HISTORIC DOCUMENTATION OF CONTINENTAL DRIFT

by John K Davidson

(with seven figures)

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The concept of continental drift started with the Ancient Greeks. Translation of part of Strabo's Ancient Greek manuscript based on Eratosthenes' mapping of sub-continental scale, geographic and geologic units which he named 'sealstones', led to the discovery that he had employed a successful, rectangular co-ordinate, mapping method. As early as c.240–220 BCE the detail of his data produced the first evidence of the continental drift of Italy from Corsica/Sardinia. Some 22 centuries later, Professor SW Carey convened an international symposium in Hobart in 1956 where he presented a global, hemispheric projection and included more detail of the same Mediterranean area. These comparisons, together with Ortelius' claim in 1596 from a partly curved global Mercator projection that, 'it was as if the Americas were torn apart from Africa/Europe', provided a sequence of shoreline co-ordinate gathering peaks that transferred to evolving mapping methods and proved continental drift.
Key Words: continental drift, Eratosthenes, sealstone mapping, Ortelius, SW Carey, global tectonics, Tasmania.

INTRODUCTION

What is continental drift? If all seven continents and continental fragments are correctly fitted back together at their matching continental shelf edges (the 200 m isobath or more precisely at the 2,000 m isobath), they would form a single continent, then the process which caused each continent to break away to its present position is termed 'continental drift'. The starting point of recognising continental drift was the first map constructed by Anaximander (600–c.546 BCE), the Greek philosopher, who imagined the Oikumene (Greek term *Oikoumene* meaning the known world) to be shaped like a cylinder, the top diameter of which being about three times the cylinder height, approximating the shape of a thickened coin (fig. 1). Eratosthenes would later (c.240–220 BCE) then successfully demonstrate some separation in the Mediterranean Sea between two of the three defined Anaximander continents of Europe and Libya (Africa).

This paper interprets three significant reassemblies of continents which have evolved over the past 2,600 years of recorded history of mapping during the past one millionth of the four billion years of Earth history, or the last 1.0% of the existence of *Homo sapiens*.

ERATOSTHENES' (276–195/194 BCE) MAPPING OF CONTINENTAL DRIFT, C.240–220 BCE

Eratosthenes, the ancient Greek polymath (fig. 2A, 2B), created his Ancient Greek map of the known world in c.240–220 BCE while working at the Library at Alexandria. This map was later reconstructed by the Greek historian Strabo c.18 BCE, while also working at Alexandria in Greek-occupied Egypt, the original map having 'vanished to history' (fig. 2; nineteenth century reconstruction by Bunbury (1883), Hamilton & Falconer 2014). In 2011, C McPhail translated the Eratosthenes map and sealstones text, also via Hipparchus (c.190–c.120 BCE), from Strabo (18–7 BCE,) as the focus of his Masters' thesis (McPhail 2011).

The relative location of cities, detail of major rivers and the three rows of symbols depicting the Taurus Mountains had progressively added details to Anaximander's map and attest to almost four centuries of geographic traditions. The blue strip parallel with the shoreline of West Libya (now Africa, fig. 2A) was established during the voyage of Hanno the Phoenician c.600–595 BCE and supported the encircling ocean concept in figure 1.

