From Eduard Suess to Emile Argand: Reflections on Tethys and India–Asia tectonics

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'The creation of a science, like that of a world, demands more than a single day; but when our successors write the history of our science, I am convinced that they will say that the work of Suess marks the end of the first day, *when there was light.*'

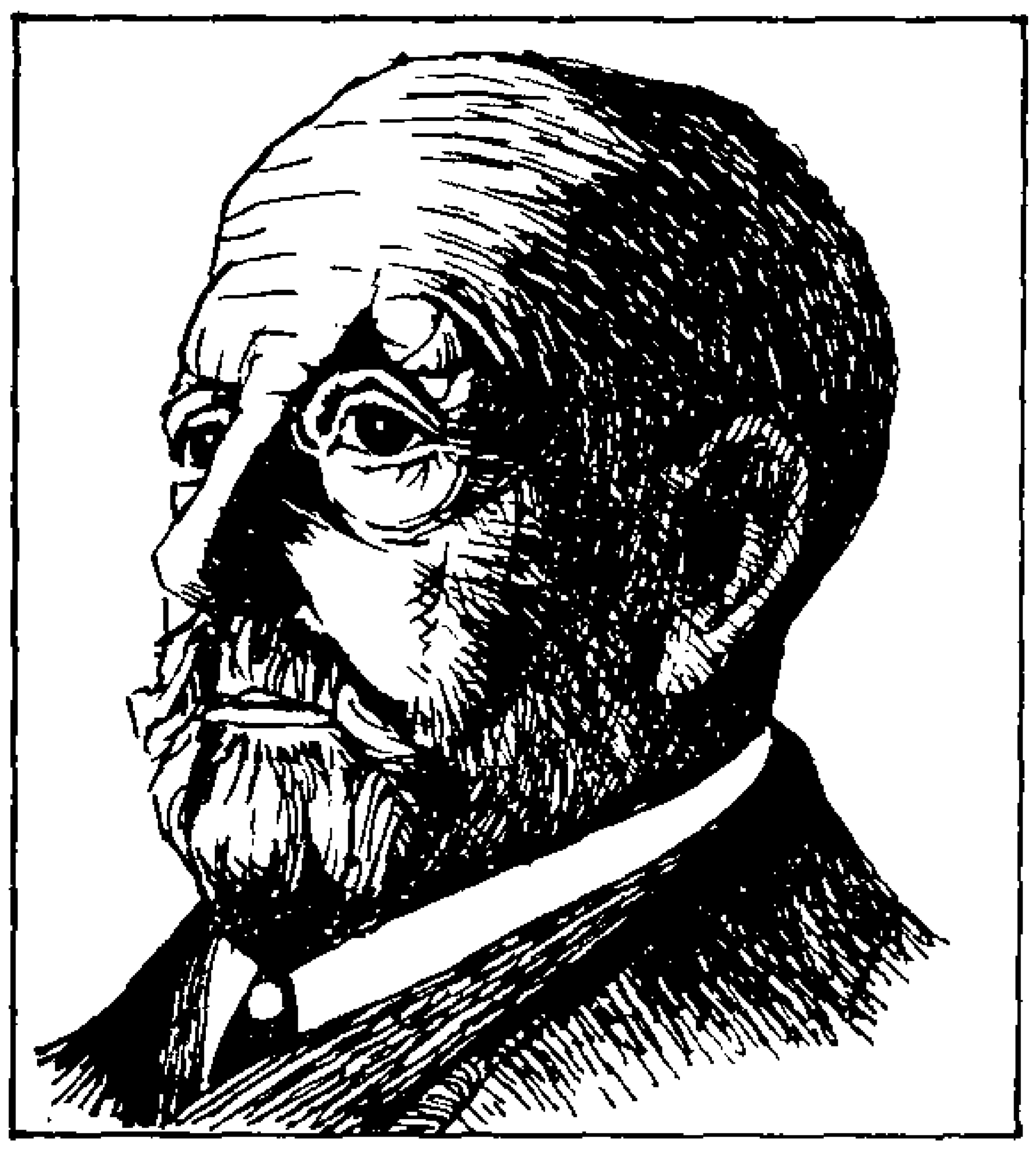
Professor Marcel Bertrand in the preface to the French translation of Suess' book, *The Face of the Earth.*

