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My Memories and Ideas about the Expanding Earth

Cliff Ollier

Before I ever heard of the Expanding Earth the topic of Continental Drift was the wild idea about the Earth. I learned of this while still at school and read a few books about it.

The topic was hardly mentioned in my university lectures, but there was a lot of discussion amongst students. I wrote my Honours Year Essay on Precambrian Glaciation, and found continental drift made a lot of sense, but it scored a low mark from the examiner.

There was a gap while I worked as a soil scientist in Africa, but I spent a lot of time in the Western Rift Valley and climbed Ruwenzori, which influenced my later thoughts.

Then I went to Melbourne University, appointed by Prof. Sherbon Hills, FRS, whose text book on Structural Geology I had used as a student. It took me a while to realise it, but he was a big player in the field, though he never discussed it with me. Hills was a Fellow of the Australian Academy of Science, and resisted the admission of Carey. Hills "stated that he [Carey] advocated continental drift. His inclusion would therefore debase the scientific standing of the Academy, rather like sponsoring Astrology!" (Elliston, 2003).

The Australian Geological Society was founded in 1952 and for the first issue of the journal articles were invited from eminent geologists including Carey. His contribution was rejected by the reviewers (Hills and Gloe) as 'fanciful'. Carey swore never to write again for the journal.

In the library I found a copy of the Carey 1958 *Symposium on Continental Drift* held in Hobart and published by the Department of Geology. It was full of fascinating detail, but the largest part was the essay by Carey himself. He had changed his mind, and discovered that

Continental Drift was not enough. He introduced The Expanding Earth. Oddly enough nobody else in the Melbourne department seemed to have read it.

The topic of continental drift was eagerly discussed by students and research students at Melbourne, who had their own club. The first big change came when one of our members returned from England with news of the paper on Continental Drift by Bullard *et al.* (1965) and especially their maps. Actually the fit of Africa and South America had been done by Carey earlier, but did not attract much attention. Carey's trick was to use a line halfway down the continental slope as the boundary rather than the coastline. The closing of the whole Atlantic was more impressive, and it had also been done by a computer! In those days people were bedazzled by computers.

It was not until about 1965 that I visited Carey himself. I was in Hobart for some other reason, and arranged to meet him in his Department. He had obviously done some homework on me, and at that time I was best-known for my work on weathering and was about to publish a book on the subject. When we met Sam started telling me all sorts of interesting things about weathering, and I guess he talked for about twenty minutes before I could get a word in and tell him "I don't want to talk to you about weathering, I want to talk about New Guinea". At that time I had been appointed to set up the Geology Department in the newly formed University of Papua New Guinea. Carey knew more about the place than anybody. But then we moved on to the expanding Earth, and he told me he was writing a book to be called *The Expanding Earth*. I asked why he used that title as it had already been used by Jordan. He dismissed that book as trivial, and told me that as a matter of fact at least ten books had been written on the topic. We went into the Departmental library and he showed me. Those in Russian and German had been translated by him, and a special book prepared with the original on the left and the translated page on the right. He hadn't done the French ones because he expected everybody could read French.

We kept in contact after that and I visited Hobart for a couple of conferences. One was essentially to celebrate his seventieth birthday, and a memorable tribute came from Max Banks, a member of Sam's department, who told us of Sam's early life, making him almost saintly. He was the eldest of five children, and when his father died he was the breadwinner. At the same time he was putting himself through university, and this in the great depression and there were no jobs. So Sam became a street conjuror. He learned how to attract a crowd, entertain a crowd and extract money from a crowd. These skills stayed with him for the rest of his life. Later on I have seen him do conjuring tricks at parties, and he was brilliant.

At the same conference I had a chat with Professor Alan Voisey who studied geology at Sydney University in the same class as Carey. They both attended a lecture by Edgeworth-David on continental drift, and when they came out Sam said to Alan "It will be a big job, but I shall spend my life proving it!"

On a later occasion in 1979 we met at a conference of the Geological Society of London on the topic of The Expanding Earth. In those days I was a Fellow of the Geological Society of London, and I knew they had a small flat to rent to visitors in the basement of Burlington House, right on Piccadilly, and I booked it. Sam arrived on the day of the meeting and had not booked any accommodation so I invited him to stay with me, as there were two beds in the flat. He accepted, and after the meeting and the conference dinner we retired there, with another friend, John Hepworth, and worked our way through Sam's duty free allowance. I had hoped we would continue on the expanding Earth theme, but Sam wanted to talk about New Guinea, especially in the war when he worked behind enemy lines. His brother did the same thing, but was unfortunately caught by the Japanese and beheaded.

John left in the early hours, but I met him later on and asked him what he thought of Carey. He said he was a fund of information and a great story teller. But he preferred a conversation to be like a table-tennis match, where I knock it to you and you knock it back to me. But Sam just serves and serves!

I remained in touch with Sam until his death. In the later years he sent me drafts of his new books to look for typos and offer the occasional suggestion. He had his own ways, and managed to avoid references – which has been a frustration to readers ever since.

Colleagues

One of the joys of being an expander was the delightful meetings with other expanders.

One important colleague was Jan Koziar[1]. He was influential in getting my book[2] *Tectonics and Landforms* published in Polish, as it had a chapter on The Expanding Earth. I visited him several times in Poland and was impressed by the tools he had built up, especially the huge globes, and the vast amount of material he had at his fingertips.

[1] *See also chapter by Jan Koziar.*

[2] *Ollier (1981).*

He also introduced me to other Poles who work on the expanding Earth, especially Stefan Cwojdziñski[1]. We are still in frequent contact.

Giancarlo Scalera was a great colleague in Italy. He made a lot of personal contributions but he was also very important in publicising expansion tectonics through conferences and publications. My best personal memory of him is when he invited me to join him on a trip to a nunnery about 70 km north of Rome, to meet descendants of Mantovani. They had a daughter in this nunnery and were visiting her from France, and thought this might be a good place to meet up. We had marvellous lunch at the nunnery, complete with wine and liqueurs. I had no idea that nuns lived so well: perhaps they don't but they certainly know how to turn it on for visitors. And after lunch the family showed us their treasures. The manuscripts of two whole books complete with diagrams, never published, by Mantovani.