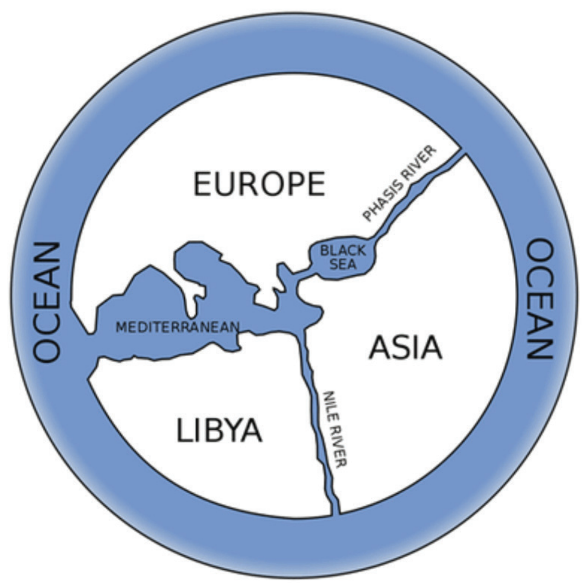
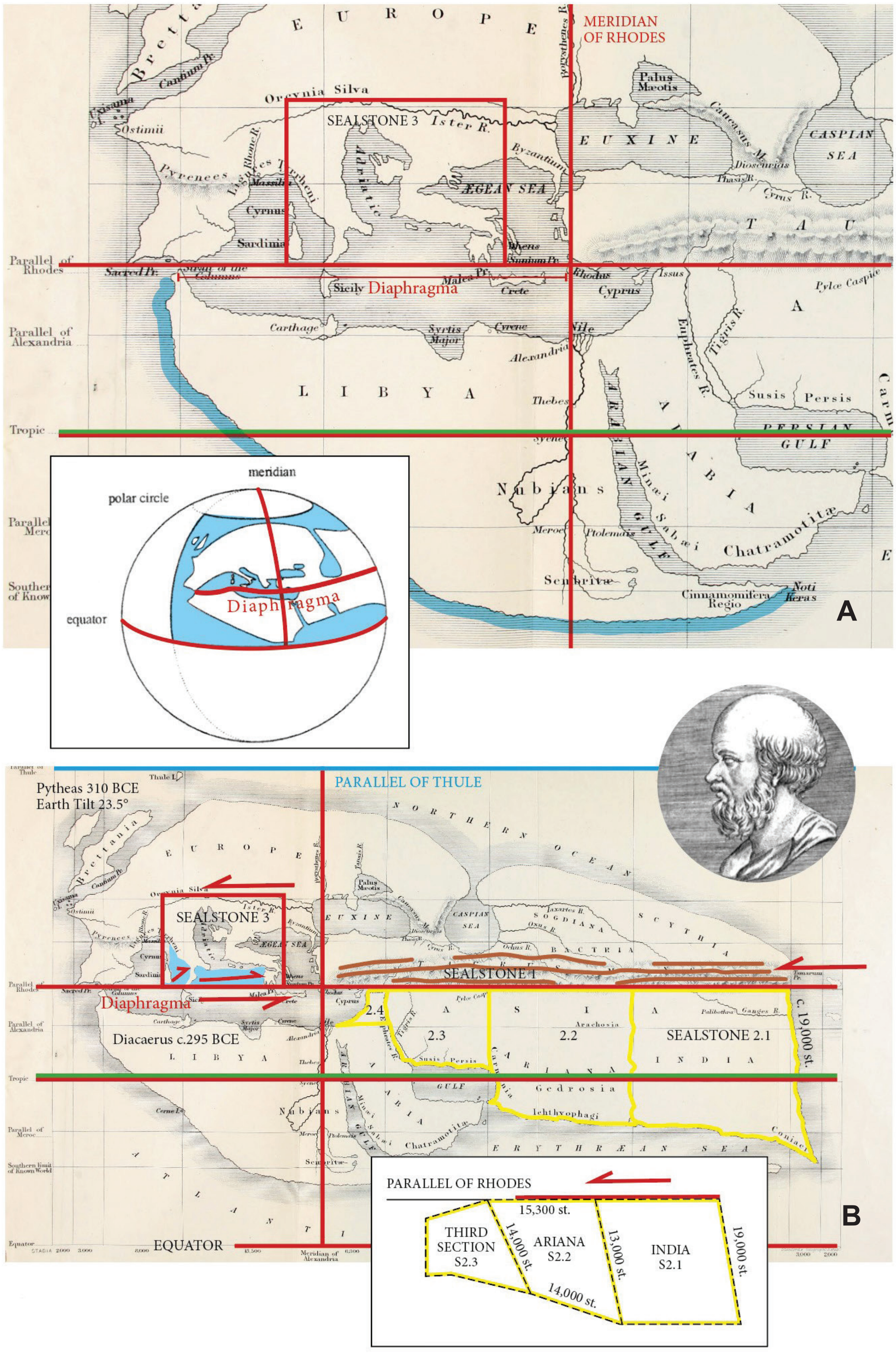


FIGURE 1 — Anaximander World Map (Open licence from *World History Encyclopedia*. https://www.worldhistory.org/image/18224/anaximander-world-map/).