In 1914 the Austrian geologist Eduard Suess, who in the words of Sir Archibald Geikie had 'made himself acquainted with the geological literature of almost every country on the face of the globe'[1], died. Ten years later, the Swiss geologist Emile Argand (1879–1940) published *La tectonique de l'Asie* (Tectonics of Asia), which reconciled Suess' ideas with the continental drift hypothesis of Alfred Wegener (1880–1930). Much of the existing literature on the development of tectonics are heavily concentrated on post-1950s achievements in plate tectonic theory, with Alfred Wegener as the father of this 'revolution in Earth sciences'[2]. Suess and Argand's names are rarely found in today's geology textbooks. Even some historians of geology[3–6] have ignored Suess' contributions. (Perhaps to overcome this shortcoming in his book, Geikie published an article on Suess in 1905 in *Nature*[1].) However, Wegener, Frank Taylor (1860–1938), Emile Argand and Alex du Toit (1878–1948), who developed the concept of drifting, colliding continents during the 1910s–1930s, were all influenced by Suess' writings and ideas.

This essay, by way of paying homage to Suess and Argand, highlights some aspects of their geologic contributions and concepts pertaining to India–Asia tectonics. The science of continental tectonics typically manifested in the India–Himalaya–Tibet region is still (to quote Newton) 'standing on the shoulders of these giants'.

Eduard Suess: Earth and politics

Details of Suess' biography and scientific career and contributions is out of the scope of this essay. Interested readers may refer to references 1, 7–14 and the references therein. Suess' autobiography, *Erinnerungen* (1916), discusses his family background and political activities with limited information on his scientific accomplishments. In this section, I shall give only an outline of Suess' life as a background to understand his geologic legacy.



Eduard Suess

Eduard Suess was born in London on August 20, 1831, to a family of German origin, but lived most of his life in Vienna. He died on April 26, 1914. Suess entered the *Gymnasium* at a very early age – thanks to his skills in English, German and French. Although he pursued higher education at Prague and Vienna, Suess never took a degree probably because of his involvement in political activities, and geological-field work and excursions. While a student, he took part in the Vienna Revolution, which ended the dictatorial age of Klemens von Metternich (1815–1848) in Austria. Suess' interest in politics and social issues continued throughout his life. He was elected to the Vienna city council from 1863 to 1886, to the Diet (*Ladtag*) of Lower Austria from 1869 to 1896, and to Parliament (*Reichsrat*) from 1872 to 1896, representing the Liberal Party.

Suess devoted his life to geology, becoming a paid assistant in *Hofmuseum* in 1852. Initially, he studied the anatomy and taxonomy of graptolite and brachiopod fossils, but then turned his attention to the mountain belts of Europe, and in 1853 took part in a geological traverse across the Dachstein mountains – a lofty mass of Triassic limestone in the eastern Alps. He then visited the Swiss Alps (from 1854), France (from 1856), Germany (from 1856), England (from 1862) and Italy (from 1867) accompanied by outstanding geologists of each region. In 1857, at the age of 26, Suess was hired as Extraordinary Professor by the University of Vienna, and despite many opportunities for higher civil positions, Suess retained his chair of professorship in geology at Vienna until 1901.

At the farewell lecture on the occasion of his resignation from the University of Vienna, Suess quoted the English writer Bulwer Lytton as saying, When a man of great age is surrounded by children, he then sees at the end of his days, not a period, but only a comma'. He then continued, 'And now I have reached the comma. When I became a teacher, I did not cease to be a student; and now that I cease to be a teacher, I shall not cease to be a student so long as my eyes see, my ears hear, and my hands can grasp. With this wish, I therefore do not step out, but take up my former position'[15]. These words eloquently express Suess' life-long passion for Earth sciences.