In Australia I was lucky enough to meet James Maxlow[2] fairly early in his expanding Earth career. He was preparing the global maps so that he could do his famous work of removing the seafloor spreading stripes, one by one, to show just how the Earth expanded. Curtin University asked my advice on finding examiners for his Ph.D. on the topic of Earth expansion, which was my one tiny part in helping to advance his rise to eminence in our branch of science.

Another man who happens to live in Perth is David Noel[3]. The first version of his idiosyncratic book *Nuteeriat*[4] brought a whole lot of new ideas, and introduced me to some more biological evidence in support of the expanding Earth. We still meet and discuss a whole range of things, obviously including Earth expansion.

I met Vedat Shehu[5] at a few conferences in Italy, and later he gave me a wonderful trip around Albania where he spent his working career as an Engineering Geologist. I helped translate some of his works in English, and we corresponded on many topics, including the Expanding Earth.

In Japan I met Professor Michihei Hoshino, and his college Takeo Yano, who speaks English and acted as our translator. I was in Tokyo at an International meeting and received a letter from Yano asking if I would take part in the session on Tectonics, and of course I agreed. He did not tell me that this was a conference arranged by his university and nothing to do with the International conference. I found myself the only foreigner in a group of Japanese. I was given

[1] *See also chapter by Stefan Cwojdziñski.*

[2] *See also chapter by James Maxlow.*

[3] *See also chapter by David Noel.*

[4] *First published Noel (1989) and recently republished Noel (2018).*

[5] *See also chapter by Vedat Shehu.*

two hours to talk, and after lunch there were eight talks in English by Japanese scientists. Then came dinner and drinks. I gather we finished dancing and singing rude Japanese songs, and then they poured me home. Years later I turned a transliteration of Hoshino's book into real English. But Hoshino's view of Earth evolution is very different from all others, either expansion or plate tectonics, and I cannot say that he was an influence on my thinking, except for one vital idea that I call Hoshino's Law, described later.

PROOFS AND INFLUENTIAL IDEAS

Here I briefly review aspects of evidence used in Expanding Earth works, first in general, and then in three sections where I made contributions of my own – not all accepted, even by fellow expanders.

The fit

The first ideas of continental drift arose from the fit. As soon as the voyages of discovery had revealed the shape of opposite sides of the Atlantic the idea that opposing continents have moved apart was inevitable. I wanted to believe it, but was told that the greatest living geophysicist, Sir Harold Jeffreys, said it was impossible, which subdued me a bit. Only very much later did I realise that his real objection was to the proposed mechanism.

The fit of reassembled continents when the Atlantic is closed is too good to be meaningless. Carey's (1958) closure of the Atlantic was within half a degree over 45 degrees of latitude, and Bullard's generally within a degree over 160 degrees of latitude. It shows the Atlantic has opened, and new seafloor has appeared to fill the gap. The seafloor argument can also be applied to the Pacific, where there are convincing biogeographical and palaeogeographical arguments that the Pacific has opened like the Atlantic (Shields, 1979; McCarthy, 2004). Indeed, much of the Pacific opening is younger than the Atlantic. The circum-Antarctica spreading site has separated several continents that fit very well when reassembled.

The fact that the continents fit so well when reassembled shows they are not increasing in area or changing their shape significantly.

Of course, not everyone agrees on the fit. Plate tectonics accepts closure of the Atlantic and fitting the Gondwanaland continents together, but not the closing of the Pacific. Some alternate hypotheses like Surge Tectonics and Wrench tectonics deny seafloor spreading and authors like Meyerhoff *et al.* (1992) and Storetvedt (1997) claim there are enough non-basalt, continental fragments in the seafloor to invalidate the fit.

Maxlow's reconstructions

Maxlow brought the status of the fit to a new level. The seafloor mapping that showed the stripes of different age of ocean was obtained before any theories were propounded and was as objective as could be. Maxlow reconstructed successive globes by removing strips of different age starting with the youngest. He produced a series of globes of the Earth different sizes over time, but when he removed all the strips the continents fitted together beautifully. To me this is a very convincing proof. See Maxlow (2018) for the latest interpretation.

Biological proofs

In the continental drift days I learned that there was biological evidence for the opening of the Atlantic, as fossils of plants and animals were found on opposite sides. Mesosaurus and Glossopteris were the favourite examples. Mesosaurus was a Permian freshwater reptile found only in Southern Africa and Eastern South America. It would have been physiologically impossible for Mesosaurus to swim between the continents. Glossopteris is a seed fern, with seeds so large and bulky they could not have drifted or flown across the ocean.

In Carey's Tasmania symposium I found a paper (Evans, 1958) including detail on the flightless birds, ratites. These did not arise from independent development of flightlessness from different species of birds, but they are all related. The article also explained they have related external and internal parasites which could not arise from independent evolution. But the ratites are now found in many now dispersed continents and places like New Caledonia – virtually impossible to reach by a flightless bird. They must have been dispersed after a time when travel to all these places was possible.

Biological evidence continued to impress me, and I later found evidence for matching across the Pacific. At first this was individual things, such as the plants found in Australia and South America, described by Van Steenis (1963) and also in an early version of David Noel's Nuteriat (1989). The real clincher for me was the work of MaCarthy (2003) who showed matching of a many species on opposite sides of the Pacific, latitude by latitude, but they were absent in possible 'stepping-stone' islands in between. There could be no other explanation for this except opening of the Pacific.