MERIDIAN
OF RHODES
E U R O P E
SEALSTONE 3
Ister R.
Adriatic
ÆGEAN SEA
E U X I N E
CASPIAN
SEA
Palus
Mæotis
Parallel of
Rhodes
Sacred Pr.
Sicily
Diaphragma
Crete
Cyprus
Rhodus
Parallel of
Alexandria
Carthage
Syrtis
Major
Cyrene
Nile
Alexandria
L I B Y A
Thebes
Tropic
P E R S I A N
G U L F
A R A B I A
Nubians
Chatramotitæ
Cinnamomifera
Regio
Noti
Keras
A
meridian
polar circle
equator
Diaphragma
Pytheas 310 BCE
Earth Tilt 23.5°
PARALLEL OF THULE
N O R T H E R N O C E A N
SEALSTONE 3
SEALSTONE 1
Diaphragma
Diacaerus c.295 BCE
2.4
2.3
2.2
SEALSTONE 2.1
c. 19,000 st.
I N D I A
Gedrosia
Ichthyophagi
E R Y T H R Æ A N S E A
EQUATOR
PARALLEL OF RHODES
15,300 st.
THIRD
SECTION
S2.3
14,000 st.
ARIANA
S2.2
13,000 st.
INDIA
S2.1
19,000 st.
14,000 st.
B

The Phoenicians were an amalgamation of two cities in the present Lebanon–Israel area c.1200 BCE and were noted for supplying cedar logs for shipbuilding around the Mediterranean resulting in the settlement of Carthage (Tunisia, fig. 2A, lower, centre, left) in 814 BCE. They probably had papyrus shoreline and city maps since they knew the significance of the Pole Star for navigation; however, no maps have been found. During this period, tin was arriving, probably into Carthage from the North Atlantic east coast and, likewise, gold from camel trains via north-central Africa and Cerne on coastal northwest Africa (fig. 2B, lower left).

Homer (800–c.746 BCE) probably used a map expanding from the Aegean Sea as the setting of his poems which famously focussed on the ten-year Trojan wars of 1183 BCE (based on Eratosthenes' calculation). The location of Troy on the Meridian of Rhodes (fig. 2A) is now an archaeological site but no maps have been recovered. As early as 1800 BCE the Mycenean Greeks of Athens and of the Peloponnese were trading with the Minoans of Crete adjacent to the south, who were sailing by night using the direction of setting star constellations to trade with Alexandria at the mouth of the Nile. The Minoan pilots were thought to carry the sequence of the setting constellations in their minds, effectively a 'map' of the direction to Crete 4,000 years ago.

From 332–320 BCE, Anaximander's Oikumene grew predominantly eastwards from the Phasis River to India (from fig. 2A to fig. 2B) due to the conquests of Alexander the Great. In 310 BC, Pytheas left Marseilles to better define the northern sector of the Oikumene. He circumnavigated Britain and on to Thule (Iceland, fig. 2B, top left) or, more likely, the Lofoten Islands of Norway. In both instances, at the winter equinox the sun was not visible. Pytheas was at the now Polar Circle and had measured the 23–24° Earth tilt of the geographic North Pole axis (fig. 2B, top left). Fifteen years later another Greek scholar, Dicaearchus (c.295 BCE), drew a straight, west-east line, from the Straits of the Columns (Gibraltar or Pillars of Hercules), east 'below' the volcano- and earthquake-prone Italian toe and Sicily, and on to Rhodes where the Colossus had been toppled by an earthquake five years after the birth of Archimedes and four years before Eratosthenes. Dicaearchus called the line the 'major parallel' or the Diaphragma (shown by the red horizontal line on fig. 2A and 2B, centre). He then aligned a perpendicular or north-south 'meridian' through Rhodes.

About 240 BCE Eratosthenes extended that perpendicular south through Alexandria, sub-parallel with the Nile River to Syene, a distance of 5,000 stadia (c.800 km). He realised that at Syene on or about 21 June the sun would be directly overhead and, if he was in Alexandria looking down a well or at the shadow of a vertical pole, the Earth was spherical if the pole, or the well, cast a shadow to the north and if they didn't, then the Earth was flat. A shadow of 7.2° was cast which is 1/50th of a 360° Earth with a circumference of 250,000 stadia also with a radius very close to 40,000 km, which we use today**.** He projected his full map onto his new spherical earth (fig. 2A, inset), an historic mapping triumph. His map shows the spread of his parallels and meridians to form a rectangular grid of east-west latitudes and north-south longitudes, now referred to as a 'Mercator' rather than an Eratosthenean map projection**.**