Suess wrote several articles and books, but he is best remembered for his two works: *Die Entstehung der Alpen*[16] (The Origin of the Alps) published in 1875, and *Das Antlitz der Erde*[17] (The Face of the Earth) (1883–1909)

The writing of *Entstehung* dates back to 1865, when Suess was commissioned to prepare a treatise on the geology of the Austrian Empire, and for which he had received a leave of absence and funds to travel. The title of *Entstehung* is rather misleading since it presents not only Suess' field observations and thoughts on the eastern Alps but also a review of mountain chains in the Northern Hemisphere, both old and young, and a model for the formation of mountains, which will be described later in this essay. 'This booklet of only 168 pages with no figures betrayed the dawn of a new era in tectonic research'[12]. *Entstehung* has not been translated into English, but brief selections are available in references 18 and 19.

Entstehung constituted a theoretical basis for Suess' *magnum opus*, *Antlitz*. The book began in 1883, when Suess signed a contract with F. Tempsky in Prague for a three-volume publication. Fascicles of the first volume appeared between 1883 and 1885, the second in 1888, and the third, Part 1, in 1901, and Part 2 in 1909. *Antlitz* was translated into French, *La face der la terra*, by Emmanuel de Margerie (four volumes, 1897–1918, Paris) and into English, *The Face of the Earth*, by Hertha B. C. Sollas under the direction of W. J. Sollas (four volumes, 1904–1909, Oxford, the fifth volume being the index, which appeared in 1924). In this essay, I have used Sollas' authorized translation[20].

Trend-line tectonics

Antlitz begins with an imaginary extraterrestrial observer (Suess himself indeed, because of his bird's-eye view of geology) who desires to unravel the tectonics of the Earth, and to do so he adopts 'the *plan of trend-lines*, written by nature on the face of the earth'[20] (III, p. 3). Trend-line tectonics or analysis of directions and attitudes in the mountains had also been used by Suess' predecessors, especially by the Swiss mountaineer Horace-Benedict de Saussure (1740–1799), the German naturalist Alexander von Humboldt (1769–1859) and the French geologist Elie de Beaumont (1798–1847) (who was impressed by Abraham Werner's notion of parallelism and directionality of mineral veins). But Suess' tectonic deductions were more sophisticated and conform to the present-day geologic knowledge.

For example, Suess distinguished between Pacific-type and Atlantic-type continental margins. In the former, mountain chains run 'either parallel to the coast or in curves concave to it, ... thus showing that some definite connexion unquestionably exists between the outer delamination of the continent and its internal structure'. But on both sides of the Atlantic, a mountain chain either 'turns its back to the sea', as in the Appalachians, or else 'cuts transversely across the structure of the land', as in Scotland. The Indian Ocean is bordered by both types of continental margins: 'The whole of the east coast of Africa, the Arabian coast, and that of Indian Peninsula' are of the Atlantic type. And 'from Chittagong, at the head of the Bay of Bengal, down to Java', and from 'the mouths of the Indus, then along the Persian Gulf' are of the Pacific type[20] (I, pp. 5–6). The validity of Suess' concept of continental margins has been confirmed on the account of plate tectonics. In 1962, Dietz[21] recognized that in an 'active' continental margin (the Pacific type), the oceanic crust (sima) is slipping beneath the sialic continent, thus forming marginal mountains owing to drag force, while in a 'passive' continental margin (the Atlantic type) the continental block is moving with the ocean floor.

