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Artikel: The rôle of accretionary wedges in the growth of continents : asiatic examples from Argand to plate tectonics

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orogenic belts form, upon collision, a species of the superfamily of non-continental-override-type collisional orogens (NCOB or Himalayan-type) in ŞENGÖR's (1990a, table II) classification.

In the following paragraphs we first review the history of ideas that led to Argand's model of accretion and continental growth through continental drift (Part I), and then discuss accretion tectonics and the enlargement of continents in the framework of our view of the widespread occurrence of Turkic-type orogenic belts as a tribute to the enormous insight Argand had into accretionary tectonics (Part II).

PART I

2. Argand's predecessors in the study of continental growth[5])

A long-held view in geology is that orogeny makes continental crust (ŞENGÖR 1990a). This view has developed gradually from older ideas that first equated continent-making with mountain-making and then recognized mountain-making as only a stage in a longer process of continent-making.

2.1 Theories of continental growth until the nineteenth century

Until about the end of the first quarter of the nineteenth century, two main opinions sought to explain the origin and history of our continents. The neptunist view from the Sumerian flood legends (cf. HEIDEL 1949; LAMBERT & MILLARD 1969) to Werner (cf. BINGEL 1934) considered them as original irregularities on the surface of our planet, explaining their growth or destruction as functions of the movements of the hydrosphere, thus taking the "obvious" immobility of the *terra firma* and the high mobility of the waters for granted. By contrast, plutonists from Eratosthenes and Strabo (e.g. STRABO, I, 3.10) to Leopold von Buch (von BUCH 1825, p. 110; 1830, p. 63)[6]) and HOPKINS (1835 and 1847) based their views on the effects of volcanoes and earthquakes and maintained that the present irregularities of the planet's surface were results of deformation generated by vertical (radial) motions that were caused by its "internal fire". The one enduring feature of these early plutonist theories of continent-generation which influenced later ideas was that continent-making and mountain-making were thought to be related processes, both being results of the internal energy of the earth.

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[5]) Continental *growth* here designates only the growth of one particular continent and not necessarily a net gain of continental mass. It is thus used differently from most modern authors (cf. DEWEY & WINDLEY 1981, p. 191). In the sense *growth* is used here, it is equivalent to what DEWEY & WINDLEY (1981, p. 191) call *accretion*. In the penultimate section of this paper we briefly discuss to what extent accretion *à la* DEWEY & WINDLEY may represent net gain of continental mass.

The reason we use *growth* in such a loose sense is because for growth in the sense of net gain in mass to be recognised, a continental crust as distinct from a mantle and/or an oceanic crust had to be distinguished first. This happened during Argand's lifetime and partly through the help of the theory of continental drift. Since a part of this paper deals with the history of ideas, employment of the modern meaning of growth could have led to confusion.

[6]) All page numbers of the publications of Leopold von Buch in this paper refer to those in his *Gesammelte Schriften* edited by Julius Ewald and his collaborators.

2.2 Theories of continental growth in the nineteenth century

In 1831 Elie de Beaumont argued that mountain ranges were produced by horizontal shortening resulting from the thermal contraction of the earth (cf. Şengör 1990a, p. 17, footnote 7). He and Dufrénoy recognised further that areas of orogenic deformation corresponded with areas of thick marine sediment accumulation (especially for the Jurassic: see Dufrénoy & Elie de Beaumont 1848). Elie de Beaumont (1852) later argued that the crushing of a marine trough between the jaws of the adjoining table-lands led to the "filling" of the trough with folded sedimentary rocks. Ongoing shortening led to the overflow of the contents of the former trough and resulted in the generation of a mountain range.

Argand later found this idea of "filling" extremely fruitful:

> "I shall never sufficiently stress what geology owes to the fruitful concept of *filling,* the apex of the thinking of Elie de Beaumont, which includes, clearly expressed or in a strongly implied form, most of the ideas with which tectonics has lived for a long time and with which it will always live, as long as the use of the concept is precisely regulated: the idea of framed folding, the idea of geosyncline, the idea of double chain and of double overturning, the ideas of unilateral overturning, of true foredeep, and of foreland" (Argand 1924, p. 327).

