Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 84 (1991)

Heft: 3: [Emile Argand 1879-1940]

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

Autor: engör, A.M. Celâl / Okuroullari, A. Haldun

Kapitel: 3: Argand, mobilism and continental growth

DOI: https://doi.org/10.5169/seals-166788

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

---

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).

chains, would unquestionably explain many features. In that respect one thinks immediately of all kinds of island festoons, of the Oceanides, and of the elongated crests that sinuate in the middle of the Atlantic and in the western portion of the Indian Ocean *(these are the ideas that led to Argand's theory of embryotectonics and they make clear Haug's influence).* This concept leads directly to the idea of the continuity and particularly of the universality of folding, which becomes the only major aspect *(legacy of two great Swiss predecessors, Arnold Escher von der Linth and Albert Heim?)* Indeed, considering from this viewpoint the closed environment formed by the entire planet, one encompasses in one swoop, and rightly so, the totality of the horizontal and vertical aspects of the deformation. It becomes completely useless to ask oneself if the radial movements follow or precede originally the tangential movements, and what their reciprocal relationships are. This question, debated by generations of geologists, is justified on the scale of small entities, but is meaningless with respect to the whole. The incapacity of the plastic media to transmit, beyond a certain distance, an effective effort is not an insurmountable obstacle if one assumes for the upper part of the oceanic substratum the same kind of heterogeneity that is displayed so clearly by the continental substratum. Thus renewed, the classical concept would allow extensive enrichments, and a long time would elapse before these sources would be depleted. *Unfortunately, in relation to all this, there is isostasy, and as we shall see much more"* (ARGAND 1924, p. 291, italics and italicised annotations in parentheses ours).

Argand thus recognised that continuous shortening leading to a unicausal history of geosynclines and orogens would not do largely because of isostasy. It was at this point that Wegener's theory of continental drift rendered him decisive help. WEGENER 1915, 1920) had shown that continental extension would lead to thinning and eventual separation of two continents, the space in between being filled with the sima (Fig. 2). This made Argand realise that his geosynclines might have been nothing more than former oceans! This revelation not only solved the problem of creating basins without violating isostasy, it also showed that STEINMANN'S (1905) and SUESS' (1909, pp. 644–646 and note 55 on p. 654) point about the presence of pelagic sediments in close association with ophiolites in mountain belts being analogous to the situation in the

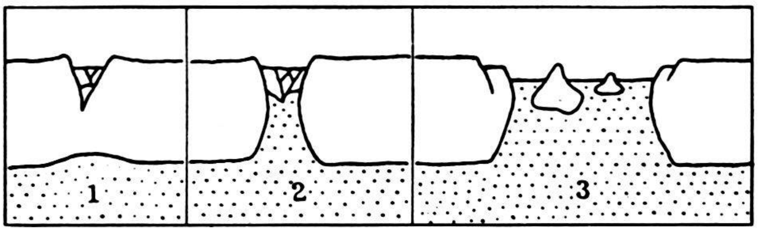

Fig. 2. Wegener's model of continental rifting showing three successive stages. 1) Origin of a rift valley; 2) Extension and further thinning of the sial under the rift; 3) Origin of an ocean with two small continental fragments (WEGENER 1920, fig. 10).

present-day oceans on the basis of the Challenger Expedition results, was essentially correct (see also STEINMANN 1925). Argand, like SUESS (1909, p. 722 and note 52 on pp. 737–738) and WEGENER (1915, p. 15, footnote and p. 69) before him, no longer needed the concept of a geosyncline:

> "The mobilistic theory has somewhat neglected the concept of geosyncline. It is therefore appropriate to sketch a connecting link. A geosyncline will generally result from a horizontal *traction* that stretches the raft of sial. The stretching is at first easier in the deeper part of the sial rather than in the upper part, where extension fractures may develop. While thinning, the sial sinks and develops a depression: the subsidence inherent in the geosynclinal process does not, therefore, stem from an original radial stress; it is only the vertical effect of a horizontal distension. The overburden of the deposits helps of course to accentuate the alveole, but the latter is not necessarily the original feature. Until compensation, the sima rises under the sial; this behaviour accounts for the frequent association of green rocks with bathyal and abyssal sediments *(this sentence refers directly to the observations by Steinmann and Suess as mentioned above)*. The mixture of abyssal with shallower sediments takes place through submarine sliding on the *(continental)* slope…
>
> If traction continues, instead of giving way to compression the sial continues to stretch and the sima appears at the bottom of the alveole. Along the transverse alignments where such a condition occurs, the geosynclinal condition is replaced by the oceanic condition; if such a situation becomes generalized, only an ocean is left. If a compression occurs at this stage or just before it, when the sial is really very thin, the lack of synergy will lead to the generation of one or two trends of marginal chains, of Circumpacific type, and not of the double chain of geosynclinal type. If the compression continues, the latter type will establish itself gradually and may perhaps eventually predominate, but the traces of the simple or double marginal condition will persist, although veiled" (ARGAND 1924, p. 299, italicised annotations in parentheses ours).