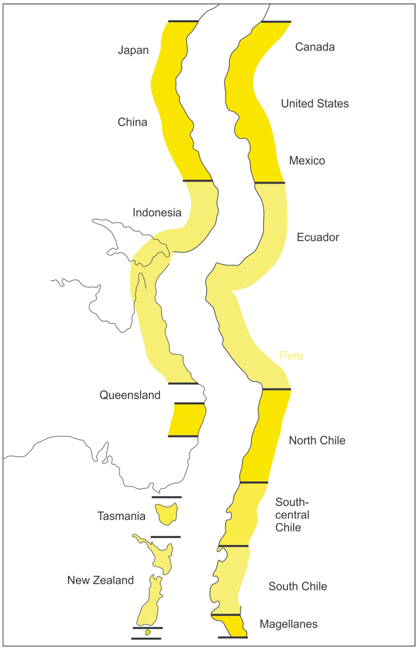

Fig 1. *Closing the Pacific. The curve of Mesozoic south-east Asia above New Guinea is reflected by the curve of the Mariana trench. The corresponding curve of northwest South America represents the actual Mesozoic outline of that region. The regions linked by trans-Pacific sister taxa (shaded) correspond precisely with the matching geological outlines. (after McCarthy, 2003).*

One of the strangest stories of plate tectonics is the alleged collision of India with Asia after drifting over a huge distance from the south and docking in a conveniently-shaped embayment in Asia. But the palaeontological evidence shows that India was never far from Pakistan and other parts of Asia (Crawford, 1979). Today the palaeontological evidence is stronger and some Gondwana fossils have been found as far as Tien Shan. This undermines one of the classic stories of plate tectonics.

Palaeomagnetism

Palaeomagnetism was another topic that attracted me very early. In 1952 I attended a lecture by Blackett on paleomagnetism – perhaps the first time I ever heard of it. He explained the magnetism in sedimentary rocks by the magnetic minerals becoming oriented in the Earth's magnetic field as they slowly drifted into the sediment. After the lecture we were invited to look at the rocks used in his work, and I noticed that one sample had been slumped (disturbed) yet still had the same magnetic reading as the other, undisturbed ones. This suggested that the magnetism was in the cement, not in the individual grains. I pointed this out to Blackett, which started a conversation, and he told me of other work he was doing, including a test with Carey to see if Spain had rotated by opening of the Bay of Biscay. I got near to going to Imperial College to do a Ph.D. with him, but National Service rules of the day made that impossible.

I followed the findings of palaeomagnetism, and was impressed by the drift paths of Europe and North America being similar but different, which could be explained by opening of the Atlantic. Since then the technique has produced many valuable results, but also some arguments because basic concepts were based on a fixed-radius Earth, as explained by Maxlow (2018).

Geometric proofs

Some proofs are simply geometric. One is the Pacific convergence. The Pacific rim is less than a great circle, so the continents around have moved from the other hemisphere and should be converging. They should be getting over the great circle concentric with the Pacific rim. They should be getting nearer to each other. But the reverse is found (Meservey, 1969). I think this is still a first-rate proof, and the argument is independent of any possible subduction. At a conference where somebody suggested subduction might explain the paradox, Carey went through the logic step by step and ended by thundering 'Meservey's argument stands inviolate!' (Elliston, 2003, p. 110).

Another geometric proof is the Arctic convergence. The northern continents all seem to be drifting north, so should be converging, yet the Arctic Ocean is a spreading site, and there is no place for subduction in this area.

Expanding universe and expanding Earth.

Most cosmologists believe in an expanding universe and if the universe is expanding, for whatever reason, it might be reasonable to tie this to Earth expansion. Eichler (in press) has produced a large book on the topic. But we have evidence of only a few heavenly bodies expanding so the Earth is quite exceptional (Ollier, 2007). The expanding Universe is by no means a proof of Earth expansion.

Many other topics add to the argument for Earth expansion, far too numerous to treat here. They include extension everywhere (Ollier, 2012a), lengthening of spreading sites (Koziar, 2018), the origin of water, direct measurements (Maxlow, 2018), hotspots, the conservation of continents and many more.

I now move to the three areas where I made my own contributions.

THE GEOLOGICAL CYCLE

Since the days of Hutton, who saw "No vestige of a beginning, no prospect of an end" the geological cycle has been a basic idea in Earth science. The Earth evolves through a cycle of geological events, driven by its internal and external heat engines. Rocks at the surface, are weathered, sediment is transported, strata may be lithified to form sedimentary rocks, deep burial eventually forms metamorphic rocks and even granite. After tectonic uplift the cycle begins again. This cycle is depicted in nearly all books of general geology, usually with little comment. Fig. 2 is based on the figure in *Holmes Principles of Physical Geology* (1965), perhaps the best general geology book ever published, so is a good example.

This simplified account of the geological cycle ignores features like salt, limestone and coal, but they can be added as minor elaborations and present no problem. Much more significant is that the cycle virtually ignores volcanic rock. Note how in Holmes's figure the basalt comes into the cycle from the side, as an unremarked addition to the cycle. Basalt is not cyclical. Basalt erupted at the Earth's surface will weather, erode, and so on but there is no process that can produce new basalt from cycling other materials. If basalt were only a minor component, this fact might be ignored, but it is not - it covers about

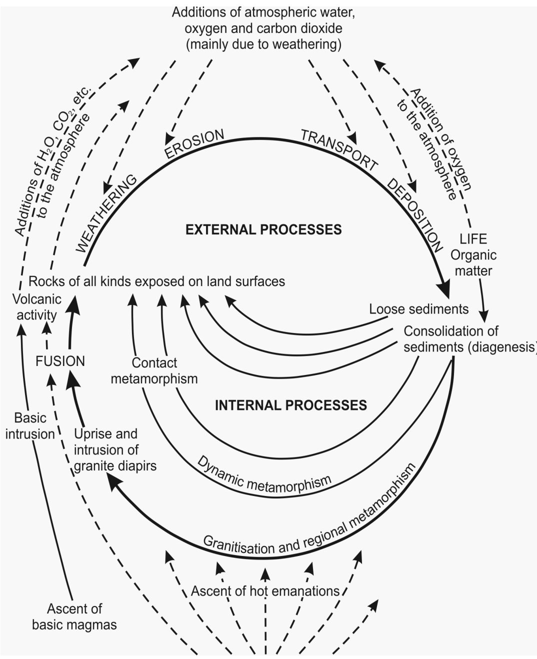

Fig 2. *The geological cycle (after Holmes, 1965). Note that basalt is not really part of the cycle, but comes in from the 'side', even though it covers about three-quarters of the Earth's surface.*

three quarters of the Earth's surface, so is the major component. The conventional geological cycle fails to account for the most massive component. Added to this is another major enigma, unexplained by the cycle. Most basalt is under the ocean. Furthermore, all the ocean-floor basalts are younger than 200 million years old. Did the geological cycle exist before 200 Ma?