Another example of Suess' trend-line tectonics is the concept of 'syntaxis' and 'virgation' – terms coined by Suess for the sheaf-like pattern of mountains converging at a common centre (syntaxis), and its opposite (i.e. divergent) pattern (virgation). These terms are seldom used in modern textbooks of structural geology and tectonics, but they provide useful concepts. The Kashmir–Pamir syntaxis is perhaps the best-known example, and indeed Suess devoted a full chapter of the Volume I of *Antlitz* to 'The syntaxis of the mountains of India' with a beautiful coloured-map drawn from the works of researchers at the Geological Survey of India. Later D. N. Wadia worked out the stratigraphy, lithology and structure of Kashmir–Nanga-Parbat syntaxis and showed it to be the result of a tongue-like projection from the Indian shield[22].

Trend-line tectonic analysis using satellite images has been applied by Molnar and Tapponnier[23,24], which has indicated the eastward displacement of Indo-China block and east–west extension of Tibet, probably related to the India–Asia collision.

Waves of Eurasian mountains

Sir Charles Lyell (1797–1875), one of the founding fathers of modern geology, in his *Principles of Geology* (1830–1833) offered little on the formation of mountain chains, probably because the grand, cataclysmic scheme of mountains could not be easily explained by his theory of a slow, gradual and uniform Earth history (Uniformitarianism). The second half of the 19th century was, therefore, ripe for a new direction in geology, tectonics and the origin of mountains. The term 'tectonics' was first introduced as *geotektonics* (Greek: 'earth-building') in the first volume of Karl Friedrich Naumann's *Lehrbuch der Geognoise* (A Textbook of Geognosy) published in 1850. In the 19th century, 'dynamical geology' included studies of both geomorphology and tectonics. Suess' *Entstehung* and *Antlitz* were seminal works in the field of tectonics.

Suess disagreed with the then prevailing concept of vertical uplift of the Earth's crust under the thermal influence of plutonic and/or volcanic activity, as advocated by James Hutton (1726–1797), Leopold von Buch (1774–1853), Alexander von Humboldt and Bernhard Studer (1794–1887). Suess provided two arguments against magmatic uplift. One was based on the age relations between magmatism and folding: folded basalts could not be the cause of their own folding, and granitic rocks of 'Central Massits' ('centralmassen' named by Studer) were much older than the molasse sediments of the same mountains. (The terms 'molasse' and 'flysch' were also coined by Studer.) Secondly, the localized size of magmatic uplifts could not explain the thrusting and folding of the entire mountain chain[16,19].

Suess then supported the idea of a secular cooling, contracting, collapsing Earth with horizontal movements to produce fold-and-thrust belts and subsidences to produce relief. The notion of a cooling, shrinking Earth goes back to René Descartes (1596–1650), Gottfried von Leibniz (1646–1716), Georges Buffon (1707–1788), Élie de Beaumont, Constant Prévost (1787–1856) (to whom we owe the analogy of wrinkles of a 'drying apple' for mountains on the Earth), and James Dana (1813–1895). Suess firmly believed in this process, rejected any absolute uplift of rocks and regarded the crystalline rocks of the

Central Massifs as tectonically passive. He concluded the first volume of *Antlitz* as claiming, 'The breaking up of the terrestrial globe, this it is we witness'[20] (I, p. 604).

For the planet under tension, Suess attributed two types of dislocations: 'tangential' movements (parallel to the Earth's surface) which produce folding and thrusting of rocks over a 'foreland'; and 'radial' movements (perpendicular to the surface) which produce subsidences or 'grabens' (after an old German expression used by miners) in the 'hinterland'. He coined the term 'horst' for small, high-standing blocks separating the grabens.

It is interesting to note that crustal extension in the hinterland of compressional orogens is now widely known[25, 26], as in the case of the Himalaya–Tibet with both east–west extension resulting in the north–south Quaternary grabens[24] and north–south extension manifested in the basement-cover detachment called the South Tibetan Detachment System[27] or the Trans-Himadri Fault[28] of Early Miocene age.