The geosyncline thus became only a certain stage in the development of an ocean (either at the beginning, or near the end, i.e. when the ocean is narrow such as the Red Sea or the Eastern Mediterranean) and consequently lost its central rôle in the theory of orogeny!

Argand then applied these views to the entire history of Asia, concluding that the Palaeozoic orogenic belts surrounding the southern and southeastern periphery of the Angaran Shield had resulted from the elimination of an immense geosyncline that had resulted from "a very old Precambrian continental displacement that could have led to the separation of the oldest nuclei of the Serindian *(i.e. the Tarim block of the Chinese literature)*, Sinian and Siberian massifs" (ARGAND 1924, p. 251; italicised annotation between parentheses is ours). These nuclei later reconverged as seen in Fig. 3 and gave rise to the late Proterozoic and the early and late Palaeozoic orogenies of Central Asia, creating what Eduard Suess had termed the Altaids (SUESS 1901, p. 250; see ARGAND 1924, pp. 183–194, 223, 250–251; see also footnote 18 below).

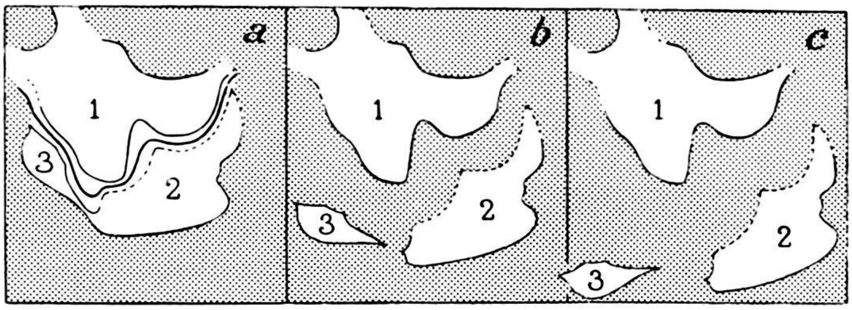

Fig. 3. Argand's "very ancient Asiatic drifts" presented in descending order of time. Key to numbers: 1. Siberian massif (Angara craton), 2. Sinian massif, and 3. Serindian massif (Tarim "craton"). Argand visualized the geometry shown in c as having evolved from a geometry similar to that shown in a by rifting and opening of *oceans* (shown shaded, Argand 1924, fig. 7; shading added by us to improve clarity).

When one reads Argand's description of the evolution of the Altaids in the light of what he said of geosynclines and his heritage of Suessian tectonics, one recognises that Argand thought of the Palaeozoic evolution of Asia in terms of both accretion[9]) *and* collision processes. It is, however, unfortunate that he was so brief in his narrative of the particulars of the Palaeozoic tectonic history of Asia, which he moreover related using the old fixist terminology!

But in one place, in his classic, Argand's narrative becomes explicit and his nomenclature novel, where he depicts the tectonics of accretion at the southern continental margin of his Serindian massif, as seen today in the structure of the Kuen-Lun range in northern Tibet (Fig. 4). In the second part of this paper the same locality will form our point of departure as the best example illustrating our present views of the tectonics of accretion in Asia! The two following quotations, presented by reversing the order of

[9]) Accretion as used in this paper, by which we mean exclusively the process of subduction-accretion that results from offscraping or the process of skimming that results from a Wegener-type continental drift, should not be confused with what has so far been termed "terrane accretion" (e.g. Jones et al. 1983., pp. 27ff; Nur & Ben-Avraham 1983). "Terrane accretion" denotes the collision of individual, coherent "terranes", i.e. "fault-bounded geologic entities of regional extent that are characterized by geological histories different from those of neighbouring terranes" (cf. Jones et al. 1983; Schermer et al. 1984), with a host continent. In this view, terranes may range from the size of the exotic blocks in mélange complexes to sizeable continental pieces. However, the word "terrane" is so inclusive that an entire subduction-accretion prism may also be implied by it. Elsewhere (Şengör 1990a, 1990b, 1991b; Şengör & Dewey 1990) Şengör has discussed at length why the tectonic analysis of orogenic systems in terms of terranes is not useful and may indeed lead to confusion and scientific sterility, and we do not repeat those arguments here.