In Plate Tectonics the oceans are growing at spreading sites. The seafloor moves away from the spreading site and is subducted (disappears) beneath an overriding plate. The oceanic material is then supposed to return beneath the ocean plate to the spreading site where it re-emerges. This is called a convection cell, and indeed the convection is envisaged as the engine driving plate movement, there is no known mechanism to drive the convection cells.

In the Atlantic, though spreading is simple and symmetrical, there are no subduction sites around Europe or Africa, South and North America, and the only subduction sites are the Caribbean and Scotia island arcs. The Arctic spreading site also has no subduction sites. The southern side of the circum-Antarctic spreading site produced new seafloor converging on the continent, but there are no subduction sites. It makes more sense to conceive the ridge moving away from Antarctica. Most sediment eroded from continents is deposited on the continental shelf of passive continental margins, where there is no postulated mechanism for returning it to the continents. Yet passive margins are about three times the length of active margins (Fig. 3) so subduction cannot keep pace with seafloor basalt production. Other problems of the cycle are described in Ollier, 2006.

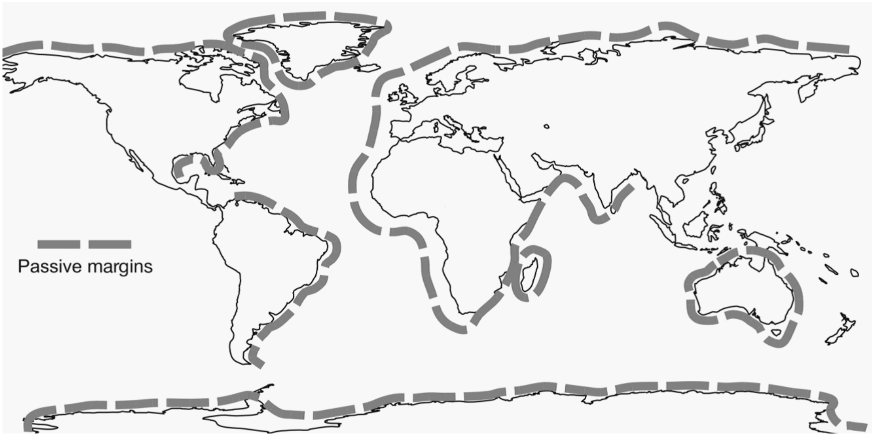

Fig 3. *The global distribution of passive margins. Sediments deposited on these margins cannot be returned to the continent by subduction. (from Ollier, 2006).*

On the western side of South America a trench borders the continent. Here debris derived from erosion of the continent is allegedly deposited. In plate tectonics subduction drags the debris down under the continent were it may be melted to form granites, and perhaps andesitic magmas that erupt as volcanoes on the continent. But the same model cannot be used in North America as there is no trench.

In plate tectonics the down-going slab consists of oceanic basalt together with an unpredictable load of sediments with different chemical compositions depending on the continental rocks that provide the offshore sediments. After re-melting, contamination, segregation of chemicals and minerals, possible emplacement of batholiths and eruption of andesitic volcanoes, the basalt returns to the mid-ocean ridge. Miraculously the subduction-associated processes have cleaned up the basalt so that what appears in the mid-ocean seafloor spreading sites is not just basalt, but a very specific type of basalt, the mid-ocean ridge tholeiitic basalt (MORB). Despite great variation in continental rocks that provide a great variety of sediments to continental margins the re-cycled subducted material that is recycled in the convection cell retains its great uniformity and eventually emerges as MORB.

Much subduction is thought to occur at the trenches bounding island arcs. But island arcs are separated from any backing continent by back-arc basins which are also spreading sites. This means major plates, such as the West Pacific Plate, do not reach the continental margin, and only the tiny back-arc basins can re-cycle continental erosion products back to the continents.

Helium isotopes

Helium is an inert gas that does not combine with other elements. It is very light, and its escape velocity is such that it is eventually lost to space. It is not recycled in the geological cycle. The helium content of the atmosphere is determined by the rate of release of helium from the solid Earth and the escape rate of helium from the atmosphere into space.

Nearly all new helium is produced at the world's spreading sites, that is mid-ocean ridges and rift valleys. Furthermore, helium comes in two isotopes. ^{4}He is not a surprise, as it is a product of the radioactive decay of uranium and thorium. ^{3}He is more mysterious, as there is no mechanism for its production in the Earth. It is generally assumed it is primordial, left over from planetary formation millions of years ago (Holland, 1984: Gold, 1987; Stuart *et al.*, 2003). It is very remarkable that the highest values for ^{3}He are at spreading sites and rift valleys, with very high ^{3}He/^{4}H ratios in Iceland and Hawaii.

Once again we see new material produced at spreading sites, not evidence of re-cycling. The most obvious conclusion from the consistent composition of MORB basalt, and the eruption of new helium, is that the basalt is being erupted for the first time. Only the need to fit into the plate tectonic cycle leads to the conclusion that basalt is recycled.