Eratosthenes 'sealstone' mapping (c.240–220 BCE)

Eratosthenes extended the geologically active Diaphragma along the southern edge of the three rows of mountain symbols of high Taurus to the Himalayan Mountains, as a single geologic/geographic unit he termed 'Sealstone 1', possibly implying some legal or trading notion to the rock (fig. 2A and 2B, east). He showed India as a rhomboid or an east-west, left-sheared square and called it 'Sealstone 2.1'. Ariana as 'Sealstone 2.2' is possibly more similarly displayed by having an approximate side-length of the order of 14,000 stadia on a skewed square. The overall point was that the topography of 'Sealstone 2.4', which reached Alexandria on the Mediterranean Sea, was less than 2.3, less than 2.2 (and less in height than Sealstone 2.1, and Sealstone 1) emphasising gradations of vertical uplift. Strabo was also impressed with this because he lived in western Türkiye and had attributed the seashells in the rocks of Sealstone 1 to uplift of a previous sea (indeed from the shorelines of the Tethys Ocean to the Taurus Mountains, to the Himalayas).

The third 'Sealstone 3', the promontories of Italy, Liguria (Corsica/Sardinia) and the Peloponnese of Greece within the red rectangular boundary in the central Mediterranean (fig. 2A and 2B), indicate Eratosthenes was more interested in this sealstone in the plan view of the widening blue areas of the opening Tyrrhenian and Adriatic seas, than of vertical uplift of Sealstones 1 and 2. Posidonus (135–51 BCE) plumbed the Tyrrhenian Sea by dropline and found it was far deeper 'than any other' (in the northern Mediterranean): in excess of 12 stadia or 2 km deep – actually 4 km today.

Comments on Eratosthenes' promontory work, reported principally by Hipparchus (c.190–c.120 BCE) and derived by Strabo (64/63 BCE–24CE) between 18 and 7 BCE were then translated by McPhail (2011). Eratosthenes had correctly deduced that stretching had caused sinking of 12 stadia and the Tyrrhenian area to extend by 1,200 stadia (or 200 km) from southern Sardinia to the 'ankle' of Italy which had rotated Italy eastwards relative to Corsica/Sardinia**.** Hipparchus also reported the Peloponnese had separated east from the 'instep' of Italy shown by the longer

FIGURE 2 — Nineteenth-century reconstruction of Eratosthenes' map of the known world c.240–220 BC (from Bunbury 1883). **A** Western half of map, inset (after McPhail 2011, fig. 3.2): Zimmerman's reconstruction of Eratosthenes Oikumene framed by the quadrilateral (fig. 2B) and projected onto the three-dimensional surface of the spherical earth; **B** the full Bunbury map of Eratosthenes, top inset: etching of an ancient seal identified as Eratosthenes; bottom inset (after McPhail 2011, fig. 4.3): showing a schematic, geometric representation of India, Ariana sealstones and the third sealstone.

half-arrowhead from the Peloponnese, about 6,000 stadia (1,000 km larger than the 'known distance' of Alexandria to Syene); in total, some 1,200 km of westward movement along the northern side of the Diaphragma, relative to no movement on the southern side.

MacPhail did not mention the word 'rotation' of Italy from Liguria. However, Eratosthenes would have realised two moving blocks could only move parallel with each other along the Equator or a great circle of a sphere; moving towards either pole or in other directions would cause them to rotate about a pole, as in the fixed point of a drawing compass. Both the Tyrrhenian and Adriatic seas open and widen in a 'V-shaped' manner from north to south indicating a pole of rotation at the north head of their respective seas and imposing shears shown by the half-arrowheads along the Diaphragma fault. When Eratosthenes projected his map onto the sphere in the figure 2A inset, he probably recognised the curved form of the 'prime meridian' through Rhodes. And so may have Claudius Ptolemy (90–168 CE), the Greco-Roman of conic-mapping projection fame, also working at the Library at Alexandria, c.150 CE.