In contrast to the vague concept of terrane accretion (which Hashimoto & Uyeda 1983, p.v., term *accretion-collision,* perhaps to distinguish it from *subduction-accretion),* subduction-accretion is a well-defined process, whereby the sedimentary cover of downgoing plates, together with occasional slivers of the material making up the basement of the plate, are transferred to growing accretionary wedges at the prow of overriding plates. In Argand's subductionless view of continental drift a similar process was envisaged to occur by skimming the top of the sima at the front of continental rafts drifting through the sima.

Both in Argand's world and in plate tectonics, accretion may be interrupted or altogether terminated by collisions. Tectonic objects formed from both accretionary complexes and collided buoyant objects constitute *tectonic* or *orogenic collages.* If more than one subduction-accretion prism come together without involving coherent buoyant entities such as island arcs or microcontinents, they simply form *accretionary complexes* (cf. Şengör & Yilmaz 1981; Şengör 1990a).

their occurrence in Argand's text, show how far "the magician ... Emile Argand" (LUGEON 1940, p. 49) anticipated our present views:

> "Therefore it is very likely that during Palaeozoic times, *the centre of what is called the Tethys* between India and Serindia *resembled more an ocean* than a marine embayment *(Argand here refers to Neumayr's map of the Central Mediterranean, which shows a narrow marine gulf to occupy the future site of the Kuen-Lun. See ŞENGÖR 1984, fig. 2 for a reproduction of Neumayr's map)* and *the young Kuen-Lun,* born from a continental slope that from Serindia sloped toward the open sea, *resembled by its deformation the Circumpacific chains* rather than half of a double chain rising from a geosyncline" (ARGAND 1924, p. 244, italics and the italicised annotation in parentheses ours) *"The Indo-Serindian space, perhaps too wide in these remote times to be designated a geosyncline,* gave rise, immediately adjacent to Serindia, to pre-Devonian folds followed by Hercynian folds: *this complex wrinkle*[10]) *was the material for the future Kuen-Lun"* (ARGAND 1924, pp. 243–244, italics ours).

In Fig. 4 we indicated the location of Argand's *bourrelet complexe* that later formed the Kuen-Lun. Notice there that Argand added a further wedge of accretionary material to the Kuen-Lun which represented the sedimentary fill of the Tethys, thus suggesting that accretion continued from pre-Devonian times until the closure of the Tethys in the Himalaya! We know now that the situation in Tibet is more complicated than this hypothesis implies[11]) (e.g. ŞENGÖR et al. 1988), but the additional wedge that Argand sketched does indeed exist and resides in the Songpan-Ganzi System (ŞENGÖR 1981, 1984; ŞENGÖR et al. 1988; see also Fig. 10 below).

In Fig. 4, clean-cut thrusts as well as complex recumbent folds are seen. This distinction, i.e. that between a *nappe du second genre* (thrust slice) and a *nappe du premier genre* (large recumbent fold) had already attracted some attention in the Alps (see TERMIER 1906) and Argand attached to it a genetic significance related to the final state of stretching during the opening of an ocean.

> "Clean-cut thrusts whose neatness originates from the fact that the old distensions had reached, along the particular transverse alignment, a perfect disjunction of the two sials. In this case, any subsequent thrust is necessarily clean-cut" (ARGAND 1924, p. 348).

---

[10]) In the original, Argand uses *bourrelet,* which Carozzi translates as "wrinkle". *Bourrelet* literally may mean a rim or a swelling, a bulge, as well as a cushion or a pad. In geology *bourrer* refers to thickening of incompetent media under shortening. We find it significant that Argand should have selected *bourrelet* to describe the complex folds that formed at a continental slope. Instead of Carozzi's "wrinkle" we should have used "complexly folded cushion".

