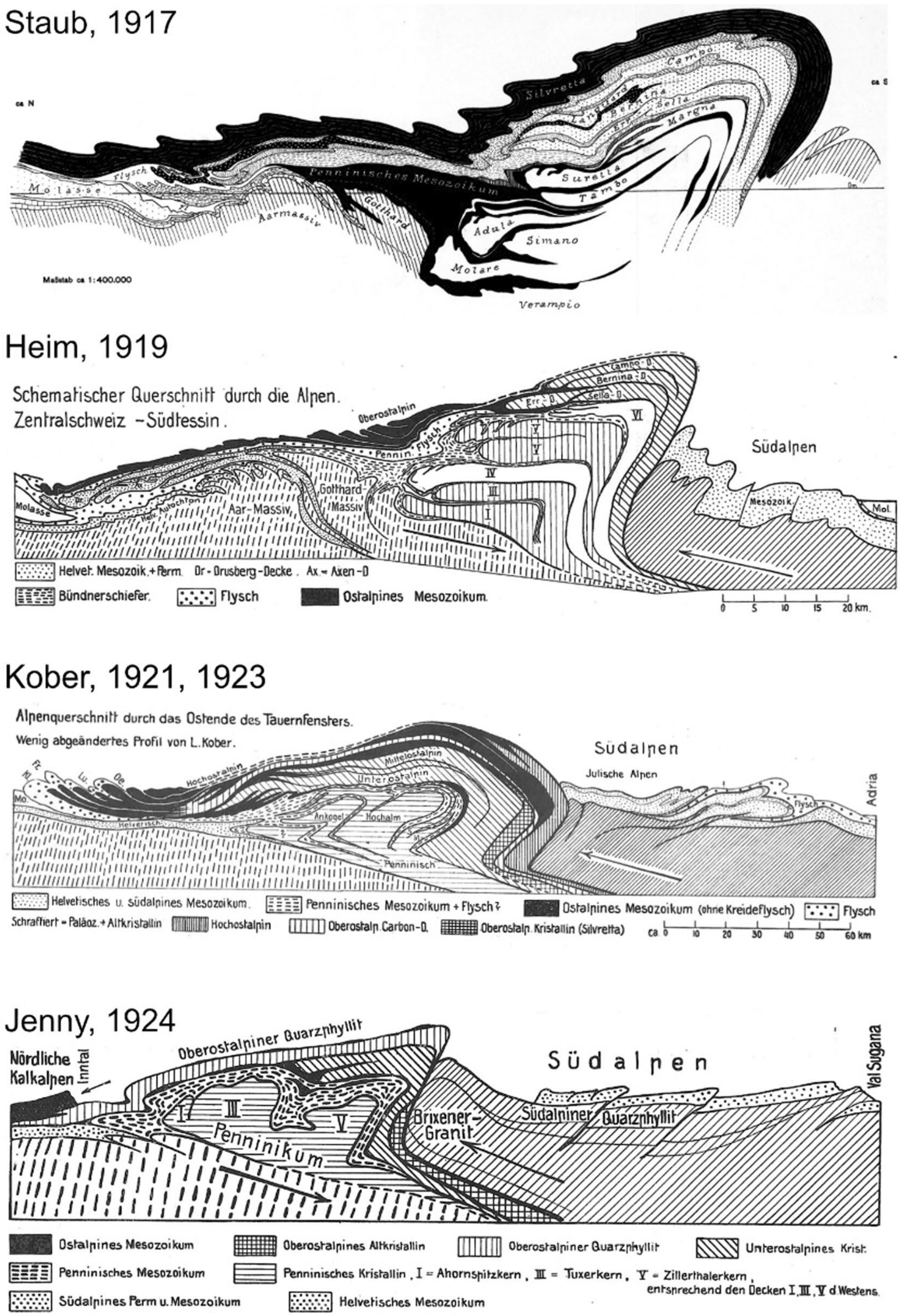

Fig. 2 Alpine sections of different authors inspired from Argand (1909; 1916). Note the arrows in the section of Heim, Kober, and Jenny, as in the section of Argand (1916); (Fig. 1b), showing the European margin underthrusting the Adriatic one. Some sections (Heim, 1919; Jenny, 1924) use the same nappe numbering introduced by Argand (1909) in the Western Alps. The deformation style, showing one major antiformal stack of basement nappes, down to several 10's of km depth, is shown in all sections, as in Argand (1909; 1916)

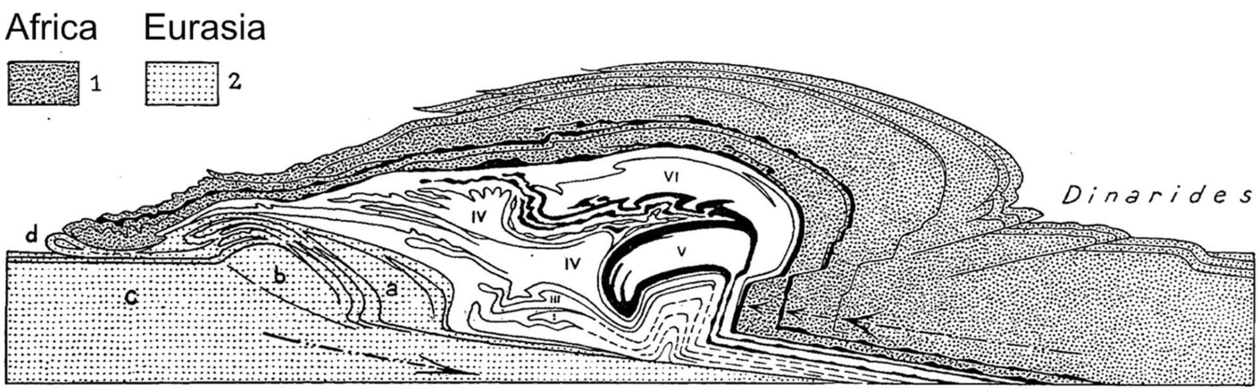

Fig. 3 Argand (1924a). Modified cross section of 1916 in the Northwestern Alps. The geometry of the nappe stack is unchanged, but the Austroalpine units are sketched on top of the nappe stack all the way through, attaining the European foreland. The legend is different with respect to 1916: only three units are distinguished: Eurasia, the Tethyan-derived nappe stack, and Africa

(Fig. 1b) and another one is a series of "lithospheric"-scale sections (Figs. 1c and 4). In the following, we will use this term, although a thermal/mechanical boundary marking the lithosphere/asthenosphere transition was certainly far from Argand's concepts and is never represented in his sections. Nevertheless, in order to acknowledge the simple presence of a mantle (Sima) layer below the crustal one (Sal) in Argand's sections, we term them as "lithospheric". By so doing, we distinguish them from Argand's older sections and those of previous literature that only display crustal structures. These sections (Fig. 3) differ from that of 1916 in that they only consist of three main units: Eurasia in the lower part, Africa in the upper part and the Pennine stack in between, although the latter one is not part of the legend. In addition, Africa is drawn all above the Penninic nappe stack, thinning northwestward, until it completely disappears north of the External Mt Blanc massif. Hence, the accent is set on visualizing the Alpine orogen as the simple result of Africa overthrusting Europe. The nappe geometry is unchanged compared to the 1916 section.

The second type of sections (Figs. 1c and 4), represents the world-first "lithospheric"-scale representation of an orogen. Only four units are represented: Africa, the Tethyan sediments, Eurasia, and the Sima. The Alpine orogen only forms a very small part of the section, just little more than 10% of its total length. Both continental units, but especially Eurasia, laterally terminate with a very thin and long margin in the Alpine realm. Giving so much space to the undeformed areas of the European and African continents underlines the concept of Argand, relating Alpine orogeny to the displacement of entire continental blocks, even very far from the chain.

Several elements sketched in the section of Fig. 1c can be considered as scientific revolutions with respect to the existing tectonic knowledge at the time of Argand: (1) the geometry of the base of the crust, all across an orogen; (2) the geometry of the continental margins and in particular that of the very thinned European one; (3) the complete underthrusting of this thin margin below Africa; (4) The continuous thin layer of Sima coating the thrust plane between the two continental blocks and attaining the external part of the Alpine Chain. The Tethyan sediments underlie this layer and they form themselves an only slightly thicker, also continuous layer; (5) the long arrows indicating that entire continents are displaced, even very far from the orogen, and that one is thrust upon the other in the orogen. We discuss these different structures in more detail below.

(1) For the first time, the section represents a specific orogen from the surface down to the mantle (Sima). No other examples of "lithospheric"-scale cross sections of this type had ever been published before Argand (1924a, 1924b). Heim (1916) did show the base of the crust below an Alpine-type

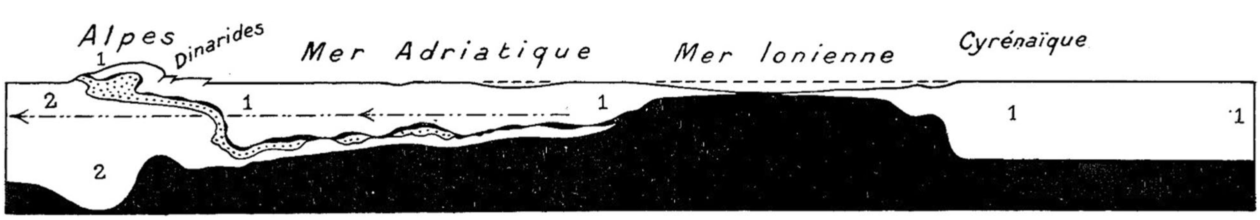

Fig. 4 "Lithospheric"-scale Alpine section of Argand (1924a). This is the very first example of a "lithospheric" section of the Alpine orogen. Note the very thinned and long continental margins

orogen, but it was only a schematic representation, albeit strongly inspired by the specific structure of the Alps. Argand linked crustal thickness with surface topography, showing a deeper, root-like base of the thickened Eurasian block below the Alps. Staub (1924; 1928a, 1928b) illustrated several cross sections with the crust overlying a "Magma-zone" (Fig. 5), but in addition to this erroneous view of the mantle, these sections are fully schematic, representing hypothetical convergence stages of the Alpine chain. The sections of Argand (1924a, 1924b) are highly simplified, but never schematic! His Alpine section of 1916 and 1924 (Figs. 1 and 4) are simplified, by illustrating only 4 units and by reducing structural complexities to the very 1 st order. All the geometrical elements shown there correspond to specific structures rigorously derived from field and map interpretations. They do not depict the alpine structure schematically, but the essential structure of the Alpine chain.

(2) The continental margins of both Africa and Eurasia are thinned, but the European one to a much larger degree, attaining some 800 km length. Hence this margin may be considered as "hyper-extended", using modern terminology. As shown below for the Cenozoic history of the Mediterranean, Argand was clearly conscious of how such continental margins form, namely by ductile, extensional thinning of a continental block. Unfortunately, Argand applied this interpretation also to the Ionian Basin (Fig. 4), the only one in the Central Mediterranean to be a Mesozoic relic (e.g., Speranza et al., 2012), and not a product of Cenozoic stretching. However, the general process of margin formation that he sketched is correct and clearly illustrated by his cross section (Fig. 4) and by his temporal reconstructions in map view.

When reading the figure captions and the text of "*La Tectonique de l'Asie*", the reader may be disappointed not to find a clear, transparent description of the observations and interpretations that led Argand to sketch such margins. Nowhere this important structural architecture of the margin is described and explained in detail. Hence, we can only speculate on which observations and lines of arguments brought Argand to his conclusions. One of them is certainly the fact that Argand interpreted the existence of unusually thick sedimentary sequences in geosynclines to be due to extensional subsidence. Geosynclines were never interpreted in this manner before. Staub (1928a; pp. 209–210) stated that Argand was the first to recognize that the formation of geosynclines would take place through extension of the crust, and that drifting of continental blocks is the primary driver of this process (see Sengör, 1982, for Argand's evolution of ideas on this same subject). This may be one important element that allowed Argand to understand that the crust underlying geosynclines was significantly thinner than that of adjacent areas, as shown by his orogenic cross sections, in which thick sedimentary sequences overlying thinned crust of one margin are thrust above the thinned margin of another continent (Fig. 1c).

The characterization of passive margins started with Suess (1883), who distinguished Atlantic and Pacific ones. Wegener (1920) sketched some simple, schematic models to link extensional tectonics and passive margin formation (Fig. 6a), but his suggested process of breaking apart small continental fragments and dropping them away from the main continental block, only produces small continental islands, never a thinned margin. Admittedly, his figure (Fig. 6b) that schematically represents the crust under the Aegean Sea, shows that extensional thinning affected a continent over a wide area, but it does not show the formation of new margins, neither are they discussed in the text. Thinned continental margins are not sketched before the onset of Plate Tectonics. Except for Argand (Fig. 4), Staub (1928a) was the only one showing

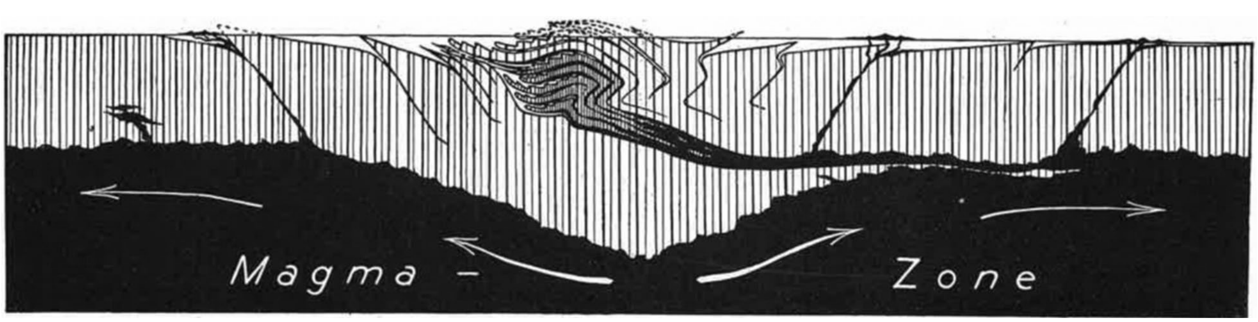

Fig. 5 "Lithospheric"-scale Alpine section of Staub (1928a). The similarity to the section of Argand (1924a), especially concerning the very thin and long continental margins, is rather obvious. However, Staub illustrated a "magma zone" underlying the entire crust. This was far from Argand's concept of the Sima

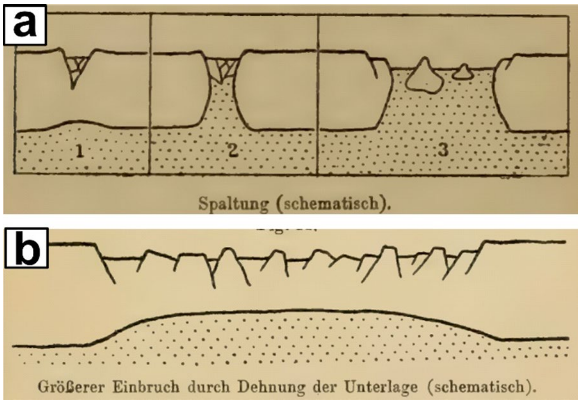

Fig. 6 Architecture of continental margins, in Wegener (1920). **a** Schematic model illustrating how faulting reduces the size of continental blocks, creating small islands and opening spaces which allow the Sima to reach the surface. **b** Thinning of a continental area by normal faulting, as in the Aegean Sea

an extremely thinned continental margin of the European crust, far behind the Alpine orogen, below the African "Rückland" (Fig. 5). However, it is likely that Staub simply reproduced in slightly modified form what Argand had sketched in 1924, as he often did with Argand's work, since he also did not provide any explanation for this new structure of the European margin. Nevertheless, no other extended or hyper-extended margins are seen in the literature until the Plate Tectonics era. Even at the beginning of the 1970'ies, as shown in a review of Dewey and Bird (1970), cross sections of continental margins only indicate incipient thinning of the continental crust. Argand was world-wide the first to conceive and illustrate thinned continental margins.