Suess also suggested the possibility of multiple-fold mountains parallel to each other, and coined the term 'posthumous fold' for old, reactivated mountains. Although Suess's focused on the Alps or what he called 'the Alpine System' (including the Alps proper, the Jura, the Apennines and the Carpathians) as the type range of fold mountains (*Faltengebirge*), he also applied his scheme to the Asian mountains and noted that 'the whole southern border of Eurasia advances in a series of great folds towards Indo-Africa, these folds lie side by side in closely syntactic arcs, and for long distances they are overthrust to the south against the Indo-African tableland'[20] (I, p. 596).

In 1878, three years after the publication of Suess' *Entstehung*, the Zürich geologist Albert Heim (1849–1937) published his two-volume work, *Untersuchungen uber den Mechanismus der Gebirgsbildung im Anschluss an die geologische Monographie der Tödi-Windgallengruppe* (Investigations of the mechanism of mountain building appended to the geologic monograph on the Todi-Windgallen Group). Heim was a student of the Alpine Master Arnold Escher von der Linth (1807–1872), who first used the term *Decke* for the overthrust Permian rocks in the Glarus district in 1841 and had accompanied Suess on a field trip to the Swiss Alps in 1854. Heim basically agreed with Suess' tectonic scheme of mountain building, but differed on one main point: he described the Glarus structure as a great double fold (*Glarner Doppelfalte*) with thrusts from both north and south, while Suess believed in the unilateral nature of tangential movements. It took a younger French geologist Marcel Bertrand (1847–1907) to reinterpret Heim's excellent field descriptions in the light of Suess' intelligent theory in 1884, although he had not visited the area. Bertrand envisioned a single, northvergent 'nappe' (French translation of the German term 'decke') in the Glarus district[29]. This was confirmed by Suess in 1892, and accepted by Heim in 1903. The nappe theory was taken up by Hans Schardt, Maurice Lugeon and Pierre Termier, and extended to other parts of the Alps; the theory finally achieved official recognition during the 1903 International Geological Congress in Vienna.

In 1907, the Hungarian geologist Lajos. v. Lóczy (1849–1920)[30] published his geological cross sections of the Sikkim Himalaya describing recumbent folds transported tectonically over long distances. His observations date back to 1878 (six years before Bertrand's paper). It, therefore, seems that field descriptions of the nappe theory were first made by Lóczy in the Himalaya. John B. Auden, Arnold Heim (Albert Heim's son), Augusto Gansser, Tony Hagen and D. N. Wadia were pioneers in applying the nappe theory to the Himalaya.

Mention should also be made here of Karl L. Griesbach (1847–1907), a geologist from Suess' Institute of Geology at the University of Vienna, who joined the Geological Survey of India in 1878 to investigate the stratigraphy of the Himalaya and became the Director of the Survey in 1894. Griesbach[31] in 1893 was the first person to describe the Chitichum Limestone blocks of Malla Johar in the Kumaun Himalaya as 'klippen' (detached nappes).

The seer of Tethys and Gondwanaland

Geikie[1] has regarded *Antlitz* as 'a noble philosophical poem in which the story of the continents and the oceans is told by a seer gifted with rare powers of insight into the past'. The word 'seer' (reminding us of the Sanskrit word *rishi* for ancient sages of India) is very profound in this context. Arthur Koestler in *The Act of Creation* writes: 'The scientist, as the artist, must live on several planes at once – look at eternity through the window of time. All great geniuses of science were endowed with this particular dualism of their faculties· a head for generalizations and an eye for minute particulars'[32]. Suess' creative imagination is evident in his hypotheses of the Tethys Ocean and Gondwanaland.

As Jenkyns[33] has pointed out, Suess' idea of the Tethys Sea stemmed from his observation of a suite of Triassic ammonite fossils collected by General Richard Strachey (1817–1908) in the Himalaya. Strachey was the author of the first comprehensive papers on Himalayan geology and physiography in 1851, which interestingly coincided with the establishment of the Geological Survey of India in Calcutta. His fossil collections were later described by Salter and Blanford[34]. Suess visited London in 1862 and was struck by the similarity between these marine fossils from a black marly limestone in India–Tibet border (the Niti valley) with those of the St. Cassian Beds of the Dolomites. (Sengör[35] mentions that still earlier Roderick I. Murchison in *The Silurian System*, published in 1839, had commented on the identical character of some of the Early Jurassic fossils from Great Britain and the Himalaya, based on Lady Sarah Amherst's collections.)