[11]) As recently as 1979 some thought that the whole of Tibet may have been underlain by an accretionary prism: "The northern border, now occupied by these eastern and western Kun Lun ranges and the Altyn Tagh, consists dominantly of medium to high-grade regionally metamorphosed rocks, whose deformation and metamorphism is pre-Devonian ... and, in places Precambrian ... From this region all the way south to the Indus Suture the rocks in the undissected part of the plateau ... [are] interpreted ... as a huge accretionary prism of sediments, mostly derived from the extensive area of late Palaeozoic orogenesis in Central Asia ..., (ŞENGÖR & KIDD 1979, p. 370). The plate tectonics context apart, this is much the same picture that Argand had.

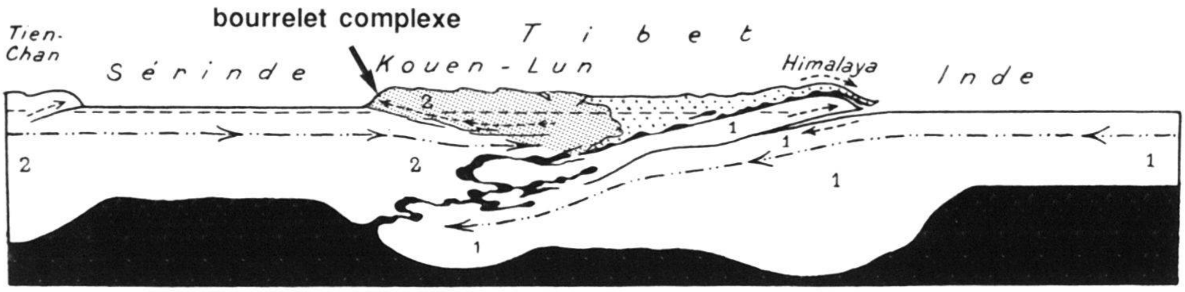

Fig. 4. Argand's cross-section across the Tibetan high plateau showing Serindia, Kuen-Lun and the Himalaya. The *bourrelet complexe* (shown by dense stippling added to Argand's figure by us) represents, according to Argand, an earlier accretionary complex that formed along the southern margin of the "Serindian block" (i.e. the Tarim) than the mainly Mesozoic one shown by Argand himself with sparse stippling ("The tectonic products arisen from the axial zone of the Tethys": ARGAND 1924, p. 348). ARGAND (1924 fig. 13).

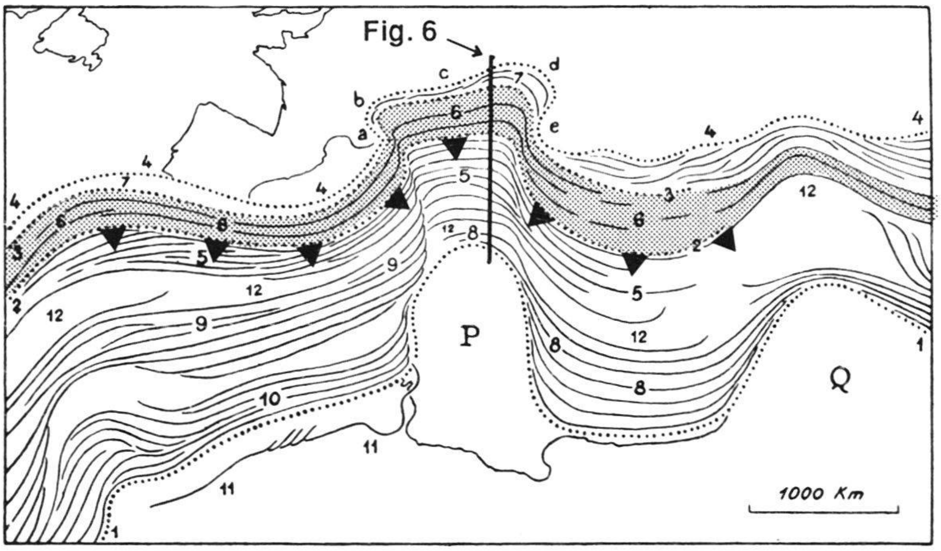

Fig. 5. The march of embryonic cordilleras in the Tethys before the final Alpine paroxysm after ARGAND (1924, fig. 20A; shading and black triangles added by us to improve clarity).

Gondwanian continental margin: 2. Lower limit of the Gondwanian continental slope; 1. Upper limit of the Gondwanian continental slope. P. African Promontory *(Adriatic Promontory);* Q. Arabian Promontory.