(3) Being entirely covered by Africa, the length of the thinned European continental margin provides a minimum amount of convergence between the two continental blocks. As often the case, Argand did not provide many explanations, but the latter length corresponds well to the inferred convergence amount between Eurasia and Africa as sketched in the map-view reconstruction of Fig. 7a (Argand, 1924a), and it is by far larger than the shortening amount recorded in the Alpine chain, based on Argand's retro-deformation in cross section (Argand, 1916; Fig. 7b). In other words, the amount of convergence recorded in the chain is significantly smaller than the total amount that took place, implying that one part was accommodated by thrusting along the interface of the two continental blocks. This process is similar to subduction, using modern terminology.

(4) The mantle (sima) and the orogenic nappe stack are linked through a continuous and thin layer, coating the interface between the two continental blocks. In spite of this geometry, which may suggest a purely tectonic origin of the sima (ophiolitic layers), Argand did not specify which processes bring such ultrabasic layer along the continental interface, up to the core of the orogen. Influenced by the early view of Steinmann (1907) and Suess (1909), with their knowledge of mafic and ultramafic intrusive magmas, Argand drew "ophiolite" layers along "embryonic" thrusts being emplaced in the early phases of Alpine orogeny. His interpretation of geosynclines as result of stretching of the Sial layer, eventually allowing the Sima to reach the bottom of the sea at an abyssal depth, was a way of initiating an ocean floor (Bernoulli et al., 2003). This is sketched in his Fig. 19 bis of "*La Tectonique de l'Asie*" (Fig. 4), where a cross section illustrates the progressive stretching of the continental margins on both sides of the Ionian Sea, eventually breaking apart and exposing the Sima. Unfortunately, as mentioned above, this area is the only part of the western Mediterranean in which modern research considers that the oceanic sea floor is Mesozoic or Permo-Mesozoic (e.g., Speranza et al., 2012 and references therein) and not a result of Cenozoic extension as inferred by Argand in the latter section. The general concept however is correct and Argand is the very first to apply it to a regional case study.

(5) Two arrows indicate the convergence of Africa and Europe and the overthrusting of the latter on the former. These arrows go all the way across each continental unit, very far away from the Alpine orogen, thus underlining the horizontal displace-

(See figure on next page.)

Fig. 7 Argand's recostructions of the Alpine and Mediterranean realm. **a** Retro-deformation of the Mediterranean realm in map view, indicating numerous steps of the displacement of coastal lines (Argand, 1924a, 1924b). **b** Tectonic map of the Mediterranean realm, showing the boundaries between major tectonic domains (Argand, 1924a, 1924b). 5: nappes austro-alpines; 7: bord des nappes helvétiques; 8: Dinarides; 9: "capuchon pennique"; 10: Atlas algérien et prolongements; 11: Atlas saharien. **c** Argand's (1916) retro-deformation of the western Alpine nappe stack in cross section, from its present state (uppermost section) to the Carboniferous (lowermost section). **c** Retro-deformation of the Western Alps in cross section. Unit n. 1 represents the"hercynian foreland". Unit n. 3: foredeep or Valaisan geosynclinal. Unit n. 4: géanticlinal briançonnais). Unit n. 5: piémontese géosynclinal. Unit n. 6: Dt Blanche nappe. Unit n. 7: géosynclinal canavésan. Unit n. 8: hercynian core-nappes and their mesozoic envelopes

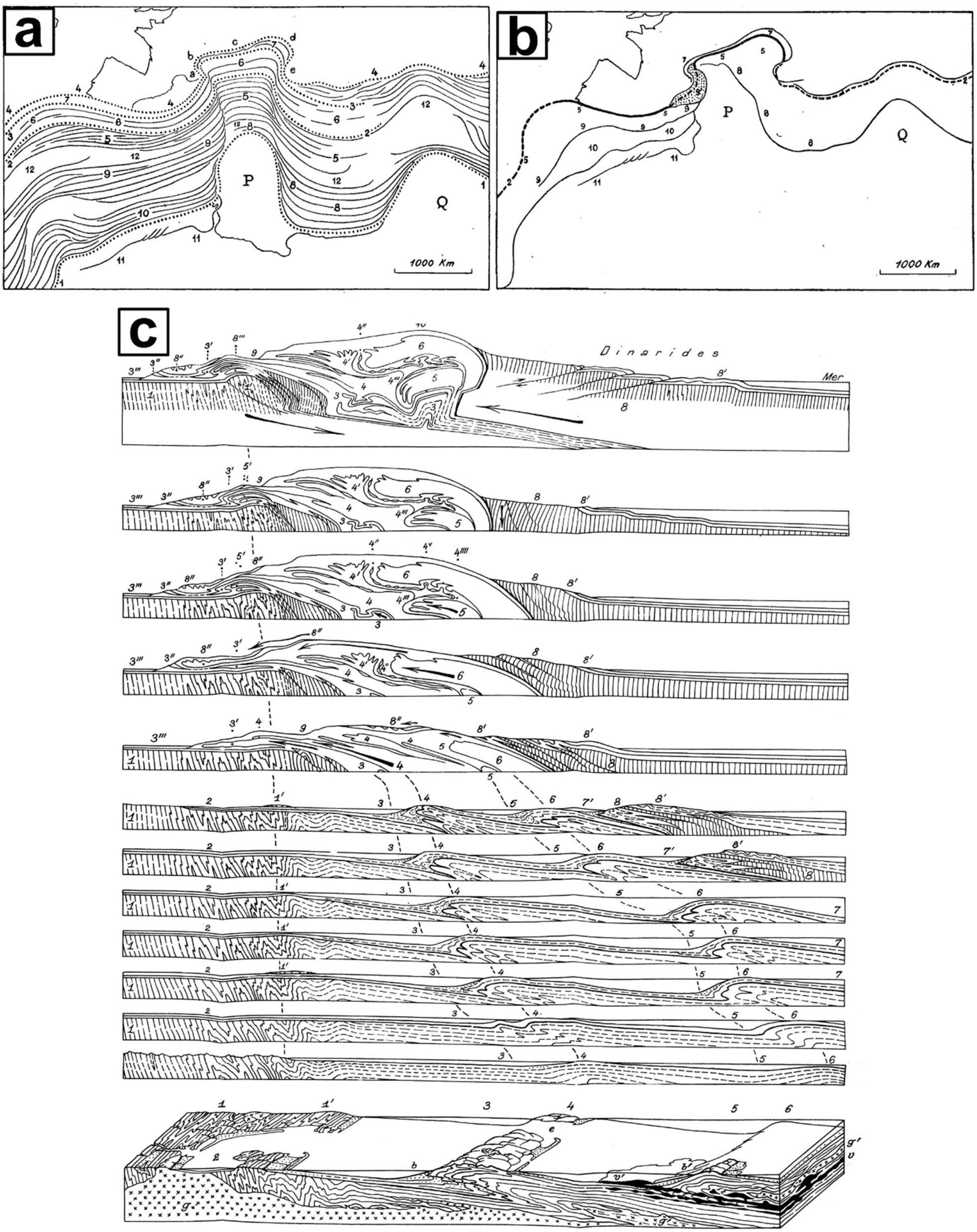

Fig. 7 (See legend on previous page.)

ment of an entire continent and not merely of a nappe stack, as was the case in the 1916 sections. Argand (1924a; p. 306) stated[3]:"*This penetration of Africa right into Europe, that I already discussed in previous times…, appears today to be un-understandable to me in the absence of continental translations, especially since the amplitude of thrusting … is enormous*". The next paragraph continues with a comparison of the Alpine and India/Eurasia settings showing that Argand's reasoning on orogenic processes was henceforth taking place in continental terms[4]:"*Another India has come here to face Eurasia, but it was of smaller size compared to the asiatic case. And instead of diving below Eurasia, it overthrusted it*". A fundamental observation guiding Argand's interpretation was his recognition of a complete continuity between the basement of the Adriatic margin in the Alps (the basement of the Southern Alps, or of the Dinarides using the terminology of Argand and the Alpine geological community of his time) and the north African plateau:"[5]*Indeed, if one moves from the crystalline basement of the Dinarides of Lombardy to the tabular areas of Tripolitania, following the Po Plain and the Adriatic Sea, no object that would move one to admit a discontinuity in the continental block at a certain time, is ever crossed nor walked along*". As a consequence, the displacement of the continental margin clearly took place together with the remaining part of the continental block.

2.2 Argand's map-view reconstructions of the Alpine realm

Since the end of the nineteenth century (Suess, 1875), scientists attempted to interpret the mutual connections of the peri-mediterranean orogens (Fig. 8) in map view (Stille, 1927a, 1927b; von Seidlitz, 1931, for review). The spatial pattern of the orogens with their inferred lateral connections in map view was termed "orogene Leitlinien" (orogenic trend lines), a term that was introduced by Suess (1883) and newly defined by Stille (1927a). These inter-orogenic connections indicated a kinematic continuity, which was interpreted in different ways (Fig. 8). Most authors (Suess, 1875; Staub, 1924) considered that the Apennines represented the lateral continuation of the Alpine chain (Fig. 8), whereas others interpreted them as separate, opposite branches of a bi-vergent system (Kober, 1914; 1923; Stille, 1927a, 1927b). Argand's concept (1924a) differed from all the others, in that it showed that the strike of the Alpine Chain continues beyond Liguria, but not into the Apennines (Fig. 9). He extended the Alps all across Corsica and the east of Sardinia, before joining them to the north-balearic area and the Betics. His interpretation of the Dinarides also differed from most other authors, excepted Suess (1875). Argand showed that the latter chain strikes from the western Po Plain to the southernmost Aegean Sea (Fig. 9).

The map-interpretations of Argand (1924a); (Figs. 7 and 9) are barely discussed in the Alpine literature of the decades following their publication, and it is amazing not to see them included into reviews and books on this specific topic (e.g., Stille, 1927a, 1927b; von Seidlitz, 1931).

3 Argand's Mediterranean kinematics

3.1 Mediterranean geology before Argand's "La Tectonique de l'Asie"

One part of Argand's work is concerned with the formation of the Mediterranean Basins and the Peri-mediterranean chains. The general ideas about this area in the years preceding 1924 were strongly influenced by Suess (1909); (Fig. 10a), who mapped the "Altaidenhorste" in the perimediterranean region. These Horst were inferred to be stable relics of Variscan crust, not having undergone any younger orogeny. One of these horsts was identified to be the Sardinia-Corsica block (Fig. 10a), albeit its northeastern-more corner (Alpine Corsica in the present literature) and also the margin of Sardinia were already attributed by Suess to the Alpine-Apenninic Chain (Fig. 10a). Termier (1911); Fig. 10b), modified this map, still keeping the concept of Altaïdenhorste and enormously widening the Corsica-Sardinia Altaïdenhorst, so that most of the Algero-Provençal Basin, and part of the Thyrrhenian one, were included in that stable Horst (Fig. 10b). The northeastern part of Corsica was clearly attributed to the Apenninic (Fig. 11b) and not to the Alpine chain by Termier[6]: "*…a land of nappes, where exceptional displacements … post-date the Oligocene*". Later in the same paper, Termier clearly showed a mobilistic approach to explain the structure of Alpine Corsica and the Elba Island, although he viewed the remaining

[3] *"Cette pénétration de l'Afrique en pleine Europe …me semble aujourd'hui inexplicable sans translations continentales, d'autant plus que l'amplitude des charriages … est énorme".*

[4] *"Une autre Inde est venue affronter ici l'Eurasie, mais elle était de moindre taille que l'exemplaire asiatique. Et au lieu de passer dessous, elle l'a surmontée".*

[5] *"Si l'on chemine, en effet, du socle cristallin des Dinarides de Lombardie aux tables de la Tripolitaine, en suivant la plaine du Pô et l'Adriatique, on ne croise ni ne longe d'objet qui autorise à admettre, pour un certain passé, une discontinuité du bloc continental".*

[6] *"…un pays de nappes, où les déplacements horizontaux, formidables … sont postérieurs à l'Oligocène".*

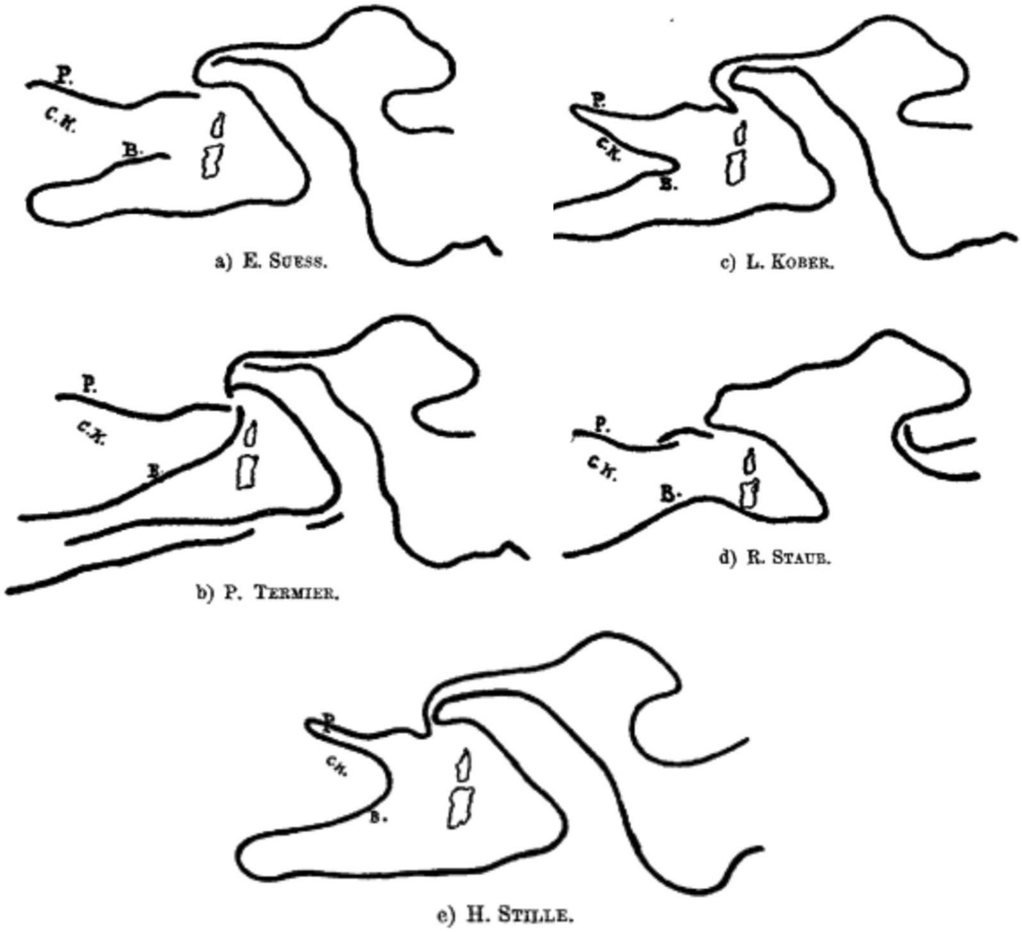

Fig. 8 Summary of the inferred orogenic "Leitlinien" (trend lines) of the Peri-mediterranean area, as reviewed by Stille (1927a)