The real founder of the geosynclinal theory of mountain-building in a contractionist framework was James Dwight Dana. His associated ideas concerning progressive *continental stabilization* have long been misinterpreted as implying *continental accretion* by orogenic consolidation of peripheral geosynclinal systems (e.g. Haug 1900, p. 630; 1907, p. 166; Aubouin 1965, p. 12; Dott 1979, pp. 252–253; for criticisms of this misunderstanding see Schuchert 1923, p. 197; Stille 1940, p. 6). Dana thought that the continents represented earlier solidified portions of a magma (or migma) ocean that once covered the earth, while the floors of the present oceans had solidified later. Thermal contraction was thus thought to have been more vigorous in the oceans and this contraction was believed to have caused the largest compressive stresses near the continents whose commonly NW-SE- or NE-SW-trending margins – Dana's "cleavage structure of the globe" (Dana 1875, pp. 746–747) – were thus thrown into broad folds of crustal dimensions: a geanticline formed adjacent to the ocean succeeded continentward by a geosyncline (Dana 1873, 1875). Dana (1873, pp. 8 and 15) emphasized that *the geosynclines were kept filled by shallow water sediments* during their development. When finally the geosyncline collapsed under ongoing shortening and the thermal weakening of its depressed floor, a mountain range was catastrophically created that consisted mainly of continental sedimentary rocks[7]).

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[7]) We here follow Fischer's (1976, p. 2) nomenclature: "Sedimentation occurs in two great realms: that related to the continental masses, and that of the great oceans ... *Continental sedimentation,* in this sense, includes not only the materials conventionally classified under this name, formed in streams and lakes and swamps, but also the deposits of the epicontinental seas, including the great limestone platforms and the evaporites of the interior basins. *Oceanic sediments* include the *pelagic deposits* as well as the turbiditic sediments of abyssal plains and trenches, and the volcanic-rich sequences near island arcs" (italics Fischer's).

Dana further argued that geosynclinal chains became younger away from a stable continental interior, indicating the progressive consolidation of the continent from its centre towards its periphery. But this did *not* mean continental growth, because geanticlines delimiting geosynclines against oceans were considered parts of continents (see the discussion in SCHUCHERT 1923, pp. 157–158). Dana thought that continents and oceans had not only differentiated early in earth's history, but that they were permanent features of the globe, thus ruling out any significant continental growth during the geological history (DANA 1873, pp. 51–52).

Dana's views provided a unified, easy-to-understand theory of sedimentation and mountain-building. He had inherited the catastrophist and regularist *Leitbild* of his European predecessors (cf. ŞENGÖR 1991c), and his views were also firmly rooted almost exclusively in continental geology and what he had learned of oceanic islands (but *not* of ocean floors) during the Wilkes Expedition to the Pacific Ocean.

Eduard SUESS (1875) spotted three problems in Dana's scheme: 1) The various regularities assumed by Dana in the spatial aspects of mountain belts: Suess was unable to agree with any of Dana's principal conclusions regarding spatial regularities of orogeny: Mountain belts did not preferably grow along or close to the present continental margins; their trends did not commonly follow preferred NE-SW or NW-SE striking "cleavage planes" (cf. DANA 1875, pp. 746–747); they did indeed generally become younger away from central stable regions, but Suess pointed out that this was a fairly haphazard process, younger chains commonly migrating back towards the continental interior and reactivating older ones (esp. SUESS 1875, p. 55). 2) SUESS (1875) did not think that mountain-building was a catastrophic process (see esp. ŞENGÖR 1991c). 3) Suess showed that the sedimentary rocks involved in mountain building were not exclusively of continental type as Dana had assumed[8]).

Suess' point that *oceanic* sedimentary rocks, i.e. former ocean floors, are involved in mountain building (SUESS 1875, pp. 99ff; also SUESS 1893, 1895 esp. pp. 1115–1116) and that they now form parts of *continents* was of enormous importance, because it showed that continents and oceans are not permanent features as Dana believed and that continents may be enlarged at the expense of oceans.