Eurasian continental margin: 3. Lower limit of the Eurasian continental slope; 4. Upper limit of the Eurasian continental slope; a) Ligurian promontory; b) Hemicyclic reentrant of the western Alps; c) Bohemian salient; d) Hemicyclic reentrant of the Carpathian region; e) Getic promontory.

Axial zone of the Tethys: 6. Axial zone of the Tethys (stippled), in part overridden in the south. 7 through 11 are embryonic nappes. The accretionary material is in the "axial zone". See Fig. 6 for the style of accretion in the axial zone.

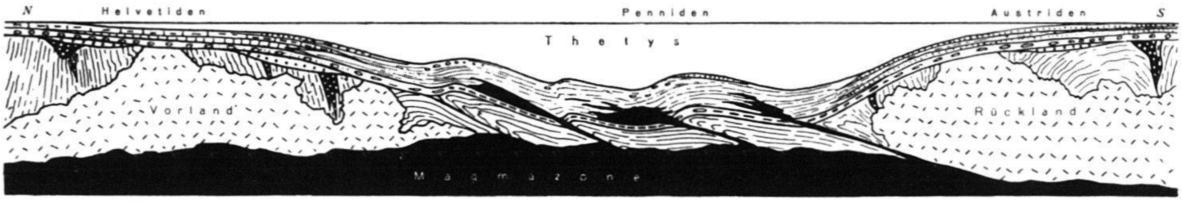

Fig. 6. Structural style of accretion in the axial part of Argand's Tethys according to STAUB (1924, fig. 61: note the misspelling as "Thetys"). See Fig. 5 for a map view and for the location of this schematic cross-section.

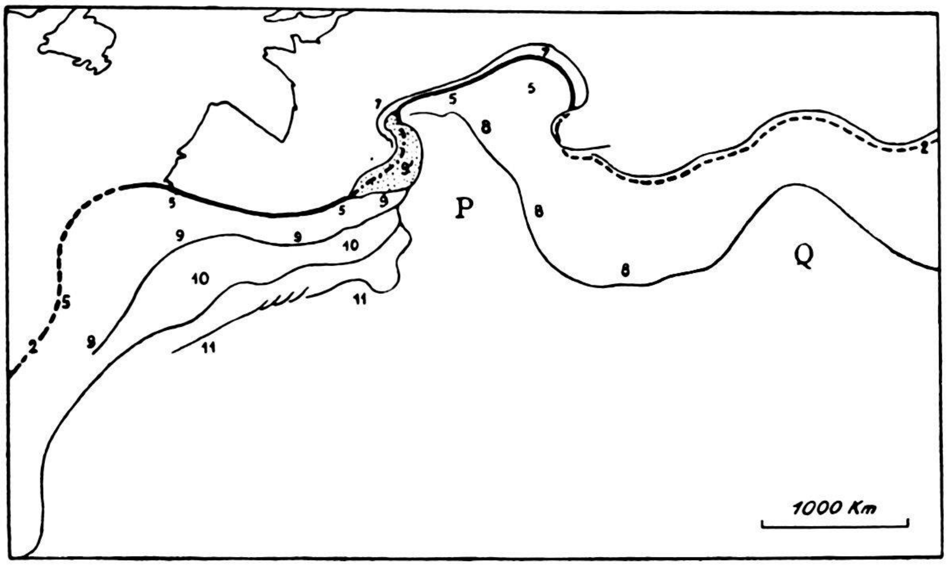

Fig. 7. Suture map of the Mediterranean orogenic belt according to ARGAND (1924, fig. 21). Dotted area represents the Pennine accretionary material "in the few regions in which they are not covered by other nappes" (ARGAND 1924, p. 360). Note the difference between suture *lines* and suture *zones* in this map.

Thus, Argand clearly underlined that he thought that not only the Kuen-Lun, but the entire Tibetan high plateau and the Himalaya had resulted from the closure of the Tethyan *ocean* that also partly supplied the material to the construction of these regions.

Argand did not leave us a cross-sectional view of the process of accretion, although he did depict it on a map (Fig. 5). We couple this map with a section by STAUB (1924), in which the details of the accretion process, by thrust stacking and close to isoclinal folding, are clearly visible (Fig. 6)[12]).