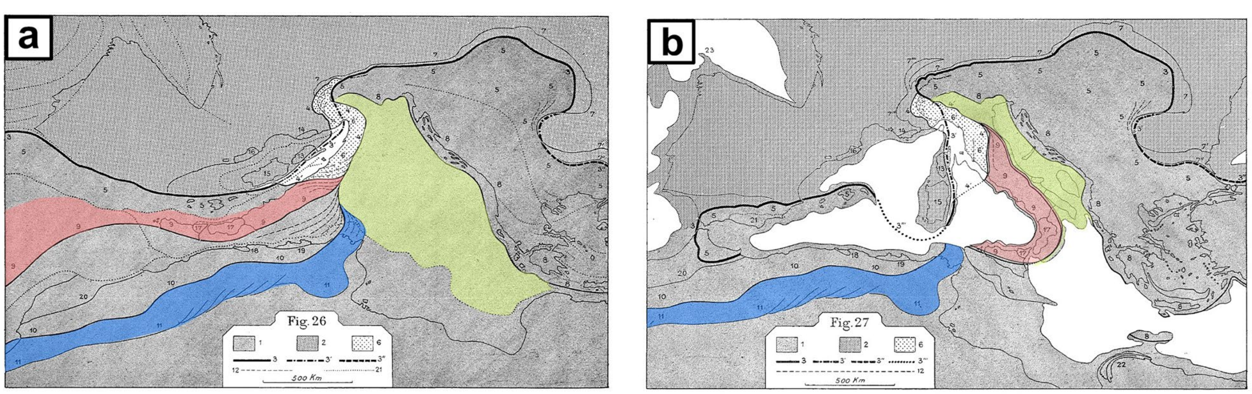

Fig. 9 Mediterranean Tectonics, modified after Argand (1924a). **a**) before the rotation of the Corsica-Sardinia block ("after the greatest Tertiary paroxysm", most likely Oligocene); **b**) present-day tectonic map of the western Mediterranean area. Legend severely shortened after Argand (1924a). See p. 360 of "*La Tectonique de l'Asie*" for the complete legend. Patterns: 1, Gondwana; 2, Eurasia; 6, penninic nappes in areas where they remained uncovered by other nappes.Lines: 3, 3', 3", northern margin of Africa. 4 and 4', external and internal margisn of the penninic zone, respectively. 5, austro-alpines nappes. 6', backfolds and retrograde nappes of the penninic Alps, underthrust below Africa and the real Apennines, which are part of this continent. Three areas are colored to allow for a rapid comparison of the present and pre-Tertiary distribution of continental blocks. Light red: Apennines; Green: Dinarides and Austroalpuine nappes; Blue: Algerian Atlas

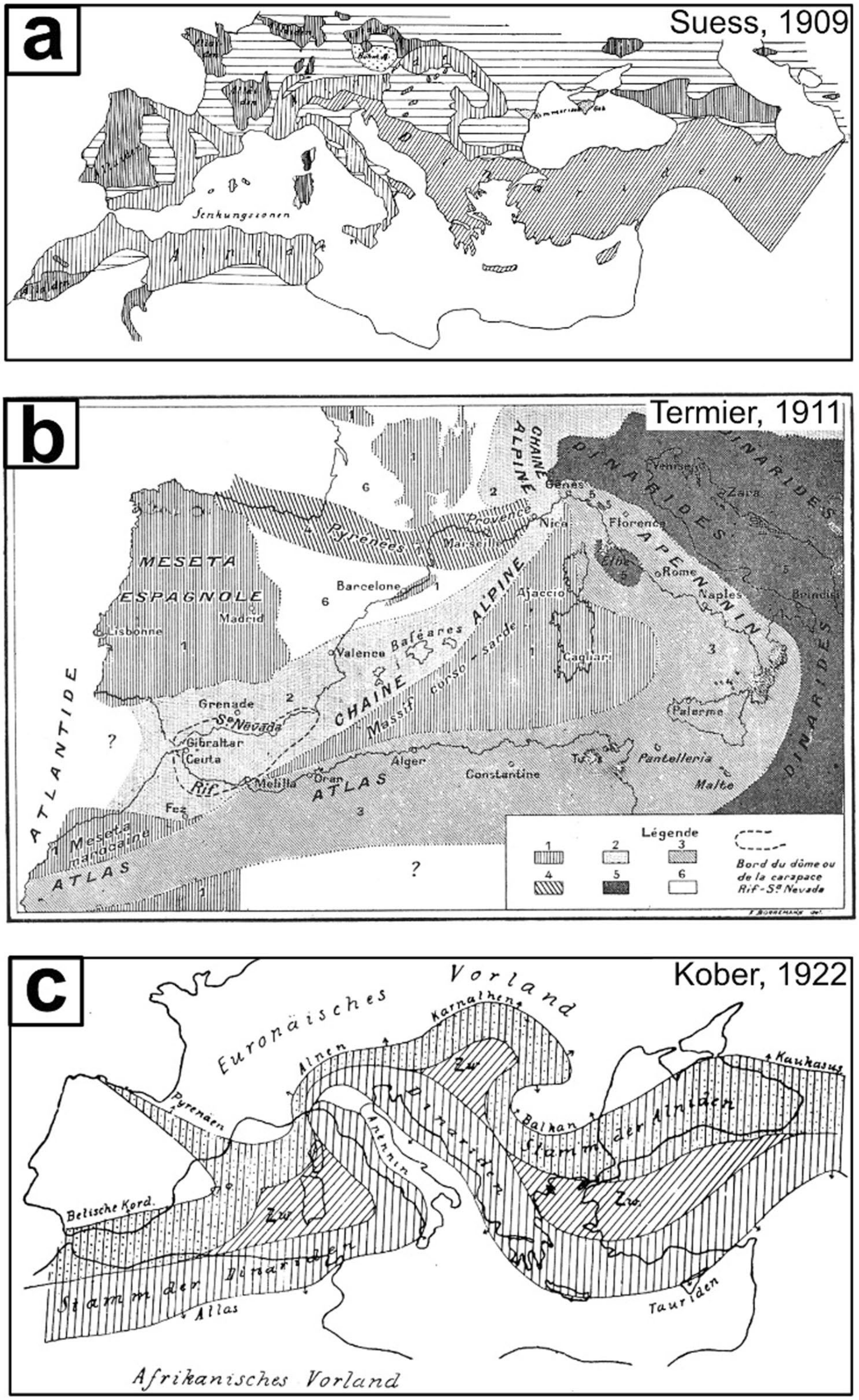

Fig. 10 Mediterranean tectonics in map view, published before Argand (1924a, 1924b): **a** Suess (1909) in Kober (1923). Vertical closely-spaced ruling: Altaidenhorste. Vertical spaced ruling: Alpides. Subsided areas on Altaidenhorste. Oblique ruling: Dinarides. **b** Termier (1911); 1, vertical ruling: relics of Altaïds. 2, Closely-spaced dots: Alpine chain. 3, Closely-spaced, oblique ruling: Apennines and Atlas system. 4, Largely-spaced, oblique ruling: Pyrenées and Provence system. 5, Dark grey: Dinarides. 6, White: parts of Altaids collapsed in ancient times and little affected by Tertiary systems. **c** Kober (1923). Zw.: Zwischengebirge. See text for description

parts of Corsica and Sardinia, together with the Algero-Provençal Basin as a large, stable Altaïdenhorst that suffered no internal deformation and was either displaced (by 300 km) as a whole block, or remained stable above a deformation zone[7]:: "… *eastern Corsica and the Elba island form one and the same tectonic unit. … either the Altaïd chunk that I mentioned before moved as an entire block eastward, overriding the schistes lustrés and the deep-seated unit, or out of a single movement, the deep-seated land was displaced westward sinking below the schistes lustrés, and dragging with it the schistes lustrés below the untouched corso-sardinian massif …The corso-sardinian massif as a whole, without being folded, would have moved 300 km eastward; or, below this immobile massif, a push originating in the East, would have buried the deep-seated unit of the Elba island by 300 km*". As a consequence, the involvement of Corsica in a horizontal displacement of several hundreds of km existed was already part of Termier's concept, that even as the upper plate of the units now exposed in the Elba Island, but he nevertheless mapped Corsica-Sardinia as a large, stable block covering most of the western Mediterranean Sea (Fig. 10).

Kober (1911, 1914, 1923, 1955) conceived orogens as bi-vergent structures, all of them consisting of coupled, opposite-vergent chains, separated by a stable area termed "Zwischengebirge" (between mountains), in other words an undeformed intra-orogenic area. During their progressive evolution, the bi-vergent chains would get closer to each other at the expense of the "Zwischengebirge", until the latter completely disappeared. Kober considered this orogenic stage as being attained and exposed in the Central Alps (Fig. 10c), where the north-verging Alpine chain is in direct contact with the south verging one (Southern Alps) that was termed the Dinaric chain at his time. To the west, the Alpine and Dinaric chains diverge from each other and leave an undeformed area between them, namely the inferred "Zwischengebirge" of Corsica and Sardinia (Fig. 10c). Hence the entire domain between Pyrenean-Provençal belt and Apennines, i.e. the Liguro-Provençal and Tyrrhenian basins in addition to Corsica-Sardinia would form the Zwischengebirge between Alpine systems, i.e., between its inferred two western branches: the Pyrenean-Provençal belt in the NW and the Apennines in the SE. The Zwischengebirge of Kober replaced the Altaïdenhorst of Suess, keeping the idea of a stable, non-orogenic crustal block (Fig. 10c). A certain degree of mobility was implicit in this model, which assumed the progressive reduction, eventually attaining the complete disappearance of the Zwischengebirge, between the approaching orogenic branches. However, no reconstruction, and even less a quantification of such a temporal/spatial evolution in the Mediterranean was attempted by Kober.

In summary, it may be stated that a dynamic and/or kinematic model explaining the formation of the Liguro-Provençal and Tyrrhenean basins did not exist before Argand (1924a). Termier (1911) considered that the Liguro-Provençal Basin corresponded to a late collapse, which hid the Alpine structures that would continuously strike from the French/Italian Mediterranean coast southward to Corsica, below the sea (Termier, 1911)[8]:"*The tertiary chain does not strike around the western Mediterranean; it crosses this Mediterranean Sea. The marine domain which is manifest to our eyes, largely results from recent collapses; and if we could … empty and dry [the abyss], we would see on their surface the continuity of the of the folds and nappes appearing again*". In other words, the idea of Termier was that the structure of the Tertiary chains is drowned under the young, collapsed basins of the western Mediterranean, but it strikes continuously below them. In contrast, Argand clearly envisaged that the formation of these chains is intimately linked in space and time with their lateral, large displacements, and with the thinning of their hinterland.

The main kinematic interpretations concerning Corsica and Sardinia before the model of Argand (1924a) were as follows: the nappes of the Apennines were displaced eastward and rooted in Corsica (Steinmann 1907), with the Elba island being part of this nappe system (Termier, 1911). Kober (1913) confirmed these interpretations, however adding that this nappe stack belonged to the Dinarides and that they were separated from the Alps by the Corso-Sardinian "Zwischengebirge". The remaining discussions were about the sense of nappe displacement on Corsica and Sardinia and their attribution to one of the adjacent orogens, but the processes possibly linking these orogens, generating the peculiar position of Corsica, Sardinia and the Elba islands in the middle of the

[7] *"… la Corse orientale et l'île d'Elbe constituent une seule et même entité tectonique. … soit que le morceau d'Altaïdes dont j'ai parlé tout à l'heure ait marché tout entier vers l'Est, d'un mouvement d'ensemble, écrasant sous lui les schistes lustrés et la série profonde; soit que, d'un mouvement d'ensemble, le pays profond ait marché vers l'Ouest, s'enfonçant sous les schistes lustrés, et enfonçant avec lui les schistes lustrés sous le massif corso-sarde inébranlé….Le massif corso-sarde tout entier, sans se plisser, aurait cheminé de 300 kilomètres vers l'Est; ou bien, sous ce massif immobile, une poussée, venue de l'Est, aurait enfoncé, de 300 kilomètres, la série profonde de l'île d'Elbe".*

[8] *"La chaîne tertiaire ne court pas autour de la Méditerranée occidentale; elle traverse cette Méditerranée. Le domaine marin qui se déroule sous nos yeux résulte en grande partie d'effondrements récents; et si nous pouvions descendre au fond des gouffres, ou mieux si nous pouvions les vider et les assécher, nous verrions réapparaître sur leurs parois la continuité des plis ou des nappes…".*

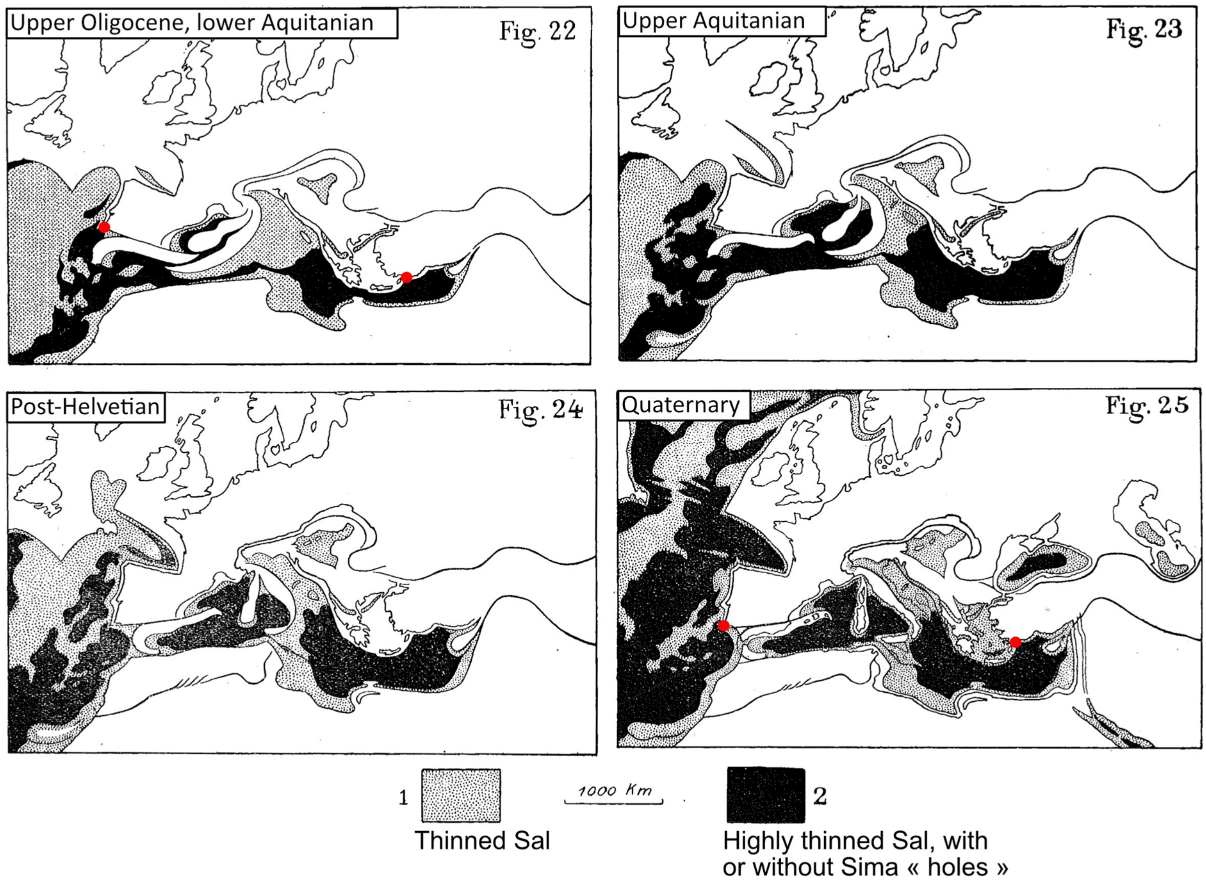

Fig. 11 Ampferer (1926). **a** Schematic tectonic map of the western Mediterranean region, subdivided into areas of shortening, "Verengerung" (vertical and oblique rulings) and areas of stretching, "Verbreiterung" (dotted area). **b** and **c** Conceptual model showing how an area characterized by a structural inheritance (horizontal and vertical marker lines in Fig. **b**) can develop an extensional domain (crossed rulings in Fig. **c**) bounded by compressional bands, as a consequence of in-plane shearing. This model was meant to simulate a Mediterranean basin bounded by orogens. Ampferer (1926) criticized the idea of Argand who envisaged arcuate chains as the result of one single orogenic process, and looked for a two-phase process, whose first phase coincided with strait chains (**b**) Map-view reconstruction of the western Mediterranean (Argand, 1924a, b), showing the progressive anticlockwise rotation of the Apennines, Corsica-Sardinia, and the formation of the Tyrrhenian and Liguro-Provençal Basins since Upper Oligocene time. Red dots are markers, showing that the distance between the south-westernmost part of Iberia and the southwestern coast of Turkey does not vary through time in spite of the compression and extension taking place between them

Mediterranean, and eventually forming the basins surrounding these islands, was never addressed. A paleogeographic reconstruction of the Mediterranean realm and/or the peri-Mediterranean chains was never proposed before "*La Tectonique de l'Asie*".