Suess also showed how sediments on ocean floors could be added to continents. He argued that orogenic belts were fundamentally asymmetric objects and that their vergence commonly developed towards a topographically inferior foreland (SUESS 1883, p. 187: they "overthrust the subsidence"). Perhaps inspired by HOLMQUIST's (1901, figs. 3 and 4; see also SUESS 1901, figs. 22 and 23; reproduced here as Fig. 1B)

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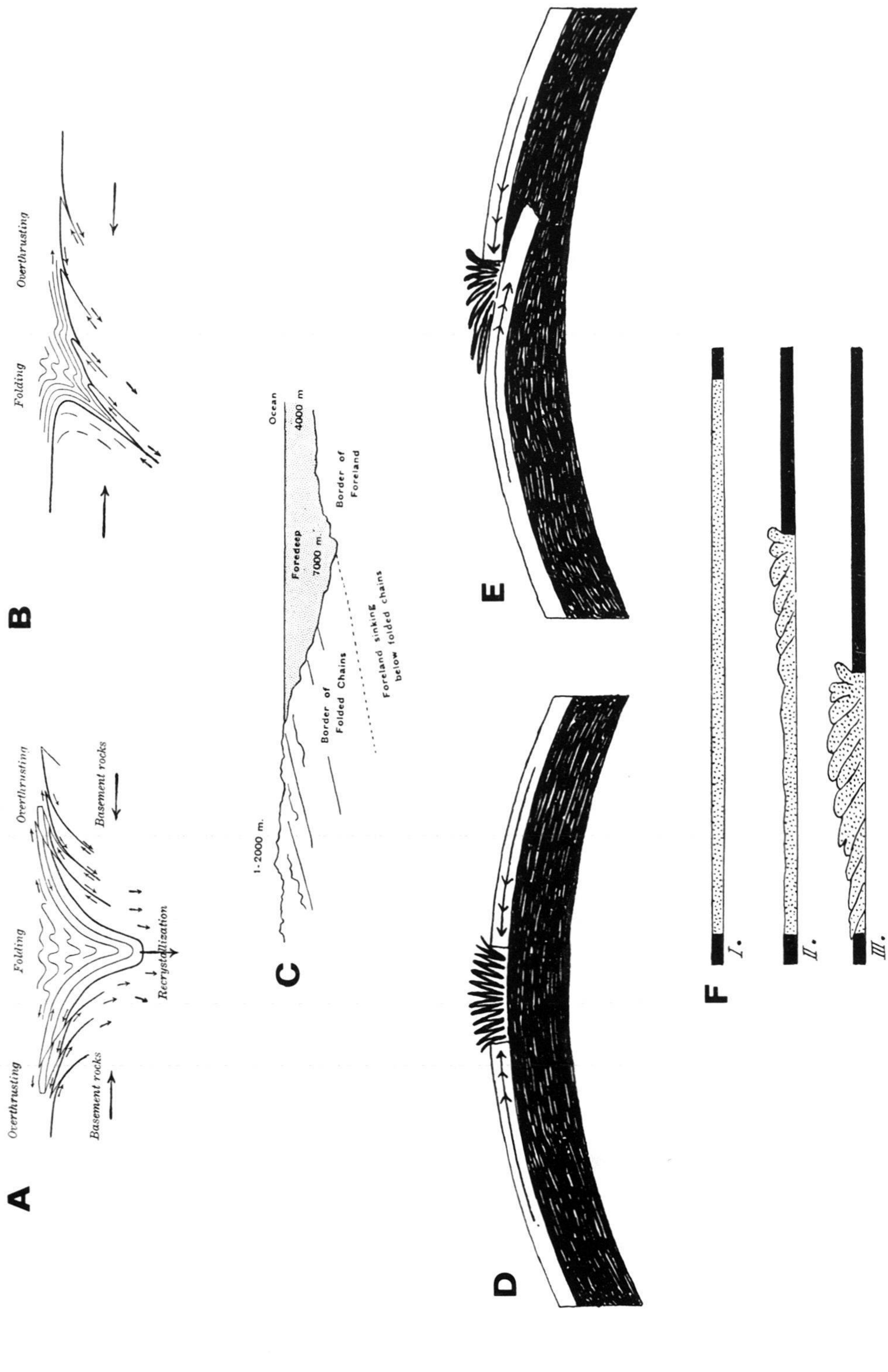
[8]) HSÜ (1973, p. 67) wrote that Suess "was wrong, however, to cite the Triassic of the eastern Alps, known to us as a tidal-flat complex (e.g. FISCHER 1963), to prove his point that the Alpine carbonates are largely pelagic ... Suess was evidently not a sedimentologist". This criticism is, however, totally unfair. Suess simply pointed out that as one went from southern Germany towards the Alps, the sediments generally became relatively *more pelagic*. "This, for example, applies in an excellent way to the Rhaetian Stage, *whose certain variations* I view with certainty to be representatives of the *deep zones of the one and the same marine realm*" (SUESS 1875, p. 98, italics ours). Indeed, as one moves southward along a palaeogeographically reconstructed late Triassic profile in the Eastern Alps (e.g. LAUBSCHER & BERNOULLI 1977, fig. 4), one goes from the European platform through the Alpine shelf finally to a deep marine environment (the *Hallstätter facies)*, however its setting is interpreted (e.g. TOLLMANN 1976, pp. 479ff, esp. 501ff; LEIN 1985). What HSÜ (1973) says is true only of the southern limit of the Dachstein reef facies (cf. FISCHER 1975), to which SUESS (1875) had not limited his argument.