MOUNTAINS

A semantic problem: Orogeny and Mountain Building

These two terms cause endless confusion. They are commonly interchanged, misuse of orogeny can carry with it all sorts of preconceptions about mountains and rock structure, and many still think that orogeny makes mountains!

Orogeny

Orogeny is a word literally meaning the genesis of mountains, and when proposed it meant just that. Unfortunately in later years the idea of folding and mountain building being the same thing became entrenched, and with a further swing the term orogeny came to mean the folding of rocks.

Orogeny is now used to refer to the structures in fold belts.

Mountain building

We have to use the longer phrase mountain building to be clear we are referring to the formation of the topographical features called mountains.

For an authority on this usage see the Glossary of Geology (Neuendorf et al., 2005), which is virtually the Bible for English speaking geologists:

> "*orogeny* literally, the process of formation of mountains. The term came into use in the middle of the 19th Century, when the process was thought to include both the deformation of rocks within the

> mountains, and the creation of the mountainous topography. Only much later was it realised that the two processes were mostly not closely related, either in origin or in time. Today, most geologists regard the formation of mountainous topography as post-orogenic. By present geological usage, orogeny is the process by which structures within foldbelt mountainous areas were formed, including thrusting, folding, and faulting in the outer and higher layers, and plastic folding, metamorphism, and plutonism in the inner and deeper layers."

Unfortunately the modern usage has not filtered down and geologists still get it wrong! For example, Winchester (2001) defines orogeny thus:

> "Orogeny: A period of crustal compression that results in mountain-building and consequent major changes in geological conditions."

In contrast to orogeny, early geologists used epeirogeny to mean the uplift of broad areas, as opposed to the narrow fold belts of mountain chains. Mountains result from erosion of areas that have been uplifted epeirogenically. This paradox was recognised long ago by Stille (1936) who wrote:

> "As a matter of fact, orogeny in the tectonic sense generally fails as an explanation for the existence of the topographically great mountains of the Earth, such as the Alps of Europe or the Cordilleras of North America. These mountains exist or still exist as a result of post-orogenic *en bloc* movements, for the most part still going on, and belonging to the category of epeirogenic processes. Thus arises the terminological contradiction, that the mountains as we see them today owe their origin not to what is called orogeny, but to an entirely different type of movement that is to be strongly contrasted with the orogenic process."

Mountains and their internal structures

Mountains occur on areas of granite, basalt, metamorphic and unfolded sedimentary rocks, as well as on folded rocks. So mountain building theories (including plate tectonics) that attribute mountain building to folding are inadequate. Theories that can only account for mountain building at colliding plate boundaries (plate tectonics) also fail, because mountains are also found on passive continental margins and deep in continental interiors.

The plate tectonics explanation for mountains that are not on collision sites is offered by Owen (2004):

> "These 'ancient' mountain systems generally have little or no relationship to the present lithospheric plate boundaries and may have begun to have formed many hundreds of millions of years ago."

In other words they were formed like the young, active margin mountains but were formed further back in time. This is not true when we determine the real age of mountain building, as described later under Neotectonics.

Many books on mountains are confused about the origin of mountains and the origin of structures inside them. Hsü's *Mountain Building Processes* (1982) is all about structures and it is simply assumed that 'orogeny' creates both internal structures and the present-day topographic mountains. Schaer and Rogers' book *The Anatomy of Mountain Ranges* (1987) is likewise about internal structures, tacitly assumed to be related to present day mountains.

Mountains and the Neotectonic Period

Previously we have assembled evidence that most mountains are products of the uplift of a plain to form a plateau, which may or may not be extensively dissected (Ollier and Pain, 2000). The original plain was usually a planation surface. The age of a mountain or mountain range is thus the age of the vertical uplift, not the last age of folding of rock (if folds are present). For example the mountains of Scandinavia, often called Caledonian Mountains, consist of Precambrian stocks Paleozoic sedimentary rocks that were folded in the Caledonian orogeny (Paleozoic). They were eroded to a low relief surface, and the mountains of today result from Neogene uplift (Japsen *et al.* 2002, Lidmar-Bergström *et al.* 2017).

Numerous methods are used to determine the age of the planation surface and the age of uplift (see Ollier and Pain, 2000; 2019 for details). All over the world there is evidence that mountain uplift has been very effective over the last few million years. Our compilation of mountains throughout the world (Table 1) shows a major phase of uplift occurred in the Plio-Pleistocene. We do not believe this is an artefact of our sampling, as workers all over the world have come to the same conclusion. If it true, it has important implications and puts constraints on possible mechanisms and theories in both tectonics and geomorphology.

In the expanding Earth scenario, I suggest we are living in a time of increased expansion. Expansion is not uniform but concentrated in specific areas, some linear (like the Andes), and some areal (Tibetan

TABLE 1. *Summary of planation and uplift times in mountain areas (for more examples and references to sources see Ollier & Pain, 2019)*

EUROPE	
Swiss Alps	Pliocene-Quaternary
Jura	Pleistocene
Apennines latest	Pliocene-Middle Pleistocene
Pyrenees	Pliocene
Central Cordilleras of Spain	Plio-Pleistocene
Baetic Cordillera	Upper Miocene-Pliocene
Western Carpathians	Upper Miocene-Pliocene
Southern Carpathians	Pliocene
Caucasus Upper	Pliocene
Urals	Plio-Pleistocene
Sudeten Pliocene-early	Quaternary
ASIA	
Tibetan Plateau	Pliocene-Quaternary
Himalayas	Pliocene-Quaternary
Kunlun	late Tertiary-Quaternary
Tien Shan	Quaternary
Turfan Depression	Quaternary
Altai	Tertiary
Transbaikal	mid-Tertiary
Karakoram	Late Neogene to present
Shanxi	Miocene-middle Pleistocene
Japan	Pliocene-early Pleistocene
Taiwan	Plio-Pleistocene
NORTH AMERICA	
Sierra Nevada	post-Pliocene
Basin and Range	between 7 and 4 Ma
Colorado Plateau Late	Pliocene to Recent
Bighorn Mountains	middle Tertiary-Pleistocene
Rocky Mountains	5 million years
Coast Ranges	late Pliocene
Canadian Cordillera	Late Miocene-Pliocene
Cascade Range	Pliocene
SOUTH AMERICA	
Colombia	Plio-Pleistocene
Chile	Pliocene and Pleistocene
Bolivia	Plio-Pleistocene
Ecuador	Upper Miocene-Plio-Pleistocene

Table 1 continued.