3.2 Impact of Argand's kinematic model of the western Mediterranean

Argand's (1924a) paleogeographic maps (Fig. 11) showed the post-Aquitanian-to-Quaternary paleogeographic evolution of the Western Mediterranean, illustrating how small continental blocks (Corsica with Sardinia; Apennines including Calabria) detached from the south Iberian coast and rotated anticlockwise about a pole located in the Genoa region, until their present-day position. The formation of the Tyrrhenian and Liguro-Provençal basins, including the nature of their crust (thinned Sal vs Sima) underlying the basins was also shown, and linked to crustal extension, which goes hand in hand with the rotation of Corsica and the Apennines. The continental crust presently forming the Apennines and Corsica is shown to be located at the southernmost margin of western Europe in the Oligocene. From the Lower Aquitanian onwards (Fig. 11), these two slivers of crust detached from the Liguro-Provençal-Iberian margin and migrated eastward, rotating around a pole situated close to Genoa. While doing so, these two slivers also separate from each other creating the Tyrrhenian basin (Fig. 11). A progressive amplification of the arc structure of the Apenninic orogen during its anticlockwise rotation of nearly 120° was also shown.

The four steps of the evolution indicated by the four maps of Fig. 11 represent a major break-through in the history of Geology. On the one hand nobody ever completed such paleogeographic maps of the Mediterranean realm, predicting how it looked like before the present. On the other hand, nobody ever constructed paleogeographic maps displacing continental blocks that changed their shape while being displaced. In fact, excluding the fixist-type of paleogeographic maps, where continental blocks are stable and only “continental bridges” appear and disappear (e.g., Marcou, 1860), the only other scientist constructing paleogeographic maps was Wegener (1920). However, Wegener (1920) was concerned with a much larger scale, and his effort was to show how the continents once belonged together, without oceanic space separating them. Wegener (1920) never created new oceanic spaces by displacing continents to their inferred older positions, his major achievement was to determine a fit between rigid continental margins, before they drifted apart (his Fig. 23). Argand's ability to model crustal displacements including both divergence and convergence, in addition to changing shapes of the displacing blocks (Fig. 11) was unprecedented and remained so for many decades. Argand's kinematic evolution of the Mediterranean (Fig. 11) is not based on a geometrical fit of coast lines. No obvious geometrical elements in the eastern coasts of Corsica and Sardinia and of the western Apennines (Western Italy) suggest by themselves the closing of the Thyrrenean Sea, nor the opening of the Liguro-Provençal one. Argand's paleogeographic reconstructions were created without the existence of any data and similar interpretations preceding them. They were a pure product of Argand's imagination, not relying on other existing, debated and evolving conceptual models. Nowhere in the literature a dynamic interpretation of the Mediterranean blocks existed before Argand.

Argand (1924a) did not provide any detailed descriptions of the evidence underlying his innovative, dynamic picture of the Mediterranean. However, he seems to have relied on sedimentological evidence, in addition to gravimetric and bathymetric one. Argand stated[9] *“Any ongoing extension, not entirely located on an intra-continental site causes a marine transgression, whose wedge records, at all instant, the widening of the extensional area»* and[10] *« …an ongoing extension results, on the vertical of a point located in the affected area, in deposits, whose nature and succession indicate a deepening (for example, the rather general deepening of the Mediterranean perimeter, at the Burdigalien-to-Lower-Helvetian transition, below its Schlier facies”* (The latter facies refers to a Burdigalian terrigenous unit of the Central Apennines). In addition, Argand used some existing gravity data to infer crustal thicknesses, as mentioned for the Adriatic realm[11]:*“The sal of the african promontory persists, stretched below the Adriatic, with thinning increasing southward, as revealed by the increasing, positive gravity anomaly in this direction”*. Argand (1924a) never quoted a specific source for such data, but it is likely that he based his statement on the work of Kossmat (1921), whose map of gravity anomalies, included the Alpine, Apenninic and Dinaric regions. Finally, bathymetric data, though not very detailed, also existed for the Mediterranean region (e.g., Konversationslexikon, 1902–1905) and it is pointed out by Schaer (2010), that Argand used the “still quite primitive” data by Murray and Hjort (1912), although Argand never mentioned any specific data source.

3.3 Argand's western Mediterranean model in the years after its publication and before Plate Tectonics

In the years and decades following the publication of “*La tectonique de l'Asie*” Argand's Mediterranean kinematics were never integrated in the conceptual tectonic models of the latter region. In fact, the ideas of Argand on this subject were neither accepted nor refuted, they were simply ignored. The geological community continued to discuss the models of Kober showing a “Zwischengebirge” between Alps and Apennines (Fig. 10c; Kober, 1923; Kober, 1923; Staub, 1928a; Stille, 1927a; Stille, 1927b), debating different interpretations about the boundaries of the Corsican “Zwischengebirge”. It is very rare to find articles discussing the interpretation of Argand (1924a) on the paleogeography of the Mediterranean in the years following its publication. One of these rare exceptions is found in Ampferer (1926), who started the second of his 5 papers on the mechanics of the Alps, with a discussion on the tectonics of the western Mediterranean and a schematic tectonic map of this region (Fig. 12a), subdivided in areas inferred to be under compressions (orogens) or under extension (basins). This suggests that Ampferer was also looking for an interpretation of the mediterranean chains and basins as the result of one and the same process. Figure 12a shows the transition from compressional areas in the Pyrenees, Alps, Dinarides,

[9] "*Toute distension en cours qui n'est pas de site strictement intra-continental détermine une trangression marine dont le biseau enregistre à chaque instant l'agrandissement de l'aire distendue (cf. les rares lambeaux d'Aquitanien marin visibles au pourtour de la Méditerranée actuelle et l'ample transgression du Burdigalien)»*

[10] *« … une distension en cours se traduit, sur la verticale d'un point de l'aire qu'elle affecte, par des dépôts dont la succession et la nature indiquent une descente (par exemple, l'approfondissement assez général du pourtour méditerranéen au passage du Burdigalien à l'Helvétien inférieur, sous son faciès du Schlier)".*

[11] *Le sal du promontoire africain persiste, étiré sous l'Adriatique, avec un amincissement qui va en croissant vers le sud, ce que révèle l'augmentation de l'anomalie gravifique positive dans cette direction*".

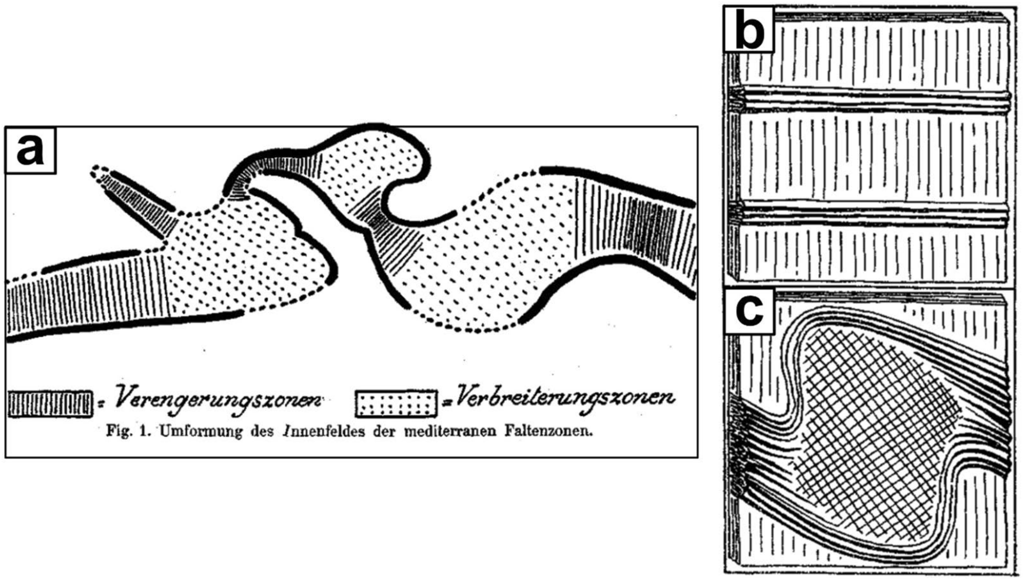

Fig. 12 Map-view reconstruction of the western Mediterranean (Argand, 1924a, 1924b), showing the progressive anticlockwise rotation of the Apennines, Corsica-Sardinia, and the formation of the Tyrrhenian and Liguro-Provençal Basins since Upper Oligocene time. Red dots are markers, showing that the distance between the south-westernmost part of Iberia and the southwestern coast of Turkey does not vary through time in spite of the compression and extension taking place between them

to extensional, or rather ("Verbreiterung", widening) areas in the Liguro-Provençal, Tyrrhenian, Pannonian, Ionan basins. Referring to these lateral changes in the western Mediterranean map, Ampferer (1926) stated that[12]"*Under-currents must flow from areas of contraction to those of widening*", however he did not mention that Argand (1924a); (Fig. 11) had already mapped out such area of extension and even related them in an evolutionary model to areas of compression. The major criticism of Ampferer (1926) to the kinematic model of the peri-mediterranean chains of Argand (1924a) concerned the absence of very large stretching along the axes of the orogenic arcs, that Ampferer expected to be a consequence of Argand's models. However, the specific kinematics of Argand's (1924a) model (Fig. 11) were not discussed.

Stille (1927b) mentioned and criticized Argand's model, however as described below (Section III), Stille also did not question the very specific interpretation of Argand (1924a), but much more the general concept of backfolding and its use by Staub (1924).

Another rare, critical comment on the Mediterranean kinematics of Argand (1924a, 1924b) is found in von Seidlitz (1931). Out of his almost 500-pages long book completely dedicated to the Mediterranean Chains, only one paragraph concerns the models of Argand (von Seidlitz, 1931; p. 118)[13]:"*Argand showed in numerous maps an eastward displacement of the Apenninic peninsula, which together with Corsica and Sardinia, once were attached with E-W strike, to the Catalonian and Andalusian coast. …why a correspondent, similar game of movement did not affect the surrounding areas too and the phenomenon stayed so locally confined (is not mentioned). Thus, one must agree with Ampferer … such displacements of the fold belts are only possible if the adjacent, surrounding areas were also affected by the same displacement*". This comment is particularly interesting, first of all because it finally took the model of Argand out of a generalized scientific silence, and second because it touched an interesting part of the model, which was not explicitly explained by Argand himself. Wilfried von Seidlitz and apparently Ampferer too (we could not find the original text of Ampferer, but he was quoted by von Seidlitz) noted that the areas adjacent to the displaced micro-continental blocks of Corsica-Sardinia and the Apennines did not undergo any displacement, while the latter blocks swinged across the Mediterranean by some 1000's of km,

[12] *"Unterströmungen müssen aus den Bereichen der Verschmälerungen gegen die Verbreiterungen zu fließen"*

[13] *"Argand entwickelte in zahlreichen Karten eine Ostwärtsbewegung der Apenninhalbinsel, die sich mitsamt Sardinien und Korsika … einst in O-W Richtung die katatanische und andalusische Küste anlegten. … warum nicht auch ein « entsprechendes Bewegungspiel des angrenzenden Umlandes» einsetzte, und die Erscheinung so lokal blieb (wird aber nicht angedeutet). Denn man muss Ampferer recht geben… solche Bewegungen der Faltungstränge nur möglich sind wenn auch die weitere Umgebung …. von denselben Bewegungen durchdrungen wurde".*

after Alpine orogeny (Fig. 11). Indeed, NE-SW striking lines across the map (e.g. the distance between Brest and Tripoli) do not change their length from the upper Oligocene to the present. The same is true in an E-W orientation, for example between the southwest of Portugal and the south-western coast of Turkey, no length changes take place through time (red dots in Fig. 11). Even in this case Argand did not describe and did not explain this fact, but it is entirely consistent with present-day interpretations, which suggest that extensional displacement in the upper plate coincides with rollback displacement of the trenches (e.g., Malinverno and Ryan, 1986). Thus, material points located outside of the trench/extending upper-plate system, do not change their initial distance during this subduction process.

Finally, Bucher (1933) in a well-known book on the deformation of the crust discussed and rejected the kinematic model of Argand for the Mediterranean, mainly based on the absence of very significant shortening in the paleo realm of the Adriatic continent, whose surface is reduced by two to three times from the Upper Oligocene to the Quaternary (Fig. 11a–d, and green-colored surface in Fig. 9).

Scientific discussions and publications on the map-scale tectonics of the western Mediterranean realm slowly died out through the 1930's and the last kinematic model proposed before world war II was that of Richter

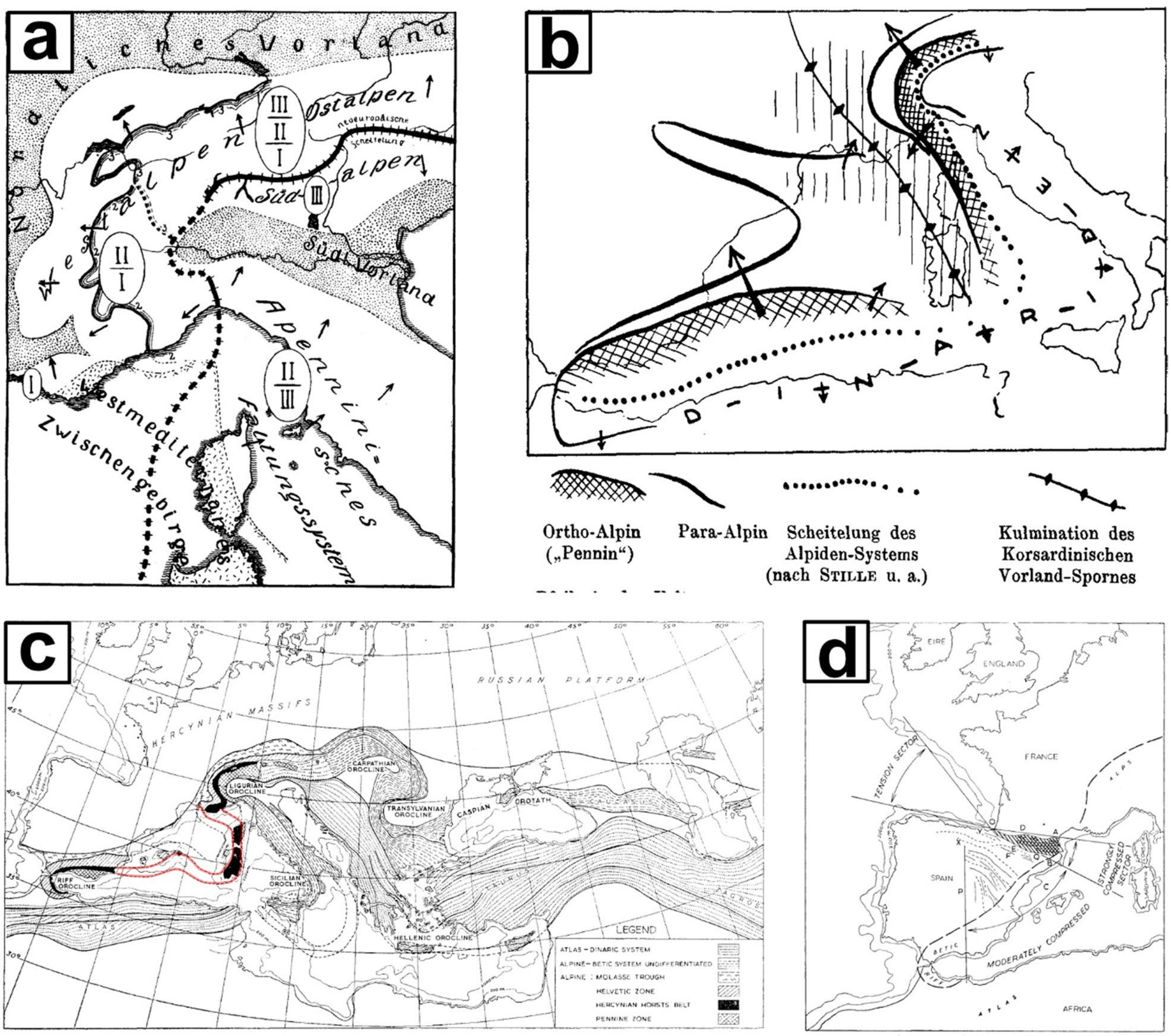

Fig. 13 Some tectonic maps of the Mediterranean published after Argand (1924a, 1924b), and before Plate Tectonics. **a** Stille (1927a, 1927b); **b** Richter (1939); **c** Carey (1955). Red lines highlight the inferred orocline with Corsica-Sardinia in its hinge; **d** Carey (1955). See text for description

(1939); (Fig. 13b), suggesting a map-scale fold, whose hinge strikes from Sardinia to the french Massif Central. This model explained the inferred curvature of the Dinarides as a single orogen that coincided both with the Betics and the Apennines. A similar concept was re-proposed by Carey in 1955 (Fig. 13c) as part of a totally new kinematic model, explaining the whole of the Alpine-Himalayan chains. Carey (1955) analyzed the general process underlying the formation of arcuate orogens, introducing the concept of oroclines, namely straight orogens that suffer progressive rotation during their development, thus finally forming arcs. Corsica and Sardinia were only one out of numerous examples, that he inferred to initiate as a straight orogens, aligned with the almost straight, E-W striking Alpine chain, and becoming folded (arcuated) in map view during orogeny. The entire process would take place under convergence-shortening conditions, in the absence of any extensional domains developing around Corsica and Sardinia. A scissor-type of displacement pattern, with the Gulf of Gascogne opening while the Pyrenees and Corsica-Sardinia were affected by compression (Fig. 13d) was suggested by Carey (1955) to explain the origin of compression. Not a hint of extension explaining the origin of the Liguro-Provençal and Tyrrhenian basins exists in this model. However, Carey (1955) had the merit of finally showing a pre-Tertiary paleogeographic map of the Mediterranean realm, the first one after Argand (1924a). Interestingly, Carey (1955) mentioned Argand (1924a), but only to state that the latter was also interested in map-view reconstructions of the Mediterranean realm! No word about the specific reconstruction of Argand (1924a) was spent, neither to acknowledge it nor to refute it. It was only in 1962 that finally a paper (Dubourdieu, 1962) acknowledged the work of Argand on the Mediterranean Sea, albeit rather superficially.