---

[12]) We included Staub's sketch to supplement Argand's with much reluctance. Staub was a Kober-Stillean in his *Leitbild* (cf. ŞENGÖR 1991c) and his mobilist views became progressively more fixist as he drifted away from Argand's influence over the years. In 1924, under the influence of Argand's grandiose views, he was a full-fledged mobilist, but already displaying his Kober-Stillean *regularistic* tendencies such as the assumption of a bilateral symmetry of the Alpine System about an Adria-axis or the regularly north-vergent structure of the *entire* Alpine System between Gibraltar and Iran. In 1928, in his *Bewegungsmechanismus der Erde*, he abandoned a part of his mobilistic views in favour of a fixed Pacific Ocean supposedly formed through a catastrophic departure of the Moon and resorted more and more to a geometrically neat and episodically evolving earth model. In *Der Bau der Glarneralpen* of 1954 he emphasized long-lived, autochthonous lineaments in the crust, and finally, in his posthumously published *Neue Wege zum Verständnis des Ostalpen-Baues* (STAUB 1971) he appeared as a full-fledged fixist with a partially contractionist framework.

All this makes us wonder how much Staub really understood Argand and how much, in the early years of his career, he was following the bright beacon of Argand simply as a bandwagon jumper. The fact that he never noticed Argand's significant 1934 revision of the theory of embryotectonics betrays, we are afraid, that Staub must have had a fairly limited understanding of Argand's views.

The only reason why we included the 1924 cross-section by Staub in our Fig. 6 as a further elucidation of Argand's views is that it was drawn at a time when Staub was in closer professional contact with Argand than later and that between 1924 and 1928, when Staub had the same cross-section reproduced in the *Bewegungsmechanismus* (fig. 1), no serious objections were raised against it.

Argand thus noticed that the closure of major oceans produced accretionary complexes that added to continents. Fig. 7 shows the situation in the Mediterranean area after continental collision, in which Argand clearly distinguished suture *lines* from accretionary material-filled suture *zones*. These two styles of continental apposition were elaborated by different people following Argand's presentation.

4. Post-Argandian mobilism and continental growth before plate tectonics

The man who developed the ideas and the terminology about suture *lines* after Argand was Wilhelm Salomon-Calvi, one of the few outstanding field geologists of the early part of this century, who became convinced of the reality of continental drift:

> "If the assumption that continents drift towards one another and thus may come into contact is correct, then surfaces of apposition *(Zusammenschubflächen)* must form. *These will be similar to faults,* because along them masses come into contact with one another, which had not been in touch before. But they have a completely different character and a completely different meaning. That is why we use a special expression for them in what follows" (SALOMON-CALVI 1930, p. 4, italics ours).

The special expression Salomon-Calvi invented was *Synaphie* (from the Greek συναφεια meaning union, unity of rythm, concordance) that may be anglicised as synaphia. He had also thought of *suture* (in German *Narbe),* but decided against it,

> "because a suture is a healed wound of a former injury, but synaphia is a welded juncture that brings together two masses that had not been one before" (SALOMON-CALVI 1930, p. 20).

This distinction between a suture and a synaphia shows clearly how well Salomon-Calvi appreciated the implications of continental drift in terms of a tremendous continental mobility.

Salomon-Calvi considered synaphias as *lines* of apposition, although he pointed out in 1936 that such lines may be multi-branched encircling former "betwixt lands" *(Zwischenländer:* SALOMON-CALVI 1936, p. 12; compare with Wegener's "microcontinent" depicted in Fig. 2). This "clean" conception of synaphias resulted from the fact that Salomon-Calvi developed his views on the examples of faults that formed following continental collision and that only partly followed the real suture zones (e.g. the Tonale line in the Alps, the North Anatolian fault in Turkey).

If dominance of folding in orogeny was a Swiss heritage through Escher and the father Heim, the dominance of thrust faulting was an Austrian conviction inherited mainly from von Richthofen's Vorarlberg work and Eduard Suess. Otto Ampferer realised very early that the enormous shortening seen in the sedimentary cover of the Alps could not have been parallelled by a similar shortening of the crust that underlay it, unless considerable portions of the crust had disappeared in a manner reminiscent of HOLMQUIST's (1901) suggestion. This, Ampferer called *Verschluckung* in 1911 (AMPFERER & HAMMER 1911, p. 699 as *Verschluckungszone)* and depicted it in a schematic section in 1928 (Fig. 1E).