OTHER REGIONS	
Ethiopian Rift	2.9 and 2.4 Ma
Western Rift	3 to 2 Ma
Ruwenzori	within the last 3 million years
New Guinea	Plio-Pleistocene
New Zealand	Plio-Pleistocene
Timor	Quaternary

Plateau and its bounding ranges of the Himalayas to the south (Gansser, 1991), and almost equally high northern rim (Zheng *et al.* 2000).

Plate tectonics believes mountains are formed by collision of plates, and has no explanation for the Neotectonic Period. The eminent geophysicist Molnar realized this, and came to the defense of plate tectonics. He wrote (2007, p. 401)

> ". . . if mountain ranges did rise simultaneously across the globe, then a demonstration of that occurrence would surely be among the more important discoveries in the earth sciences."

In all humility, this is exactly what I have shown.

Molnar recognized that young and universal mountain uplift was not consistent with plate tectonics, and came to its defence. He launched a severe attack on Neotectonics and wrote

> "For virtually every mountain belt and high plateau, as well as for many topographically minor features, a credible, if not outstanding, geologist has asserted that that high terrain rose abruptly in Pliocene and/or Quaternary time."

And later

> "... although not all inferences of recent increases in mean elevations (or whatever has been meant by the word 'uplift') need be false, most surely are."

Why does he think so many get it wrong? Because

> "The lack of a globally synchronous change in rates of plate motion in the past few million years denies any suggestion of a globally synchronous, coordinated rise of high terrain a sensible tectonic cause".

In other words, because the Neotectonic Period is incompatible with plate tectonics it must be wrong. He boldly states (p.404) that

> "a simultaneous uplift of mountain ranges throughout the earth and beginning at 2-4 Ma cannot have occurred and, therefore, did not occur" (p 404).

The breathtaking arrogance that all the 'credible if not outstanding' geologists are wrong and Molnar is right is astonishing, at first sight. But in fact Molnar is taking a stand for the entire Plate Tectonics camp and is stating the presumed view of all its followers, who comprise a vast majority of geologists in the world today. The number of examples of Neotectonic uplift is now much larger than the list used by Molnar, and I do not believe so many eminent geologists are mistaken. If Neotectonic uplift survives all attempts at disproof there is something wrong with the plate tectonic mechanism of mountain formation.

Mountains and the expanding Earth hypotheses

Even some supporters of the expanding Earth hypothesis have problems with mountain building because they are stuck with the one-to-one association of mountains with compression.

For example Brunnschweiller (1983), although in many ways sympathetic to expansion, thought that:

> "… one cannot use Earth expansion as the motor for crustal movements of the sort which build mighty orogenic belts the internal structure of which clearly points to horizontal foreshortening through collision. Expansion on its own will prevent, rather than create, crustal collision."

He was writing mainly of the European Alps, where he held an old fashioned interpretation that ignored their Pliocene planation and later vertical uplift.

Some early explanations of mountain building within an expanding Earth hypothesis were also flawed (in my opinion) because they still retained the old ideas of the fold mountain model and compression as the basis of mountain formation.

King (1983) believed in an expanding Earth and his book is largely an investigation of continental margins where collision of plates is impossible. He emphasises 'cymatogeny', a term he coined himself, for uplift of broad swells, which is a variety of epeirogeny.

> "At the Earth's surface [cymatogeny] is expressed by arching, scores of metres in height, hundreds of kilometres in width, and

sometimes thousands of kilometres long.' … … 'Some arches are formidable (the Andes), some are inappreciable to the eye (the Congo-Zambezi divide)."

He was well aware of planation surfaces and their significance:

> "… planation surfaces upon high lands often show them to owe their present elevations not to any original orogenic compression but to repeated vertical uplifts of former denudational plains."

He repeatedly emphasised vertical tectonics:

> "So the fundamental tectonic mechanisms of global geology are vertical, up or down and the normal and most general tectonic structures in the crust are also vertically disposed. But when we write vertical on a sphere, we mean radial, and so for an Earth sphere we really mean expansional."

He was aware of the Neotectonic Period:

> "Few of the major mountain ranges of the Earth, indeed, were later than mid-Cenozoic in their orogenic (rock-deforming) phase, and planation of the original mountains was achieved almost everywhere before the Pliocene period.' 'Most of the world's [older] ranges … were obliterated and the terrain reduced to a plain by Miocene and earlier erosion. Renewed cymatogeny later arched the Miocene plain into tablelands. After this uplift, renewed valley incision carved the tablelands into a maze of later mountains …"

Carey (1994) developed his ideas of mountain formation on an expanding Earth through many publications. He was influenced by earlier ideas of 'geosynclinal' mountains with folded sedimentary rocks, but he realised that folding did not involve compression or crustal shortening. He was at great pains to emphasise the role of gravity and of radial forces in the Earth, rather than compression and tangential forces. He believed mountain formation (he termed it orogenesis) occurred on an expanding Earth undergoing continuous crustal extension. His model is very complex and not really applicable to most mountains, and is discussed in detail in Ollier (2003).

I propose that mountains can be produced on an expanding Earth without the necessity for any compression and folding. Mountain building only requires a radial force to cause vertical uplift. I believe the significant feature is that radial uplift by expansion in the Earth is not uniform, but is concentrated in or confined to certain lines or zones. The mountain ranges of today show where Earth expansion is most active today. Furthermore, many mountains also have indications of extension (Apennines, Andes, Tien Shan). This is also readily supplied by expansion.