In summary, the general impression emerging from the post-Argandian literature is that the kinematic model of Argand (1924a) for the western Mediterranean remained largely ignored by the geological community working in the Alpine/Mediterranean realm, until the era of Plate Tectonics. The only specific critique addressing and refuting the Mediterranean kinematic model of Argand was included in a general book on tectonics, not written by an Alpine/Mediterranean geologist (Bucher, 1933). In fact, it took over 30 years (Carey, 1955) after la "Tectonique de l'Asie" for scientists to upraise the idea of Argand (1924a) and illustrate the distribution of tectonic units before orogeny in map view and proposing alternative models. It is amazing that this approach to tectonics was not repeated, possibly with different interpretations before 1955. One reason for that may be the fact that finally nobody other than Argand really understood the link between continental convergence and mountain building. Horizontal shortening was recognized, but finally it never became seriously linked to the displacement and convergence of continents. Orogeny kept a static touch, with a fixed "Zwischengebirge", mysteriously reducing its size through time.

3.4 Argand's Mediterranean model after "Plate Tectonics"

New interest on the origin of the Corso-Sardinian block was raised in the Plate Tectonics era, mainly as a consequence of paleomagnetic studies. Based on paleomagnetic orientations from Permian volcanics in northwestern Corsica, differing from those assessed in continental France, an anticlockwise rotation of 53° of Corsica was suggested (Ashworth and Nairn, 1965); (Fig. 14a). The authors related this rotation to Alpine orogeny. Ashworth and Nairn (1965) never quoted Argand, referring instead, to the rotational model of Carey (1955); (Fig. 13c) discussed above. Nairn and Westphal (1967), showed a difference of 22° in the declination values of Permian magmatic rocks in Corsica compared to the southern coast of France (Estérel Massif). They concluded that either the declination varied as a consequence of the changing Earth's magnetic field through time, or Corsica may have rotated relative to the Estérel by 25° in post-Permian time. Even in this paper Argand is never quoted. The same authors published another paper a year later (Nairn and Westphal, 1967), stating that the 25° rotation of Corsica relative to the Estérel is consistent with the fit of the −1000 m isobath of both coasts. Argand was still not quoted, and Sardinia was not mentioned at all in their model.

Stanley and Mutti (1968), based on petrographic studies (heavy-mineral analyses) and on already existing paleomagnetic orientations, assessed paleo sediment-transport directions and concluded that the

(See figure on next page.)

Fig. 14 Some tectonic maps of the western Mediterranean published at the beginning of the Plate Tectonics era and mostly based on paleomagnetic data. **a** Ashworth and Nairn (1965), highlighting the different paleomagnetic directions of western Corsica, with respect to southern France. **b** Nairn and Westphal (1968), showing a best fit of the western Corsica coast and the southern French coast, after back-rotation of Corsica. **c** Alvarez (1972), showing that both Corsica and Sardinia were attached to the southern French coast, before the opening of the Liguro-Provençal and Tyrrhenian basins. **d** Malinverno and Ryan (1986), showing the progressive opening of the opening of the Liguro-Provençal and Tyrrhenian basins, by the progressive retreat and arching of the Apenninic subduction zone. Numbers indicate millions of years

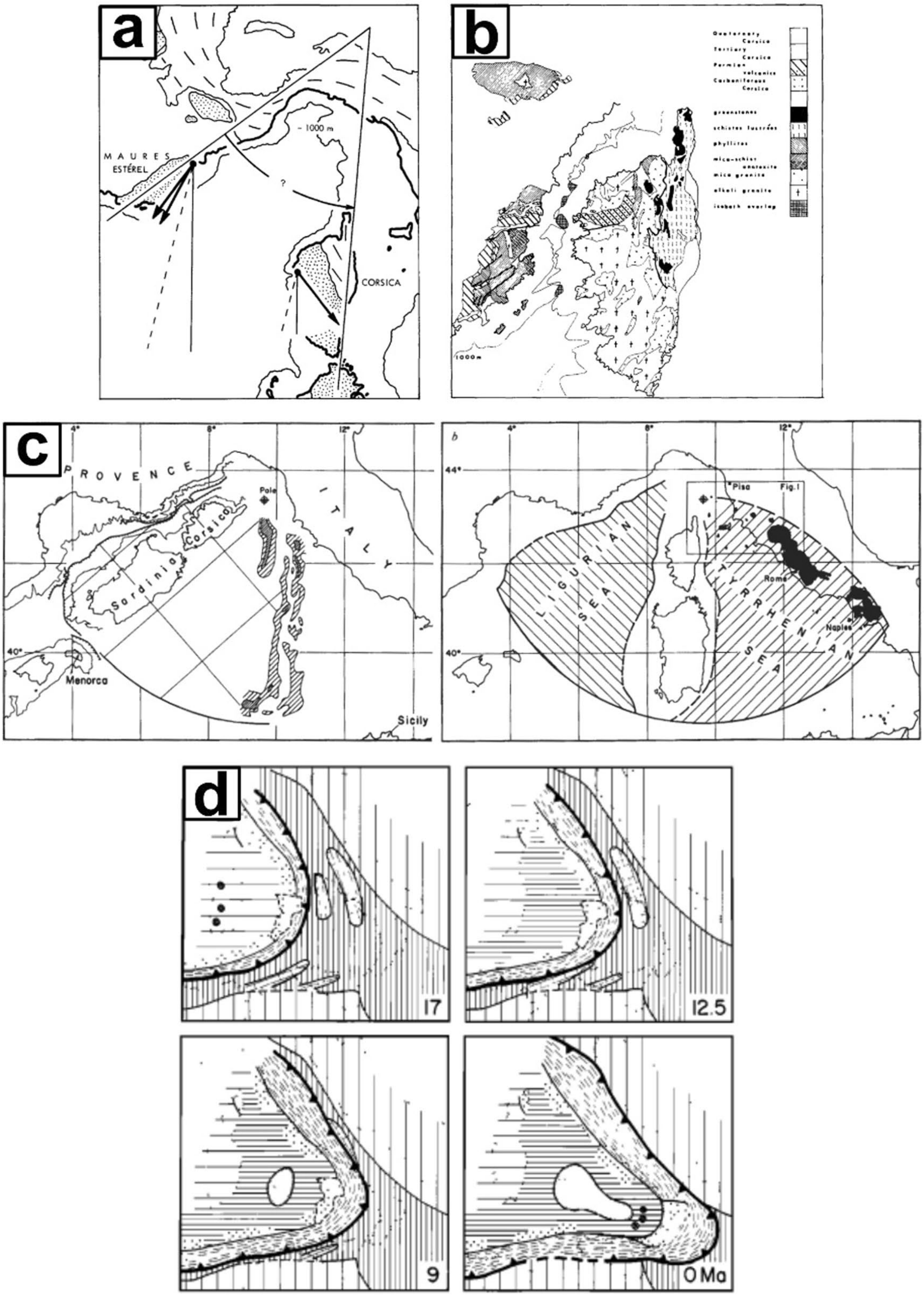

Fig. 14 (See legend on previous page.)

Liguro-Provençal Basin opened by rifting and tectonic rotation during and following Alpine orogeny. This is exactly the interpretation of Argand (1924a), although he was not quoted in their paper.

A later paleomagnetic study (De Jong et al., 1969) showed that even in Sardinia, paleomagnetic declinations of Permian rocks differ from the ones on the southern French coast, thus suggesting that both Sardinia and Corsica may have undergone a rotation. The model of Argand (1924a, 1924b) was finally quoted in this paper. In the following years a series of papers, all published in *Nature,* and largely based on paleomagnetic data (Fig. 14c; Alvarez, 1972; Alvarez et al., 1974; Lowrie and Alvarez, 1974) all discussed the rotation of the Corso-Sardinia block without ever mentioning the work of Argand, and without setting the latter rotation into a larger-scale geodynamic frame, as previously shown by Argand (1924a).

It was Hsu (1971) that explicitly discussed the kinematic Mediterranean model of Argand in detail for the first time. Hsu (1971) recognized that Argand's reconstruction was largely correct from a geometrical point of view, but criticized its chronology: *"There is likewise no compelling reason for assuming a Middle Tertiary rotation of Italy away from Corso-Sardinia".* Based on the available age and amount of displacements of the Atlantic and those between Africa and Eurasia, Hsu (1971) couldn't conceive a rotation of Corsica-Sardinia associated with the opening of the Liguro-Provençal Basin in the Tertiary, "*when a north–south compression between Europe and Africa resulted*". Therefore, he proposed that the opening of the Tyrrhenian Basin and rotation of the Apennines took place during Cretaceous time and were linked to the opening of the Tethys realm. Hence, the first time that Argand's model was properly acknowledged, it became amended with a new and wrong (n.d.r) chronological interpretation! In the same year, Laubscher discussed the kinematics of the Alps/Apennines and Tyrrhenian realm (Laubscher, 1971a, 1971b), suggesting E-W displacements of continental blocks along large strike-slip faults. These displacements are incompatible with significant rotation of Corsica-Sardinia and the Apennines. In a later paper (Laubscher, 1975), the existence of a rotation of the Corso-Sardinia block is explicitly questioned. Hence, half a century after its publication, the correct (based on present knowledge) concepts of Argand were still far from being accepted.

Smith (1971) and Smith et al. (1982), using the 1000 m-depth submarine line of continental margins and a geometrical best-fit approach to set continents back to their original position, proposed new palinspastic reconstructions of the Mediterranean area (Fig. 15). Smith (1971) acknowledged the reconstruction of Argand (1924a), stating however that it "*permitted the fragments to behave as non-rigid bodies. Although non-rigid deformation has obviously occurred, there are at the present time no reliable objective methods that enable one to correct for its effects. The writer believes it preferable to treat the fragments as rigid bodies (that is, as parts of plates), to make the reassembly, and then to examine what kinds of corrections might be necessary to obtain a better fit. … The criteria for making the reassembly are entirely geometrical*". In other words, the latter authors favored, in contrast to Argand (1924a), an objective methodology to interpret a process, whose specific nature could not be adequately interpreted by the methodology they chose. The result was a set of paleogeographic maps (Fig. 15), showing the progressive opening of the Mediterranean from Jurassic time. However, the backward closure of the latter basin by rigid-body displacements implied significant E-W extension during opening of the Mediterranean, as shown by length changes between southwestern Spain and Cyprus in map view (Fig. 15). This is in contrast to the kinematic model of Argand (1924a); (Fig. 11), which in turn is consistent with present-day knowledge, suggesting that extension in the Liguro-Provençal Basin was due to rollback of the Adriatic (Apenninic) slab, thus resulting in no bulk changes of length on the scale that includes both the basin and the orogen (e.g., Jolivet and Faccenna, 2000).

In summary, when the Mediterranean kinematic model of Argand was finally taken into consideration at the very beginning of the 1970's, it was criticized and replaced by alternative models that were by far less accurate from the stand point of present-day knowledge.

4 Argand's interpretation of the Alpine/Apenninic "knot"

Geologists struggled when attempting to relate the Alps and Apennines, since the early nineteenth century. The first studies pointed out to similarities and differences in lithology and rock-units (Pareto, 1861), lately shifting to point out that mainly metamorphic rock-types are characteristic of the Alps, in contrast to widespread exposures of sedimentary rock-types in the Apennines.

Steinmann (1907) first recognized that the nappe structure of the Apennines is opposite to the Alpine one: Austroalpine-like nappes forming the lower units (Toscanides) and Penninic-like (Radiolarite-and ophiolite-bearing) units in the hangingwall. He also interpreted the root of these nappes to be located in East-Corsica, thus inferring an eastward-directed transport. Steinmann (1907) stated[14]: "*Because it is the general opinion that*

[14] "*Da der allgemeinen Auffassung nach die Faltungsrichtung im Apennin der der Alpen entgegengesetzt ist, so ist, wenn auch der Apennin Deckenstruktur besitzt, ein umgekehrtes Verhältnis der beiden Deckensysteme zu erwarten*".

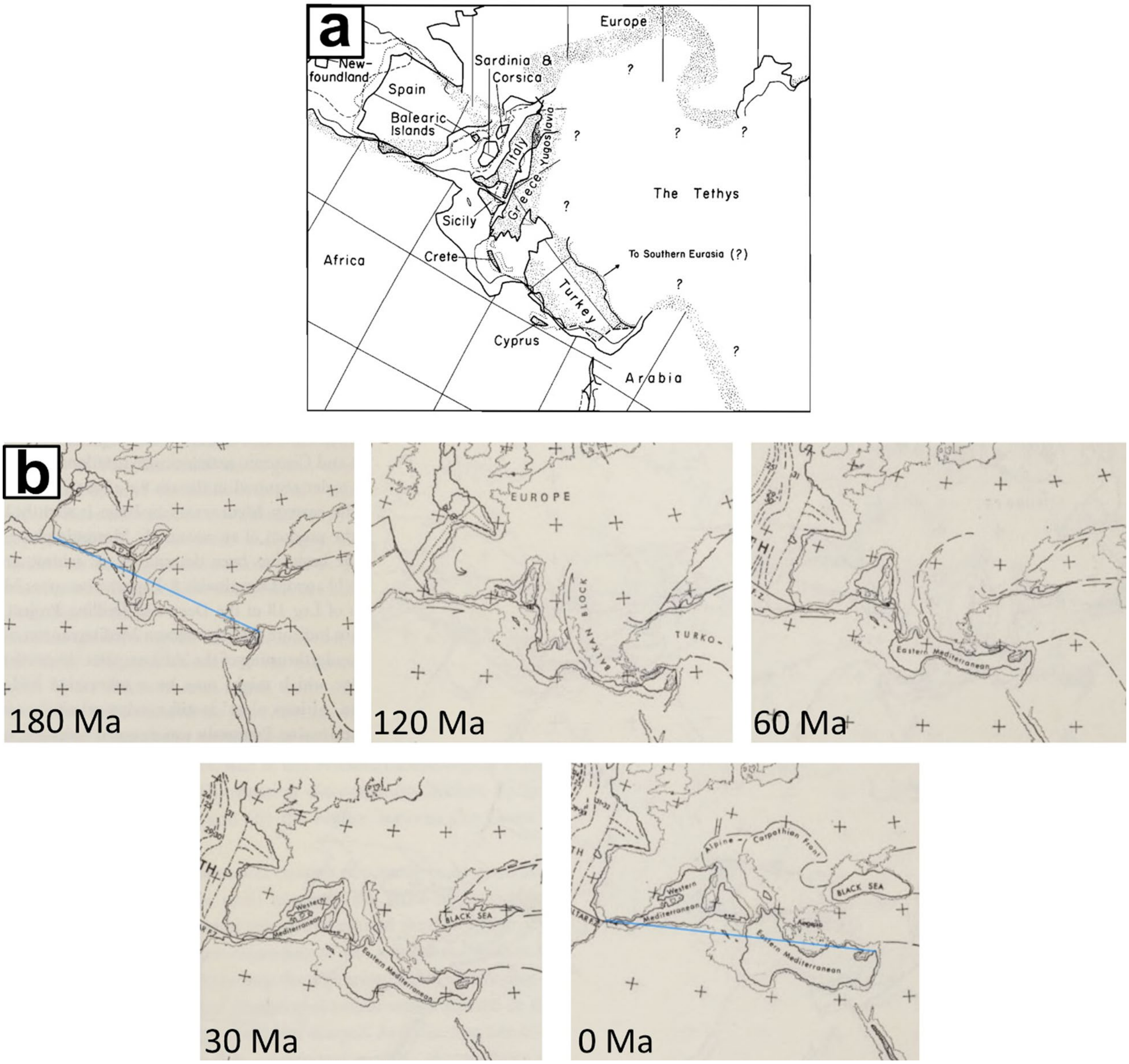

Fig. 15 Paleogeographic reconstruction of the Mediterranean region, **a** by Smith (1971) and **b** by Smith and Woodcock (1982), performing a best-fit of the continental coast lines at a depth of 100 m below sea level. The Jurassic and Cretaceous maps are quite similar to the previous interpretation of Smith (1971). The light blue line serves as a marker to highlight its progressive shortening from the present to the Jurassic, hence the large E-W extension inferred to take place during formation of the Mediterranean Basins, in contrast to present-day interpretations and to Argand's interpretation (Fig. 11)

the fold direction in the Alps and Apennines is opposite, if the Apennines also consist of a nappe structure, then both nappe systems are expected to have opposite relationships". This interpretation was first contrasted, but later validated by Termier (1909), after his studies on Elba and on the relationships between the nappe-stack of Elba and Corsica.