In 1885, Suess' geologist son-in-law, Melchior Neumayr, proposed an east–west equatorial seaway called *zentrales Mittelmer*[36] (Central Mediterranean) extending from the Alps to the Himalaya partly on stratigraphic grounds (similar Jurassic marine deposits) and partly drawn from ancient Asian myths which have referred to such seas[37]. In an article published in 1893 (mainly to refute James Dana's hypothesis of the permanency of the continents and oceans), Suess proposed the term Tethys, 'after the sister and consort of Oceanus' in the Greek mythology for 'the folded and crumbled deposits . . . of a great ocean which once stretched across part of Eurasia . . . stand forth to heaven in Tibet, Himalaya, and the Alps'[38]. This is also how the Paleozoic–Mesozoic platform sediments to the north of the Great Himalayan Range came to be called 'Tethys Himalaya' by Auden[39], Heim and Gansser[40] and Gansser[41]. Suess later developed the tectonic implications of Tethys in his *Antlitz* when he considered Tethys to have bordered the northern shores of Gondwanaland

The concept of Gondwanaland was also put forward by Suess, and again by drawing from geological discoveries in India In 1872, Henry B Medlicott (1829–1905) described certain coal-bearing formations in the Indian Peninsula, which he termed as 'Gondwana System'[42], after the Kingdom of Gonds – a Dravidian tribe in central India The Gondwana formations were subsequently found to range in age from Late Carboniferous to Lower Cretaceous, representing fluviatile and lacustrine sediments with glacial boulder beds (tillites) at their base and containing plant fossils such as the fern leaves *Glossopteris* The term 'Gondwana flora' was popularized by Otokar Feitmantel (1848–1891) in his 1876 papers.

In 1885, Suess in the first volume of *Antlitz*[20] (I, p. 596), following discoveries of *Glossopteris* flora in the Indian Peninsula, Madagascar and central Africa, coined the term 'Gondwàna-Land' to denote an ancient supercontinent in the Southern Hemisphere including those lands and the supposedly 'sunken' basin of the Indian Ocean. (In this Suess was also influenced by Philip Lutley Sclater's idea of 'Lemuria' – a hypothetical land spanning the Indian Ocean from Madagascar to India and Ceylon.) Later, in Volume II of *Antlitz*[20] (p. 254), Suess extended his Gondwàna-Land to include Australia, but in Volume III[20] (p. 500) he replaced Australia by South America (without the Andes), and finally[20] (III, p. 661) he grouped Australia and Patagonia as a second southern supercontinent called Antarctis. In the northern hemisphere, Suess distinguished Laurentia (North America and Europe) and Angara-Land (East Siberia and parts of China).

Suess knew where the clue to understanding the Earth's history lies – determining the absolute ages of rocks and events. This task has been achieved only in our century – thanks to the radiometric dating techniques. But Suess pondered on this problem, concluding the second volume of *Antlitz* rather mystically, 'We hold the organic remains of the remote past in our hand and consider their physical structure, but we know not what interval of time separates their epoch from our own; they are like those celestial bodies without parallax, which inform us of their physical constitution by their spectrum, but furnish no clue to their distance. As Rama looks out upon the Ocean, its limits mingling and uniting with the heaven on the horizon, and as he ponders whether a path might not be built into the Immeasurable, so we look over the ocean of time, but nowhere do we see signs of a shore'[20] (II, p. 556).