The expansion model does not suffer the limitations of other models which all demand a mechanism for compression.

DYKES

Volcanic activity at the Earth's surface results from eruption of lava, brought up as magma from deep in the Earth mainly through dykes. The crust of the continents is made of sial, of roughly granitic composition and about 30 km thick, and the mantle is made of gabbro which is the same composition as dolerite (the commonest dyke filler) and basalt (the most common volcanic rock). The underlying mantle is presumed to be the source of magma that is intruded through dykes and erupted as volcanoes. Dykes thus connect the mantle to the Earth surface.

Dykes are space filling and require extension in the Earth's crust. Their matching walls have moved apart and magma filled the space (Fig. 4). Volcanic intrusion is therefore permissive, which means that dyke rocks come in to fill a space created by tension. We should not imagine that a thin dyke, just metres wide, can force its way into a crack and push aside a plate a few kilometre thick and many thousands of kilometres across. Rather there is some force pulling the plates apart and the dykes come in to fill the space created when a crack appears.

More positively Hoshino (1998) wrote:

> "Volcanism does not take place in the compressional crust."

This truism requires much more emphasis, and I like to refer to it as Hoshino's Law.

Dyke swarms

Dykes commonly occur in 'dyke swarms' (Fig. 5) where many dykes are intruded as a roughly parallel array, suggesting a common tensional regime, and over a limited time period that may be many thousands of years.

Dyke swarms therefore provide an opportunity for quantifying the amount of extension, and sometimes the rate of extension.

Holmes records (1965, p.250):

> "Along a fifteen-mile [24,140 m] stretch of the coast of Arran, for example, a swarm of 525 dykes can be seen, the total thickness of the dykes being 5,400 feet [1647 m]. Here the local extension of the crust has been more than one mile in fifteen. (6.8%)."

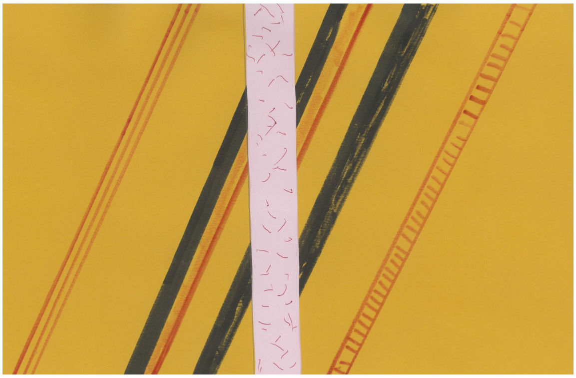

Fig 4. *Diagram of extension by dyke intrusion. Note how the inclined strata match when the dyke is removed. The thickness of the dyke therefore equals the amount of extension. (from Ollier, 2012a)*

The Mull (Scotland) dyke swarm has a total thickness of over 1000 m and indicates a stretching of the crust of 3.8%. In part of northern Iceland an 80 km – wide fissure swarm underwent 5 km of extension between 1975 and 1985 (Steinhorsson and Thoraninsson, 1997).

Wang and Jin (2006) describe Late Paleoproterozoic (1,800 Ma) dyke swarms of part of the North China Craton, and they calculate crustal extension at that time of 0.43%.

Dykes are common enough to be a significant cause of Earth expansion. For Russia it was estimated that there are more than 700 swarms (>200 of Precambrian age and >500 of Phanerozoic age). Ji'an *et al.* (2004) note that the dike swarms in the northern part of the North China Craton can be divided into five age groups according to isotopic dating: 1,800-1,700 Ma, 800-700 Ma, 230 Ma, 140-120 Ma, and 50-40 Ma.

Many dykes are Precambrian, because it covers a large part of Earth history. The oldest known dykes are in Greenland, and go back 3,510 Ma (Nutman *et al.*, 2004). The largest dyke swarm on Earth is probably the Mackenzie dyke swarm in the Canadian Shield which is about 3,000 km long 500 km wide, and about 1,270 Ma old. A Canadian national dyke swarm map compiled by Buchan and Ernst (2004) revealed 453 swarms with an age distribution as follows: 35 Archean, 76 Paleoproterozoic, 60 Mesoproterozoic, 31 Neoproterozoic, and 162 Phanerozoic (97 Paleozoic, 27 Mesozoic, 38 Cenozoic). I provide many more examples in Ollier (2012b).

Mid-ocean ridges

Believers in seafloor spreading think that new dykes are intruded at mid-ocean ridges. The new dykes are bounded by earlier dykes, and then still older. The sea floor is created by successive intrusion of

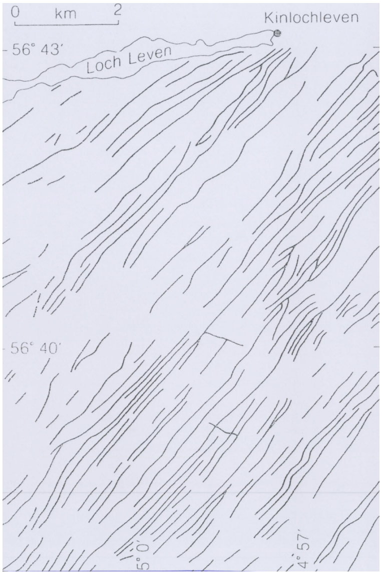

Fig 5. *Dyke swarm near Loch Leven, Scotland. (from Ollier, 2012b)*

dykes. In plate tectonics it is often assumed that the intrusion of new dykes pushes apart the earlier ocean, but we have seen this is virtually impossible. It sees that since the Jurassic expansion of the Earth has caused repeated fracture at the weakest part of the crust, mid-ocean ridges, where dykes have been intruded as the crust was pulled apart.

Since the Jurassic the oceans have grown in area as dykes were intruded, and this process has produced about two third of the rocks at the Earth's surface. Dyke intrusion is the mechanism for most of Earth expansion. The successive strips that Maxlow removed in his demonstration of Earth expansion are bundles of dykes.