Argand's (1924a) sections very clearly provided a solution to the problem of the opposed vergence of these two neighbouring orogens (Fig. 16). Europe and the Penninic units are underthrust by several hundreds of km below Adria. However, the uppermost part of Adria together with the Penninic units are backthrusted southward (Fig. 16), thus accommodating many hundreds of km of shortening and inverting the polarity of the nappe stack. As a consequence, the Penninic nappes eventually overlie the Adriatic (Austroalpine in the sense of Steinmann, 1907) ones.

Staub (1924); (Fig. 17) proposed a similar concept, likely aware of the ideas presented by Argand in Brussels in 1922 (Schaer, 2010, described Argand's worries concerning the publication of some of his ideas by Staub), suggesting that the inverted Alpine nappe sequence of the Apennines resulted from backfolding. Staub (1928b) was often remembered as the first one to propose backfolding of the Alpine nappe stack to explain the Apennines (e.g., von Seidlitz, p. 446), however, Staub's illustration is a mere schematic sketch of a recumbent folded nappe that continues to accommodate shortening by increasing amounts of backfolding (1924); (Fig. 17). Argand's (1924a); (Fig. 16) section is completely different in that it sets the assumed backfolding in the specific regional tectonic setting of the Alps and Apennines, providing a clear, lithospheric-scale picture of the orogenic structure.

Kober (1923); (Fig. 18), presented an interpretation of the Alps/Apennines in cross section that differs from that of Argand (1924a), but he did not show any "lithospheric"-scale sections, nor a structural level sufficiently deep, to allow for the interpretation of the link between west-vergent Alps and east-vergent Apennines. In his section, structures are simply cut off at an arbitrary and undefined crustal depth-level, hence not providing any kinematic explanation on how and if the Alpine and Apenninic forelands interacted. Argand's interpretation based on vergence changes between upper and lower crustal levels, may not be correct with respect to present-day knowledge, but it is clear and logic and perfectly illustrated thanks to a lithospheric-scale figure (Fig. 16). Kober (1923) never discussed the model of Argand (1924a), he only mentioned it once to say that it also included the nappe structure of the Apennines, and did not add it to his reference list. Just like Stille (1927a, 1927b), Kober also considered that backfolds cannot be larger than the "primary" folds, rejecting the Argandian eastward vergence of the Apennines as the result of large-scale backfolds of a west-directed chain.

Kober (1928), in a paper concerned with the tectonics of Corsica, quoted Argand (1924a), together with a long list of other authors, but only to say that different tectonic models had been proposed. It is difficult to understand how such tectonic studies, specifically addressing the problem of the Alps and Apennines in the years after 1924 could avoid to comment the "lithospheric"-scale sections of Argand across the Alps and Apennines, his paleogeographic maps of the area, and his conclusions on the relationships between northern Apennines and western Alps.

In a long paper on the Mediterranean orogens, Stille (1927a) redefined the general concept of an orogen, stressing that it consists of two branches, thus reasserting the Kober (1914) view, and adding that the two orogen branches correspond to the two margins of the geosyncline. Stille insisted on the idea that the Apennines are distinct from the Alps and from Corsica and Sardinia,

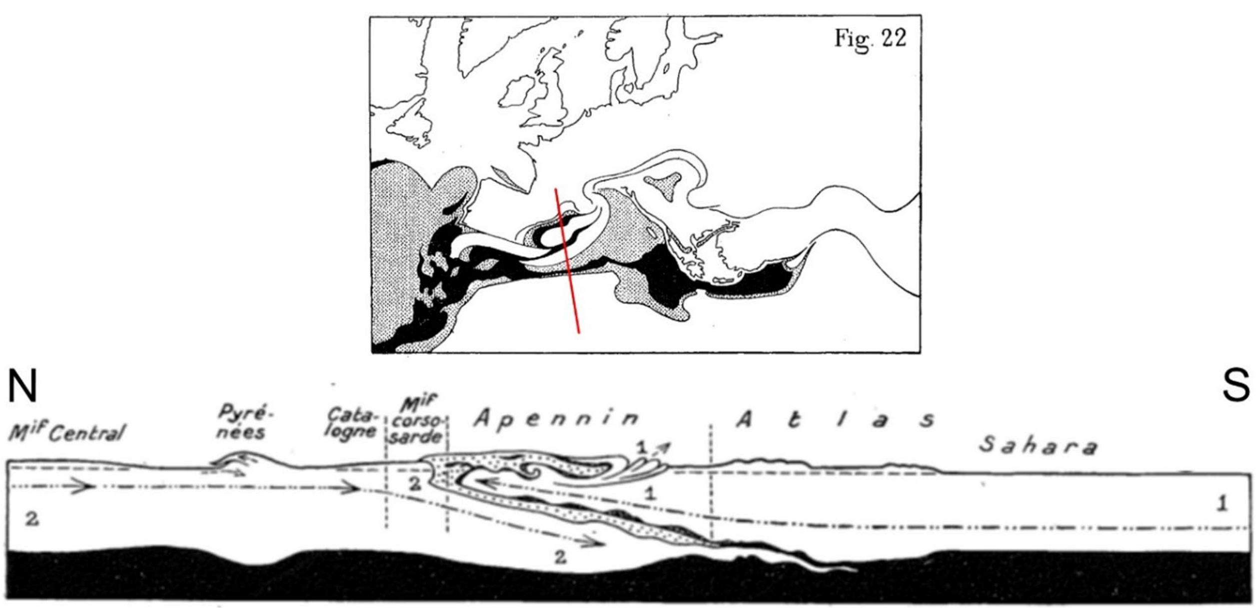

Fig. 16 Cross section of Argand (1924a). Argand did not show the exact trace of the section in his publication, but it seems to be located as in the upper inset of the figure, i.e. showing an inferred Upper Oligocene setting, and not the present-day one. The future sites of Miocene extensional basins are shown by vertical stippled lines. The European continent is underthrust southward below Adria, showing a sort of subduction, and a very large backfold/backthrust generates the Apennines in the upper Adriatic plate

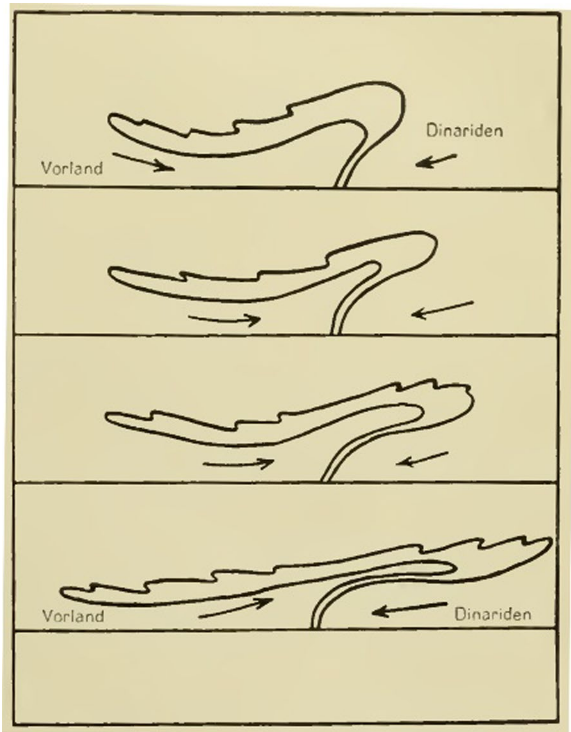

Fig. 17 Schematic sketch of Staub (1924), showing the progressive amplification of a backfold, to explain the Apenninic vergence (folds above the "Dinariden")

but he never showed any lithospheric-scale section, to propose a model alternative to that of Argand (1924a), explaining the Alps-Apennines relationships.

Stille (1927b) criticized the importance that is generally given to backfolding, specifically in the tectonic interpretation of the Apennines. He recalled that the bivergent, "two-branches" orogenic model of Kober is generally more appropriate, and specifically more adapted to explain the Alps and Apennines. He argued that the inverted sequence of the nappe systems in the Alps and Apennines could not be taken as a robust argument to assess backfolding in the Apennines. He considered (rightly, n.d.r.), that this nappe sequence „would obviously be the same, if rejecting the Apenninic-Dinaric backfolding, we considered the Apennines as primary, opposite branch of the western Alps" (Stille, 1927b). Interesting, Stille (1927b) brought his argument against the backfolding model of Staub (1924), but never discussed the validity of the cross section of Argand (1924a), showing the NW-thrusting of Africa on Europe and the backfolding of the Penninic/Adriatic nappe stack.

It took half a century, before a new lithospheric section, illustrating the anatomy of the Apennines at depth was re-proposed, namely by Boccaletti et al. (1971); (Fig. 19). Their cross section, based on the new Plate Tectonic concept of subduction, suggested that the eastward-verging Apenninic chain, resulted from a change in the subduction polarity of the Alpine system through time. An Eocene eastward directed "Alpine"-type of subduction flipped to a west-directed "Apenninic subduction" in the Oligo-Miocene, as suggested by present-day concepts (Molli and Malavieille, 2011; Beaudoin et al., 2017).

In summary, no lithospheric-scale sections across the Apennines or Alps/Apennines were re-proposed after Argand (1924a), except for very schematic ones (Kraus, 1936; 1954; Kober, 1955), and no explicit, critical discussions of Argand's sections were published until the Plate Tectonic era, half a century after "La Tectonique de l'Asie".

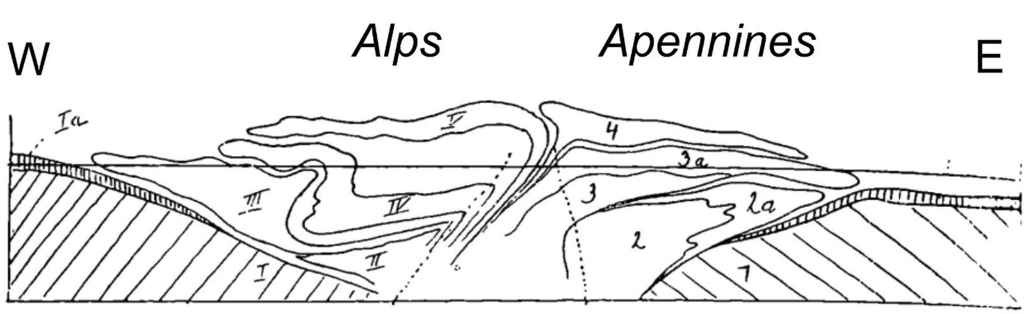

Fig. 18 E-W cross section of the Alps and Apennines from Kober (1923). Thus, both branches with their opposite vergence are in direct contact with each other. The very steeply W-dipping axial part of the section, separating the two adjacent chains, is a suture. In Kober's view it represents a mature evolutional stage of a bi-vergent orogen, in which the "Zwischengebirge" separating both branches (Alps and Apennines) of one and the same orogenic system, has disappeared. The profile trace runs from W to E respectively, from Castelvecchio via Savona and Ronca to Bobbio and Piacenza. On the left (W) the Alps, on the right the Apennines. In the Alps: I = the foreland. Ia = its Mesozoic. II = the Simplon nappes III = Bernard nappe. IV = Monte Rosa nappe. V = nappe Dent Blanche and the Sestri Ponente zone. Between IV and V lies the Schistes lustres of the Voltri group. For the Apennines: 1 = the foreland, 1a = its Mesozoic. 2 = crystalline of the Carrara Nappe 2 a = its Mesozoic. 3 = crystalline of the Tuscanides. 3a = their Mesozoic. 4 = Ligurides. The dotted line indicates the young volcanism in the suture zone

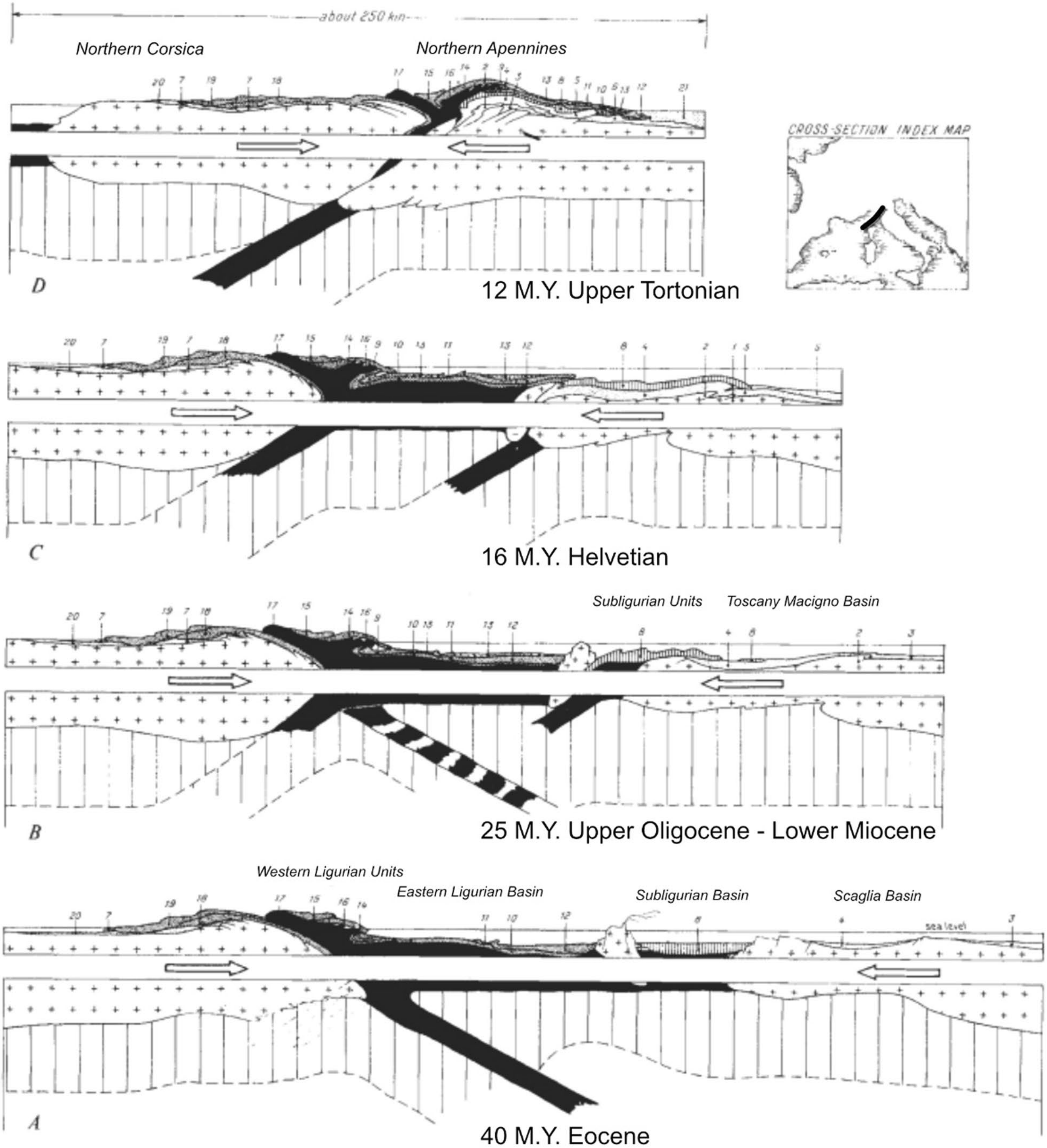

Fig. 19 Evolution of the Alpine/Apenninic system as interpreted by Boccaletti et al. (1971). The interpretation invokes two distinct subduction zones, but most importantly a flip in the polarity of the main subduction, starting in the Upper Oligocene. These sections illustrate for the first time after Argand (1924a) a lithospheric-scale structural and kinematic model, which illustrates the change of polarity in the nappe sequence of the Alps and Apennines