A
Overthrusting
Folding
Overthrusting
Basement rocks
Basement rocks
Recrystallization
B
Folding
Overthrusting
C
1:2000 m.
Ocean
4000 m
Foredeep
7000 m.
Border of Foreland
Border of Folded Chains
Foreland sinking below folded chains
D
E
F
I.
II.
III.

interpretation of the orogenic architecture in Scandinavia, Suess (1924) interpreted deep-sea trenches as places where oceanic sediments became incorporated into the folded margins of the continents by offscraping above giant thrust faults (Fig. 1C). He thus maintained that continents grew peripherally at the expense of oceans. Sometimes two continents would become welded to one another by the contents of the former ocean floors and the "filling" of the intervening marine space as the two nuclei approached one another (Suess 1895, p. 1116).

Suess also recognised important extensional and some strike-slip events in terrestrial tectonics and noted that extension commonly took place in regions where compressive deformations no longer occurred (see esp. Suess 1909, pp. 304–330, 720–721 for extension; Suess 1883, pp. 153ff for strike-slip).

Thus, when Argand formally commenced his geological studies in 1905, Suess had nearly completed the theoretical foundations of his terrestrial tectonics, on which Argand was to construct one of the most elegant conceptual monuments in the history of our science.

3. Argand, Mobilism and Continental Growth

Between 1905 and 1915 Argand devoted his energies mostly to sorting out the structure of the Alps and began developing an interest in global tectonics, especially of Eurasia. His Alpine studies led to his corroboration and amplification of Suess' views on the one-sidedness of the Alpine edifice, the immense mobility betrayed by the highly complex nappe structures, and the deep-sea nature of the Alpine "geosynclinal" sedimentary rocks (Argand 1909, 1911, 1916). His efforts to reconstruct the history of evolution of the Alps culminated in the theory of embryotectonics, which was little more than shortening a composite geosyncline along giant recumbent folds that eventually had come to rest one upon the other in the present-day structure of the Alps. As Şengör has shown elsewhere (Şengör 1982), Argand's embryotectonics was a bold combination of the fixist views of Suess and Haug. But Argand was quick to recognise that continuous shortening could not create both the geosyncline and the mountain range that resulted from its collapse:

> "The classical concept *(i.e. Dana's and Stille's versions of the contraction theory)* combined with that of basement folds certainly allows bold interpretations. Here is one that I have considered: the Mediterranean-type seas, the marginal seas, and the oceans be but basement synclines. These geosynclines of a new type, formed by lateral compression and becoming the location of more particular types of lateral compressions, generating

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Fig. 1. A. Holmquist's hypothetical explanation of the Scandinavian overthrusts. The symmetric case (Holmquist 1901 and Suess 1901). B. Holmquist's hypothetical explanation of the Scandinavian overthrusts. The asymmetric case (Holmquist 1901 and Suess 1901). C. Suess' model of oceanic underthrusting and marginal folding associated with growth of mountains (Suess 1924, drawn before 26th April 1914). D. Ampferer's model of symmetric accretionary orogeny (compare with Holmquist's symmetric case; Ampferer 1928). E. Ampferer's model of asymmetric accretionary orogeny with *Verschluckung* (compare with Holmquist's asymmetric case and Suess' model of orogeny; Ampferer 1928). F. Ampferer's model of the progressive growth of an accretionary wedge (I, II and III).