Of course real oceans are more complex than just a simple mid-ocean spreading site, but the complications seem to be part of the same story. For the North Atlantic for example, there are extra spreading sites, and Hole and Natland (2019) write:

> "Local extensional tectonism … represents the most important control on the distribution of magmatism in the North Atlantic Igneous Province, with each period of magmatism being related to its own, local rifting event".

Volcanoes in areas of alleged compression

Many volcanoes are found in areas which are popularly regarded as areas of compression, and certainly so in plate tectonic hypothesis. The most obvious one is the Pacific "Ring of Fire" – a distribution of volcanoes around the Pacific Rim recognized long before the invention of plate tectonics. Yet the volcanoes themselves suggest that the Pacific Rim is a region of extension, not compression. The dominant feature of the western margin of South America is the Andes, which in Plate Tectonics are regarded as formed by the pressure associated with subduction. Yet Gansser (1973) wrote:

> "Above all we lack indications of compression along the oceanic and continental crust interface. Along the coastal belt block faulting has been the most important tectonic process since the Mesozoic..."

The second set of 'anomalous' volcanoes are those of island arcs. In plate tectonics island arcs are attributed to subduction, but there is a lot of evidence of tension in island arcs in the form of lots of rifts, graben and half graben (for examples see Ollier, 2012b), many with associated volcanism. Behind island arcs lie back-arc basins which are invariably extensional. The arc is thus located between a spreading back-arc basin and a spreading ocean, and it should be no surprise that it is an area of extension too. The volcanoes mark extension, as per the Hoshino Law.

Dykes through Earth history

Dykes have been intruded through most of geological time. It would seem that dyke intrusion into cratons was dominant until the Mesozoic, when seafloor spreading appeared as a new extension mechanism. Different oceans originated at different times. This appearance of seafloor spreading might correspond to an increase in the rate of global expansion claimed by some authors.

So dykes become a vital factor in deciding between continuous extension (and therefore an expanding Earth), or subduction as in plate tectonics.

Significance of Vertical Dykes

Most dykes and dyke swarms are nearly vertical, indicating that the intruded rocks have not been folded since the dykes were intruded. The crust has remained essentially stable, which rules out significant compression and folding in the area. And this is most of the Earth's surface. Dykes not only signify crustal extension but also the lack of compression. Their very existence undermines many ideas of compression, folding and mountain building.

Conclusion on dykes

In conclusion, the Earth expands mainly by intrusion of dykes. The sea floors result from successive intrusion of dykes at seafloor spreading sites. Before the Jurassic intrusion of dykes was in dyke swarms through sialic crust, but since then intrusion at mid-ocean ridges has been dominant, and more frequent than earlier causing more rapid expansion of the Earth.

Regarding the cause of expansion of the Earth, it is not enough to produce more ‘matter. What we have to produce is a large amount of new basalt, as basalt is not recycled, and the isotopes show it is new.

The world distribution of volcanoes does not support the idea of subduction and compression around the Pacific Ocean, or at island arcs. To maintain the view that volcanoes can erupt in a compressive zone requires suspension of belief in the Hoshino Law: Volcanism does not take place in the compressional crust.

The plate tectonic hypothesis depends entirely on subduction at ‘active’ continental margins and island arcs. Such subduction is presumed to cause compression and indeed Plate Tectonics explains mountain formation by compression at subduction sites. But the distribution of volcanoes, actually concentrated on so-called ‘active margins’, suggests that they must be areas of extension.

So I conclude that all we know about dykes shows that plate tectonics is impossible.

Final thoughts

A summary of my own views is that the Earth is expanding by repeated intrusion of dykes. Since the Jurassic these have been mainly at mid-ocean ridges, and sea floor spreading became the main mechanism of Earth expansion, replacing intrusion of dykes through sialic continents. Dyke intrusion is the mechanism of expansion. I have nothing to say on fundamental cosmological mechanism, except that the Earth is an exceptional body with properties and mechanisms not present on the vast majority of bodies in the universe. My problem for the Earth is not the creation of vague matter, but the production of new basalt.

Expansion tectonics must be accepted eventually. There are fundamental proofs and a vast amount of supporting data that simply do not fit into plate tectonics. Acceptance will require a paradigm shift so will take some time. At present most geologists are not even aware that there are problems with plate tectonics. I once heard Carey opine that someday an American will discover the Earth is expanding, the concept will be accepted, and the whole idea will be attributed to him.

About the Contributor

Cliff Ollier was born in Manchester and educated at Bristol University (B.Sc, M.Sc., D.Sc.), spenting most of his life in Australia as a geologist and geomorphologist. He is the author over 400 scientific papers and ten books including *The Origin of Mountains* (2000) and *Tectonics and Landforms* (1981) which even then had a chapter on *The Expanding Earth*. He has worked in many universities including Melbourne, Australian National, Oxford, Papua New Guinea, New England, East Anglia, and South Pacific and has done field work in many countries. He applied geomorphology to large-scale tectonics through studies of planation surfaces, drainage evolution and great escarpments. He has travelled to over a hundred countries and lectured at over a hundred different universities. He is married with two children and three grandchildren, and long retired. The illustration shows Cliff Ollier in tectonic mood. Drawing by Rudi Boscovic, 1979.

This essay was first published as a chapter in the 2020 book, *The Hidden History of Earth Expansion*, which is widely available from good bookshops in both Hardback and Paperback editions, as well as a Google eBook.

The *Hidden History of Earth Expansion* presents the personal histories of some of the most well-known researchers into Earth expansion in 14 original essays. In addition to furnishing us with their personal histories, as they strived to explore the seemingly overwhelming evidence for confirmation of Earth expansion, the authors' highlight areas where further research is required.

The chapters expressly written for the book are:

• Chapter XIII •

• Chapter XIV •

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