5 Alpine concepts from Argand's "*Tectonique de l'Asie*" in books and papers on the Alps, after 1924

In the following we analyse, in chronological order, if and how the scientific community embraced the innovative concepts of Argand on the Alpine chain, after their publication. Ampferer (1926) is one of the very few authors that reproduced one of Argand's (1924a, 1924b) lithospheric-scale alpine sections in an own publication. However, Ampferer, who never proposed an alternative cross section himself, was skeptical about Argand's sections. In addition to some rheological misconceptions, Ampferer mainly doubted that the structural record to be expected from thrusts accommodating some 1000 km of displacement was far from being present in the Alps. Ampferer interpreted Argand's concept of orogenic arcs as that of convergence and shortening accommodated between rigid, immobile blocks, thus creating an arc between them. Collet's (1927) book on "*The structure of the Alps*", which provided a rather complete overview of all parts of the chain, reproduced several cross sections and block diagrams of Argand, but all derived from publications older than "*La Tectonique de l'Asie*". The only figures taken from the latter work are the sketches explaining in map view the differences between "confined and unconfined virgations". None of the significant elements reported above, are presented and discussed in the book of Collet. The innovative cross sections and tectonic maps of Argand (1924a) are ignored.

Heritsch (1927) reviewed the history of Alpine nappe theories between 1905 and 1925, never quoting "*La tectonique de l'Asie*», although the attribution of Alpine nappes to the Tethyan realm, or to the Eurasian and African continents is clearly sketched there by Argand (1924a) for the first time.

The 1929 edition of Wegener's "The origin of continents and oceans" quoted several times Argand (1924a) and reproduced some of his sections, albeit not the Alpine ones, in order to support the idea of large continental displacements related to the building of mountain chains on the lithospheric scale. The previous edition of the same book by Wegener (1920) only discussed mountain chains as the result of thickening by folding, and the internal structure of an orogen was never shown nor described there.

Kraus (1931), in a paper linking the formation of the Alps with that of their neighbouring chains, criticized the idea of Argand that the African continent could possibly override the European one. His critique was based on a claimed mechanical knowledge of orogenic processes, first recalling that Ampferer considered that stresses cannot be transmitted for more than 100 km through rock masses, and second, questioning the underthrusting of Europe below Africa[15]:"*Why the pressure at depth, where the mass is supposed to escape, should be less than that at the surface, which only supports the atmospheric pressure?*". Kraus considered that the contraction theory still provided a better explanation and also that "*displacements and tectonic ideas that derive from them can only be understood assuming flow of currents at depth*". This criticism was more theoretical, or rather more speculative, in nature, and did not provide any alternative cross sections to those of Argand (1924a).

Bailey (1935), in his classical book "*Tectonic essays, mainly Alpine*", presented four chapters on different Alpine areas, and one of them on the Pennine Alps, the area most intensely studied by Argand. Only one figure of the chapter (Fig. 28, p. 119), showing a section across the Rhone Valley, was inferred to be modified from Argand, without specifying from which publication, but in fact it looks much more as a figure from Schardt and/or Lugeon than from Argand. No figure and no part of the text of "*La tectonique de l'Asie*" were ever mentioned, and no attempt to illustrate the Alps in a large frame was undertaken. Argand was only quoted for local, regional geological details, except at the very end of the chapter, which Bailey terminated as follows: *"Personally I never feel safe of my foothold when I try to follow Argand into the dim recesses of the past; but this does not lessen my admiration for a guide that has opened up so many secure routes through the hitherto almost trackless Pennides".* Bailey referred here to the work of Argand (1916), on the retro-deformation of the Alpine chain. The Alpine view of Argand (1924a), which widened the tectonic setting of the Alps to the continental and "lithospheric" scales was completely ignored. Interestingly, the nicely written chapter II, on the *"chronology of tectonic discovery"* terminates its historical synthesis in 1893, with the interpretation of the Préalpes as nappes by Hans Schardt, albeit the book was written in 1935! Against the idea of Schaer (1991), suggesting that Bailey was an exception in a community not open to the new ideas of Argand (1924a), we note that Bailey also did not follow the innovative concepts of "*La Tectonique de l'Asie*", inspite knowing this work so well that he even presented a summary of this book in Nature (Bailey, 1926). Clearly, the idea that the understanding of orogeny may require to link structures with processes acting on a scale, both horizontally and vertically, larger than that of the nappe stack, appears to be far from Bailey's approach, and most probably from many more geoscientists of that time, consciously or unconsciously.

Richter and Pilger (1939) published an almost 400-pages long monograph on the relationships between Corsica, the Alps and the Pyrenees. Argand's "*Tectonique de l'Asie*" was never mentioned there and the bi-vergent orogenic model of Kober was applied to the entire area, explaining that Corsica, together with the Maures Massif of southern France formed the "Zwischengebirge" of the N-Pyrenean branch of the Pyrenean orogen.

[15] "Wieso ist in der Tiefe, gegen welche hin die Massen ausweichen sollen, geringerer Druck als oben, wo nur der Atmosphärendruck lastet? "

Moret (1950) finally reproduced the Alpine, lithospheric-scale sections of Argand (1924a), but as the illustration of a historic model that he inferred to be outdated, because the Alpine chain would now be shown to form by the[16]"*sinking of the axial, crystalline substratum»*, which would result *« from a kind of suction following the initiation of convective currents in the seismic zone, and not from tangential, compressive stresses due to the northward drift of Africa"*. Even the large displacements accommodated at the base of each nappe are replaced by « simple gravity-driven mass flow» on the uplifted flanks of the chain (Moret, 1950). In summary, in the 1 st quarter of a century following the publication of "*La Tectonique de l'Asie*" the most classical text books on the Alps continued to reproduce the older Alpine sections of Argand, those of 1916 or 1909, but never the 1924 section illustrated in Fig. 1c. The inclusion of Argand's (1924a) section in the paper of Ampferer (1926), can be considered as an exception, and its only scope was a rather severe criticism.

Kober (1955), in his book "*Entstehung und Bau der Alpen*", reproduced (p. 331) the sections and the block diagram of Argand (1916) on the western Alps in addition to the modified section of the latter figure from Argand (1924a); (Fig. 3). However, the caption of the latter figure in Kober's book did not quote Argand, but Dal Piaz (1945) instead, whom reproduced Argand's figure in a publication of 1945! In fact, Argand (1924a) was never quoted in the book of Kober (1955). Can one imagine that Kober was not aware of the real bibliographic origin of this figure? Or was he in bad faith? Concerning the "lithospheric" structure of the Alps and neighboring regions, Kober reproduced the figure of Staub (1928a) that we show and criticize above in our Fig. 5. Why not reproducing Argand's cross sections of 1924 (Figs. 1c, 4), which certainly were the original source of inspiration of Staub?[17] In any case, Kober, so profoundly interested in the deep structure of the Alpine orogen, presenting himself a model of the lithospheric structure of the Alps (Kober, 1955), avoided to discuss the concepts and cross sections of Argand (1924a). He mentioned that the latter are different than his own, but did not provide any argument nor a discussion. He merely stated (Kober, 1955, pp. 22–23) that his schematic section[18]"*is different from that of Argand… My image is closer to that of E. Kraus, in that we both seek deep-seated tectonics. Surely some matter is sucked to lower depths. A downflow in the sense of Ampferer is possible*". In the same paragraph Kober continued rather enigmatically as follows[19]:"*Whether my picture is more correct than that of E. Argand is not a matter for schools and persons. The important is the truth, the cosmo-geo-logic truth. This is what we all seek for, along different pathways. But the real truth is given by the Earth gravitation*".

In summary, in the period from 1927 to 1955, excepted for an incipient attempt of Ampferer and for Alfred Wegener, geoscientists did not feel the need of widening the scale of their view of the Alpine orogen, neither by setting its structure in the frame of the peri-mediterranean chains, nor by trying to relate upper-crustal- and "lithospheric" structures. Large-scale kinematic models and associated paleogeographic reconstructions, as found in "*La Tectonique de l'Asie*", were entirely lacking in the literature. It is likely that the conceptual approach of Argand, strictly linking orogenic structures to continental displacement was not really understood and/or accepted in the decades following 1924. In the absence of a quest for this link, neither paleogeographic maps nor "lithospheric" models were really needed. Even after the publication of "*La Tectonique de l'Asie*" the concept of 2-branch orogens and its application to the Alps (Kober, 1914) continued to be the dominant model for several decades. The latter model is far from explaining orogenic processes as such, and very far from the continental-kinematic model of Argand (1924a), which was simply and clearly illustrated by his "lithospheric" sections.

It is interesting that Argand received the Cuvier Prize from the Paris Academy of Sciences in 1927 "for his work on structural geology, and especially his researches on the Pennine Alps" (see a report in the "Prize Award" in *Nature*, 1928). This statement suggests that the scientific community did not seem to be conscious that Argand discovered and described for the first time the general anatomy of orogens and the kinematics of their evolution on the lithospheric scale, and simply honored the structural work of Argand's scientific youth. Several arguments may partly explain this. Indeed, Argand's

[16] « *l'engloutissement du substratum cristallin axial dans ce tronçon résulterait, non pas d'un effort de compression tangentiel dû à la dérive africaine vers le Nord, mais d'une sorte de succion consécutive à la naissance des courants convectifs dans la zone sismique ayant entraîné la croûte entre les deux zones listriques subbriançonnaise et alpino-dinarique, et tout cela suivi du plissement, du « bouillonnement» des sédiments briançonnais et penniques»*

[17] The suspicion that Kober consciously avoided to quote Argand is very strong, because this same approach is used for other figures of his book. For instance, his Fig. 50, reproduces a cross section of the Western Alps, quoting Moret (1950), but Moret himself fairly stated that this section was reproduced from Argand.

[18] "Es ist ganz anderer Art als das Argand-Schema der Alpen… Mein Bild nähert sich dem Bilde von E. Kraus insoferne, als wir beide Tiefentektonik suchen. Gewiss wird Materie hinabgesogen. Eine Unterströmung im Sinne von O. Ampferer kann man denken ".

[19] "Ob jetzt mein Bild richtiger ist als das von E. Argand, ist keine Angelegenheit der Schulen, der Personen. Auf die Wirklichkeit kommt es an, auf die kosmo-geo-logische Wahrheit. Diese suchen wir alle, auf verschiedenen Wegen. Aber der wahre Weg ist durch die Gravitation der Erde gegeben ".

oral presentation of this work at the International Geological Conference in Brussel was not a rhetorical success (Carozzi, 1985). As reported by Schaer (1991), in a letter to his friend and geologist Paul Arbenz Argand wrote[20]:"*I've been criticized a lot for speaking very quickly, but it's just as hard for me to speak slowly as it is to write quickly… It's always the disparity between the speed of the chains of ideas and the slowness of the organ. If I try to speak slowly, I can't finish my sentences, and I make myself look like a fool*". In addition, "*La Tectonique de l'Asie*" was the last publication of Argand, except for one on the Penninic domain in 1934. Hence, Argand did not insist on these concepts in any other publication. Indeed, "*La Tectonique de l'Asie*" was translated in English, but only in 1977, by Carozzi. Schaer (1991) mentioned the form of Argand's manuscript as a factor that possibly inhibited its acceptance in the scientific community: "*Written in French, in a poetic and complex manner which is sometimes even difficult to read for a native speaker of French, this work was only within the reach of a limited number of researchers*". However, the message of Argand's figures and figure captions is too clear to have been misunderstood or not understood, and Argand was scientifically too visible for not having noticed his book on the Tectonics of the Earth. Finally, all previous publication of Argand were also written in French and did have a great impact on the Alpine community.

6 Conclusions

The Alpine concepts presented by Argand in "*La Tectonique de l'Asie*" result from a scientific pathway that starts with detailed observations and interpretations in a specific Alpine area and become integrated in a progressively increasing scale of observation, which is first that of the entire mountain chain, and later the lithospheric-scale including all continents involved in orogeny. Argand's earlier Alpine studies (Argand, 1909; Argand, 1916) largely impacted the scientific community of his time and that of the following decades, which is at odd with the continuous disregarding of the entirely new, and at least as much innovative maps, cross sections, and tectonic concepts on the Alpine and Mediterranean realm presented in "*La Tectonique de l'Asie*". The first-order similarity of Argand's Alpine sections with those of other orogens shown in "La Tectonique de l'Asie", namely the building of a mountain chain where a continental margin is thrust above another one, and both are shortened and thickened together, points to a general law underlying collisional orogenic processes, that Argand recognized, worldwide.

The Mediterranean kinematic evolution presented by Argand is extraordinary, both because of its present-day validity to a very large degree, and also for the radical break that it created with any previous model. Argand's Mediterranean model did not improve and/or modify previous ones, it represented a new beginning, a complete change of paradigm.

The scientific community arrived at the conclusions of Argand on the Mediterranean kinematics 45 years after his publication, but following a different path and approach compared to those of Argand, and not giving credit to him for a long time. The scientific community after Argand (1924a, 1924b) disregarded Argand's interpretations until paleomagnetic data from Corsica and southern France showed different directions, hence pointing to an anticlockwise rotation of Corsica. In a next step, based on the bathymetry and geometry of the continental margins, Corsica was rotated back to its inferred original position, namely attached to southern France. Argand (1924a, 1924b) did not start from a set of locally significant geophysical data that were not available at his time. His starting point was a general concept of mountain building closely linking horizontal displacements, crustal thickening/thinning, isostasy, and kinematics to the detailed knowledge of regional geology, stratigraphy, and tectonics of the entire Mediterranean area. As a consequence, Argand's discovery of the anticlockwise rotation of Corsica and Sardinia is only one element of the discovery of the Oligo- to Present Mediterranean kinematics. In contrast the rediscovery of the anticlockwise rotation of Corsica at the end of the 1960'ies is merely the re-discovery of the rotation of a small crustal block. As a consequence, one can sadly state that the impact of « *La Tectonique de l'Asie*» on the evolution of Alpine and Mediterranean tectonic concepts was not significant. The geological and geophysical communities were not scientifically mature to receive and include these new concepts in their mode of reasoning. Most likely, in spite of the acceptance of nappe tectonics, geologists remained fixists to a certain degree, as shown by one of the fathers of nappe tectonics in the Alps (Termier, 1922, 1929). The lack of a mechanism explaining the process, as often considered a main weakeness in Wegener's theory, is probably not the reason for ignoring Argand's work for half a century, as it was not expressed so in the literature following "La Tectonique de l'Asie".