Drifting continents

At the turn of this century, contraction as a mechanism of orogeny (mountain-building process) came under attack by several lines of evidence, both from geology and from geophysics[43]. Geological arguments included: (i) mountains are not distributed uniformly like wrinkles on the drying apple, but are confined to well-defined linear belts on the surface of the Earth; (ii) mountain-building events occur in relatively short, violent episodes, which is not consistent with the secular cooling hypothesis; and (iii) crustal shortening and fold–thrust belts for thousands of kilometers far exceeded the estimated amounts of cooling of the Earth. Geophysical discoveries included the contribution of radioactive heat to the Earth's crust, thus refuting the very assumption of a cooling Earth, and the process of isostacy, implying that the lighter rocks of the so-called 'land bridges' or 'sunken continents' would not have collapsed to form the ocean basins as Suess had thought. The ocean floor is lower because it is composed of denser rocks

Frank Taylor[44] in 1908 (published in 1910) and Alfred Wegener[45] in 1912 proposed the idea of drifting continents In doing so they borrowed several important ideas from Suess. ('Taylor waited until the final volume of Suess' great work had appeared, and then, in an address delivered at Baltimore on 29 December 1908 . . . , presented his theory of continental movements'[46].) While Taylor's emphasis was on the bearing of continental movements on the formation of 'Tertiary mountain belts' such as the Alps and the Himalaya, Wegener concentrated on the process and history of continental *verschiebungen* ('displacements', later called drift) Wegener adopted Suess' threefold structure of the Earth's interior (the nife, sima, and sal, the latter changed by Wegener to sial), with sialic rocks floating on sima. He included all of Suess' ancient continents in a Late Carboniferous Pangaea ('all land') surrounded by Panthalassa ('all seas'), with Gondwanaland forming the southern landmass and the Tethyan zone as the site of 'Lemurian Compression' manifested in the Tertiary mountains of Eurasia. Wegener described his ideas in a well-written book *Die Entstehung der Kontinente und Ozeane* (1915) (English translation by J. G. A. Skerl, *The Origin of the Continents and Oceans*, 1924)

Enter Emile Argand

Emile Argand was born in Geneva on January 6, 1879, and died in Neuchâtel on September 14, 1940, after serving as Professor of Geology at the University of Neuchâtel for 29 years. His interest in alpine mountaineering, extensive reading of books, and experience as a draftmanship in a construction company immensely helped Argand when he began studying geology in 1904 at the University of Lausanne, where he met Maurice Lugeon (1870–1953), one of the Alpine masters. Argand worked intensively on the structural geology of the Pennine Alps in Switzerland, and in a seminal publication in 1908 he established the inversion of metamorphic zones in the Dent Blanche nappe; he also developed block diagrams (or 'stereograms', as he called them) to unravel the three-dimensional structures observed in the field.

Although Argand is less known than Suess (Argand's name is not included even in encyclopedias such as Britannica and Americana[1]), he was a true successor to Suess. Both these gentlemen were from continental Europe

Emile Argand

with an immense interest in Alpine tectonics, both were skillful in languages and stylish writing of geologic literature, both were seers and great synthesizers, and both of them appreciated the tectonic significance of Asia to unravel the evolution of the continents. Argand and his mentor Lugeon were fascinated by Eduard Suess and Marcel Bertrand, and Argand knew *Antlitz* by heart. Details of Argand's life and work have been recorded by his friends, colleagues and pupils[47–50] (and the references therein)

In 1915, impressed with Albert Einstein's idea of relativity physics considering time as the fourth dimension of matter, Argand delivered a lecture at the Swiss Geological Society arguing that in our tectonic studies, time should be taken into account in order to understand the sequential evolution of orogenic belts. He termed this approach as 'embryotectonics'. In the same year he also came across Wegener's idea of continental drift. In 1916, Argand published his major synthesis of the western Alps (*Eclogae geologicae Helvetiae*, **14**, 145–191), discussing the evolution of these mountains from the Carboniferous to the Present times and linking the motor of this orogeny to the movement of 'African Promontory' (now called Adria) towards the coast of Europe and the 'plasticity' of rocks associated with orogenic deformation. He later applied these concepts to analyse the formation of Eurasian mountains as a whole.