Whereas Wegener completely embodied a deductive scientific approach, Argand had an inductive one. The progressive widening of his scientific research from the middle/upper crustal segment of the Alpine chain to the entire lithosphere of all mountain belts of the Planet

[20] *"On m'a beaucoup reproché de parler très vite, mais il m'est aussi difficile de parler lentement que d'écrire rapidement…C'est toujours la disparité entre la vitesse des trains d'idées et la lenteur de l'organe. Si je m'efforce à parler lentement, je ne puis finir mes phrases, et je me donne l'air d'un idiot".*

allowed him to develop a generalized picture of orogeny, being the result of very significant lateral continental displacements and the superposition of their stretched marginal areas. The lithospheric-scale sections of Argand (1924a) are world-wide the first ones to show the superposition of continental margins as the prime mountain-building process, long before the acceptance of Plate Tectonics. But even in this latter era of Plate Tectonics, and even if the work of Argand was claimed to be the result of "intuitive kinematics" (Laubscher, 1971a), his kinematic model on the Mediterranean is much closer to current interpretations, compared to models of the 1970's (Laubscher, 1971a; 1971b; 1975; Hsu, 1971; Smith et al., 1982), which were proudly based on quantitative approaches.

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Author contributions
Claudio Luca Rosenberg contributed to both the historical research and writing Giancarlo Molli also contributed to both the historical research and writing.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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References

Alvarez, W. (1972). Rotation of the Corsica-Sardinia microplate. *Nature Phy. Sci., 235*, 103–105.
Alvarez, W., Cocozza, T., & Wezel, C. F. (1974). Fragmentation of the Alpine orogenic belt by microplate dispersal. *Nature, 248*, 309–314.
Ampferer, O. (1926). Zur Auflösung der Mechanik der Alpen: 2. Fortsetzung. *Jahrb Geol Reichsanstalt, 76*, 125–151.
Argand, E. (1911). Les nappes de recouvrement des Alpes Pennines et leurs prolongements structuraux. Beiträge zur Geologische Karte der Schweiz. Neue Folge, XXXI Lieferung.
Argand, E. (1909). L'exploration géologique des Alpes pennines centrales. *Bulletin de la Société Vaudoise des Sciences Naturelles, 45*, 217–276.
Argand, E. (1916). Sur l'arc des Alpes occidentales. *Eclogae Geologicae Helvetiae, 14*, 145–191.
Argand, E. (1924a). La tectonique de l'Asie. Comptes rendus de la XIII^e session du Congrès géologique international, Bruxelles 1922, Liège, fascicule 1, pp. 171–372
Argand, E. (1924b). Des Alpes et de l'Afrique. *Bulletin De La Société Vaudoise De Sciences Naturelles, 55*, 233–236.
Ashworth, T. P., & Nairn, A. E. M. (1965). An anomalous Permian pole from Corsica Palaeogeography. *Palaeoclimatology, Palaeoecology, 1*, 119–125.
Bailey, E. B. (1926). Structural features of the Earth. *Nature, 2955*(117), 863–864.
Bailey, E. B. (1935). *Tectonic essays, mainly Alpine* (p. 191). Clarendon Press.
Beaudoin, A., Augier, R., Jolivet, L., Jourdon, A., Raimbourg, H., Scaillet, S., & Cardello, G. L. (2017). Deformation behavior of continental crust during subduction and exhumation: strain distribution over the Tenda massif (Alpine Corsica, France). *Tectonophysics, 705*, 12–32.
Bernoulli, D., Manatschal, G., Desmurs, L., & Müntener, O. (2003). Where did Gustav Steinmann see the trinity? Back to the roots of an Alpine ophiolite concept. *Geological Society of America, Special Papers, 373*, 93–110.
Blanchard, R. (1915). La structure des Alpes. *Revue De Géographie Alpine, 3*, 163–227.
Boccaletti, M., Elter, P., & Guazzone, G. (1971). Plate tectonic models for the development of the Western Alps and the Northern Apennines. *Nature Physical Sciences, 234*, 108–111.
Bucher W. H., (1933). *The Deformation of the Earth's Crust* (p. 518). Princeton University Press, Princeton.
Carey, S. W. (1955). The Orocline Concept in Geotectonics, Part I. *Papers and Proceedings of the Royal Society of Tasmania, 89*, 255–288.
Carozzi, A. V. (1985). The reaction in continental Europe to Wegener's theory of continental drift. *Earth Sciences History, 4*, 122–137.
Collet, L. W. (1926). The Alps and Wegener's theory. *The Geographical Journal, 67*, 301–306.
Collet, L. W. (1927). *The structure of the Alps* (p. 290). Edward Arnold & Co.
Dal Piaz, G. B. (1945). La genesi delle Alpi. *Atti R Ist Ven Sc Lett Arti, 104*, 467–498.
De Jong, K. A., Manzoni, M., and Zijderveld, J. D. A. (1969). Palaeomagnetism of the Alghero trachyandesites. *Nature*, *224*, 67–69.
Dewey, J. F., & Bird, J. M. (1970). Mountain belts and the new global tectonics. *Journal of Geophysical Research, 75*, 2625–2647.
Dubourdieu, G. (1962). Le déplacement de l'Europe occidentale. *Comptes Rendus Hebdomadaires des Séances De L'académie des Sciences, 254*, 510–512.
Heim, A. (1908). Der Bau der Schweizeralpen. Neujahrsblatt der Naturforschenden Gesellschaft in Zürich auf das Jahr 1908. 26.
Heim, A. (1916). Die Schwereabweichungen der Schweiz in ihrem Verhältnis zum geologischen Bau. Geol. Nachl. Nr. 24. - Vierteljschr. *Natf. Ges. Zürich, 61*, 93–106.
Heim, A. (1919). Geologie der Schweiz. Leipzig : Chr. Herm. Tauchnitz, pp. 704.
Heim, A. (1921). Geologie der Schweiz, Band II. Chr. Term. Tauchnitz, Leipzig. 476.
Heritsch, F. (1927). Die Deckentheorie in den Alpen (Alpine Tektonik 1905–1925). *Fortschritte der Geologie und Paläontologie, VI*, 1–210.
Hsü, K. J. (1971). Origin of the Alps and western Mediterranean. *Nature, 233*, 44–48.
Jenny, H. (1924). *Die Alpine Faltung Ihre Anordnung in Raum und Zeit* (p. 176). Verlag von Gebrüder Borntraeger.
Jolivet, L., & Faccenna, C. (2000). Mediterranean extension and the Africa-Eurasia collision. *Tectonics, 19*, 1095–1106.
Kober, L. (1913). Die Bewegungsrichtung der alpinen Deckengebirge des Mittelmeeres. Peterm. geogr. Mitt., Gotha 1914, und Verh. der 85. Vers. deut. Naturforscher und Ärzte 1913
Kober, L. (1914). Alpen und Dinariden. *Geologische Rundschau*, *5*, 175–204.
Kober, L. (1915). Alpen und Dinariden. *Geologische Rundschau, 5*, 175–204.
Kober, L. (1921). *Bau der Erde* (p. 324). Gebrüder Borntraeger Berlin.
Kober, L. (1923). *Bau und Entstehung der Alpen* (p. 283). Gebrüder Borntraeger Berlin.
Kober, L. (1928). Beiträge zur Geologie von Korsika. Sitzungsber. Ak. Wiss., Wien, Math. Naturw. Klasse, Abt. I, Bd *137*, 481–490.
Kober, L. (1955). *Bau und Entstehung der Alpen* (2nd ed.). Franz Deuticke Wien.
Konversationslexikon, M. (1902–1905). J. Meyer (eds). Bibliographisches Institut, Leipzig.
Kossmat, F. (1921). Die Mediterranen Kettengebirge in ihrer Beziehung zum Gleichgewichtzustande der Erdrinde. Abhandlungen der Mathematisch-Physchen Klasse der Sächsischen Akademie der Wissenschaften, XXXVIII bd, n. II, 1–62.
Kraus, E. (1936). *Der alpine Bauplan* (p. 352). Gebrüder Borntraeger.
Kraus, E. (1954). Neue Überlegungen zum Bau der Alpen. *Mitteilungen der geologischen Gesellschaft in Wien, 47*, 141–158.
Laubscher, H. P. (1971a). The large-scale kinematics of the western Alps and the northern Apennines and its palinspastic implications. *American Journal of Sciences, 271*, 193–226.
Laubscher, H. P. (1971b). Das Alpen-Dinariden-Problem und die Palinspastik der südlichen Tethys. *Geologische Rundschau, 60*, 813–833.
Laubscher, H. P. (1975). Plate boundaries and microplates in Alpine history. *American Journal of Science, 275*, 865–876.

Le Vigouroux, P. (2022). The XIII International Geological Congress of 1922 in Brussels (Belgium): Between wounds of the Great War and theory passed under silence. *Episodes, 45*(4), 457–467.
Lugeon, M. (1902). Les grandes nappes de recouvrement des Alpes du Chablais et de la Suisse. *Bull Soc géol France, 4*, 723–825.
Lugeon, M. (1940). Obituary for Emile Argand. Speech given on December 6th 1940, at the University of Neuchatel, in a "solemn session" in front of the Neuchatel Societies of Natural Sciences and Geography. *Bulletin De La Société Neuchâteloise des Sciences Naturelles, 65*, 24–53.
Malinverno, A., & Ryan, W. B. F. (1986). Extension in the Tyrrhenian Sea and shortening in the Apennines as a result of arc migration driven by sinking of the lithosphere. *Tectonics, 5*, 227–245.
Marcou, J. (1857–1860). Lettres sur les roches du Jura et leur distribution géographique dans les deux hémisphères. Paris: Friedrich Klincksieck, 364 pp.
Molli, G., & Malavieille, J. (2011). Orogenic processes and the Corsica/Apennines geodynamic evolution: Insights from Taiwan. *Int J Earth Sci (Geol Rundsch), 100*, 1207–1224. https://doi.org/10.1007/s00531-010-0598-y
Moret, L. (1950). Les idées Nouvelles sur l'origine des chaînes de montagnes. *Revue De Géographie Alpine, 38*, 223–278.
Murray, J., & Hjort, J. (1912). *The Depths of the Ocean* (p. 821). Macmillan.
Nairn, A. E. M., & Westphal, M. (1967). Sur l'aimantation de rhyolites permiennes en Corse. *C. r. Acad. Sc. Paris, 265*, 319–321.
Nairn, A. E. M., & Westphal, M. (1968). Possible implications of the palaeomagnetic study of late Palaeozoic igneous rocks of northwestern Corsica. *Pal Pal Pal, 5*, 179–204.
Pareto, L. (1861). Coupes à travers l'Apennin, des bords de la Méditerranée à la vallée du Pô, depuis Livourne, jusque à Nice. Bull. Soc. Géol. De France, Ser. 2, XIX, Paris.
Prize Awards of the Paris Academy of Sciences (1928). Nature, 3037, *121*, 74–75.
Richter, G., Pilger, A. (1939). Korsika, Alpen, Pyrenäen. Tektonische Zusammnehänge und Gegensätze. Abh. Ges. Wiss. Göttingen, math.- phys. Kl., III. Folge (= Beitr. z. Geol. d. westl. Mediterrangebiete, herausg. v. H. Stille), *19*, 236–239.
Rosenberg, C. L. (2024). Alpine cross sections through time: a mirror of the evolution of observations and ideas on the tectonics of the Alps. In N. Bellahsen & C. L. Rosenberg (Eds.), *Geodynamics of the Alps* (pp. 1–78). ISTE Wiley.
Schaer, J.-P. (1991). Emile Argand 1879–1940: Life and portrait of an inspired geologist. *Eclogae Geologicae Helvetiae, 84*, 511–534.
Schaer, J.-P. (2010). Swiss and Alpine geologists between two tectonic revolutions. Part 1: From the discovery of nappes to the hypothesis of continental drift. *Swiss Journal of Geosciences, 103*, 503–522.
Schardt, H. (1904). Note sur le profil géologique et la tectonique du massif du Simplon. *Eclogae Geol Helv VIII, 2*, 173–199.
Schardt, H. (1906). *Die modernen Anschauungen über den Bau und die Entstehung des Alpengebirges* (pp. 308–346). Actes.
Şengör, A. M. C. (1982). A note on a late revision of the theory of embryotectonics by Argand himself. *Eclogae Geologicae Helvetiae, 75*, 177–188.
Smith, A. G. (1971). Alpine deformation and the oceanic areas of the Tethys, Mediterranean, and Atlantic. *Geological Society of America Bulletin, 82*, 2039–2070.
Smith, A. G., & Woodcock, N. H. (1982). Tectonic syntheses of the Alpine-Mediterranean region A review. *Alpine-Mediterranean Geodynamics, 7*, 15–38.
Speranza, F., Minelli, L., Pignatelli, A., & Chiappini, M. (2012). The Ionian Sea: The oldest in situ ocean fragment of the world? *Journal of Geophysical Research, 117*, B12101. https://doi.org/10.1029/2012JB009475
Stanley, D. J., & Mutti, E. (1968). Sedimentological evidence for an emerged land mass in the Ligurian Sea during the Paleogene. *Nature, 218*, 32–36.
Staub, R. (1917). Über Faciesverteilung und Orogenese in den südöstlichen Schweizeralpen. Beiträge zur geologischen Karte der Schweiz. Neue Folge, XLVI. 76 Lieferung, 165–198.
Staub, R. (1924). Bau der Alpen. *Beiträge Zur Geologische Karte der Schweiz NF, 52*, 1–272.
Staub, R. (1928). *Der Bewegungsmechanismus der Erde dargelegt am Bau der irdischen Gebirgssysteme* (p. 270). Gebrüder Borntraeger.
Staub, R. (1928). Der Deckenbau Korsikas und sein Zusammenhang mit Alpen und Apennin. *Vierteljahr Naturforsch Gesell, Zurich, Jahrg, 73*, 298–347.
Steinmann, G. (1907). Alpen und Apennin. *Zeitschrift der deutschen geologischen Gesellschaft, Monatsber, 59*, 177–183.
Stille, H. (1927). Über westmediterrane Gebirgszusammenhänge. *Abhandlungen der Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-Physikalische Klasse. Neue Folge, Bd, XII*, 3.
Stille, H. (1927). Die sogenannte Rückfaltung des Apennins. *Nachrichten der Gesellschaft der Wissenschaften zu Göttingen Mathem-Physikal Klasse, 1927*, 292–312.
Suess, E. (1875). *Die Entstehung der Alpen* (p. 168). W. Braumüller.
Suess, E. (1883). *Das Antlitz der Erde, v. Ia (Erste Abtheilung)* (p. 310). F. Tempsky, Prague and G. Freytag.
Suess, E. (1909). *Das Antlitz der Erde, v. III/2 (Dritter Band. Zweite Hälfte. Schluss des Gesamtwerkes)* (p. 789). F. Tempsky, Vienna and G. Freytag.
Termier, P. (1903). Les nappes des Alpes orientales et la synthèse des Alpes. *Bull Soc Géol France, 4*(3), 711–765.
Termier, P. (1909). Sur les nappes de l'Ile d'Elbe. *Comptes Rendus De Séances De L'académie des Sciences, 148*, 1648–1652.
Termier, P. (1911). Les problèmes de la Géologie de la Méditerranée occidentale. *Revue Générale des Sciences, 30*, 1–33.
Termier, P. (1922). *À la gloire de la terre* (p. 447). Paris, Desclée de Brouwer.
Termier P. (1929). Les idées et le langage de la tectonique à propos d'un livre d'Émile Argand. In: La Vocation de savant, (1929), Desclée de Brouwer, Paris, 233–250. Article or lecture not dated but later than 1924.
Wegener, A. (1920). *Die Entstehung der Kontinente und Ozeane* (2nd ed., p. 130). Friedr. Vieweg & Sohn Akt.-Ges.
Wegener, A. (1929). *Die Entstehung der Kontinente und Ozeane* (4th ed., p. 231). Friedr. Vieweg & Sohn Akt.-Ges.
Wilckens, O. (1911). Wo liegen in den Alpen die Wurzeln der Überschiebungsdecken? *Geologische Rundschau, 2*, 314–330.

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