Argand's masterpiece *La tectonique de l'Asie*[51], which appeared in 1924 after much pressure from Lugeon on Argand to write it down, was actually the text of his presentation to the opening session of the 13th International Geological Congress in Brussels on August 10, 1922 (The English translation[49] of *Tectonique* has been published by Albert Carozzi in 1977.) Also in 1924, the French translation by Manfred Reichel of Wegener's *Die Entstehung der Kontinente und Ozeane* appeared. Reichel was Argand's assistant at the University of Neuchâtel and the translation was carried out under Argand's guidance Argand elaborated on many of Suess' tectonic concepts and attempted to detach them from contractionism and 'fixism' and to develop them in the framework of 'mobilism' of the continental drift hypothesis. He focused especially on continental deformation, which had been overlooked by Wegener probably because Wegener was a meteorologist, not a tectonist. This task was well-performed by Argand, who, like Suess, was the 'prince of geometry'[50] of the face of the Earth. Argand's ideas were propagated in Asia by his pupil T. K. Huang, who became the President of the Chinese Geological Society, and in continental Europe by his pupil (and later his successor at Neuchâtel) Charles E. Wegmann.

In *Tectonique*, Argand produced a comprehensive, coloured geological map of Eurasia, the first version of which was completed in 1912 and extensively used by Argand in his geotectonic lectures For this map, which was presented by Emmanuel de Marguerie at the International Geological Congress (IGC) in Toronto in 1913, Argand was awarded the Spendiaroff Prize by the IGC. *Tectonique*, however, went much beyond Asian tectonics and provided a grand design for continental deformation based on the collision and plasticity of continental rafts. Argand analysed Eurasian tectonics and the Alpine Cycle of orogeny as the end result of the '*drawing together* of two continental jaws, Indo-Africa and old Eurasia, with a narrowing of Tethys'[49] (p. 31). He was the first geologist to propose the full-scale underthrusting of India beneath the Asian continent, driven by drift process, to produce the lofty Himalayan mountains and the Tibetan Plateau. This concept still enjoys the support of some geologists[52–54]. Burchfiel and Royden[55] present a good review of the various thoughts on the tectonics of Asia during the post-Argand period.

Like Suess, Argand too recognized the clue to solving the enigma of the Earth's evolution· 'Geology is a science of past', declared Argand in 1919. 'The future is geophysics'[47]. The history of plate tectonic theory has proved him to be right. Argand ended his *Tectonics of Asia* insightfully as saying: 'We have questioned all of Asia, and she has responded rather generously; she has informed us of other lands, and there are few she does not help us understand better'[49] (p 165).

Concluding remarks

Through Suess, Europe-Alpine geology and Asia-Himalayan geology held a symbiotic relation: studies in the Gondwana and Tethyan formations in India were utilized by Suess and his successors to work out the evolution of the continents, and in turn, the Alpine nappe theory developed by Suess, Heim, Bertrand and Argand shed light on our understanding of Himalayan orogeny. Ultimately, the tectonic links between these two aspects of Suess' legacy paved the way to designation of the Himalaya as the type example of continent-to-continent collisional orogen within the framework of plate tectonics[56].

The plate tectonic theory has undoubtedly revolutionized our understanding of the Earth's machinery, but its conceptual formulation has been based largely on the studies of the ocean floor. Thermotectonic behaviour of the continents is too complex to be subjected to the simple motion of rigid plates with deformation confined to plate boundaries[57, 58]. Suess and Argand represented the culminations of orogenic research before the 1950s The transition period from the contractionist and fixist concepts of Suess' time to Argand's mobilist view of the continents constitutes a crucial stage in the development of continental tectonics. Therefore, an analysis of Suess–Argand's legacy is not merely a historical curiosity but also a refinement of the plate tectonic theory in the light of continental behaviour. In this respect, the geology of India–Himalaya–Tibet has played and is still playing a leading role.

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