In the failing days of the Roman Empire, Macrobius (active from 399–c.450 CE) showed five horizontal 'Diaphragmas' or shears on his globe, apparently coinciding with northern and southern tropical and polar circle latitudes and the Equator (fig. 3), suggesting he extended the function of the Eratosthenes Diaphragma from a sheared and later compressed seaway to the dual role of horizontal, climatic-boundary seas which drained to the encircling ocean. The red Diaphragma in figure 3 was north of the green parallel of longitude between the Tempurata Nostra and the Perusta (Tropics). Hiatt (2007) said there were an estimated 150 versions similar to figure 3 before 1100 CE, many stemming from German monasteries, like the figure 3 sketch (c.1000 CE). The influence of Eratosthenes' sealstone method spanned 14 centuries until 1154 CE when a Chinese ship was sighted off Morocco, indicating spice and silk trade shipping west from the Indian Ocean may not have rounded southern Africa's Cape Town until then, and, more likely, had crossed from northeast Africa across the Sahara to the Mediterranean coast prior to that date via camel trains. By 1487 Diaz, the Portuguese mariner and explorer, provided competition from the Portuguese by reversing the shipping direction from the Atlantic to Indian oceans.

The Conclusions from McPhail's (2011) study of Eratosthenes include:

> *…the fragments of Eratosthenes' Geography, despite constituting only a small portion of the total work (three volumes), are predominantly cartographic in nature, conveying a good spread and depth of information regarding how the Oikumene should be drawn.'* (p. 171).
>
> *Scholars have frequently expounded that Eratosthenes was one of the first and foremost proponents of scientific cartography. Earlier maps were often ethnologically driven, communicating a Hellenistic worldview in which the Greeks in the centre of the map were juxtaposed against the barbarian peoples of the periphery. By way of contrast, Eratosthene's parallels, meridians…and other cartographic systems are believed to have engendered a far more systematic and objective image of the world. (*p. 171)
>
> *Pytheas, c.310 BCE voyage throughout northern and western Europe was so unique and influential that it would not be far off the mark to assert that Eratosthenes' knowledge of this region was driven almost entirely from On the Ocean… surveyed the Atlantic coastline as far north as the land of Thule… His observations of celestial phenomena in these regions shaped his depiction of parallels of latitude north of Massalia (Marseilles).* (pp. 173–174)

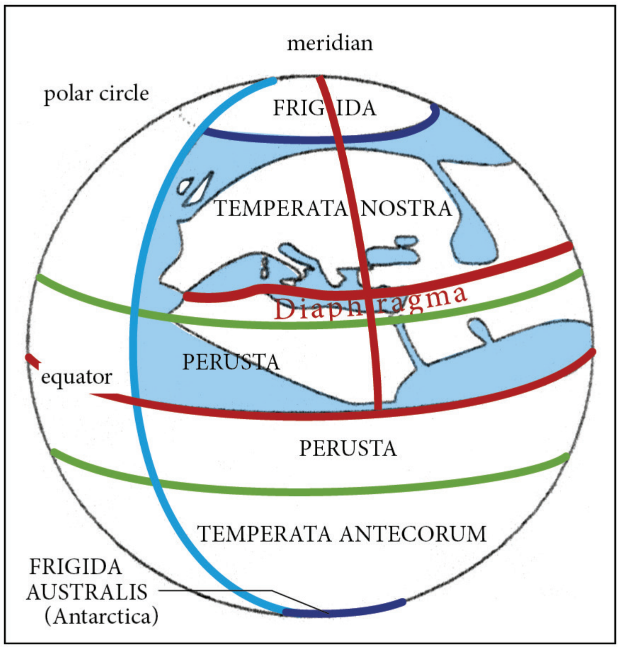


FIGURE 3 — After McPhail (2011, fig. 3.2): 'Zimmerman's reconstruction of Eratosthenes Oikumene framed by the quadrilateral and projected onto the three-dimensional surface of the spherical Earth' overlain by the author's sketch of climatic 'diaphragmas' from Hiatt (2007, p. 152).

Only a decade earlier, Alexander the Great's 'bematists or 'footsteppers' (specialists who measured distances by pacing) had combined on the ground measurement of distances with celestial readings. Pytheas is the earliest method of celestial coordinate gathering of shorelines that did not become prominent again until 1487, over 1.5 millennia later.

ORTELIUS (1527–1598 CE) CARTOGRAPHY OF CONTINENTAL DRIFT, 1596 CE

Trading-related sea battles increased, and shoreline co-ordinate number pairs also grew from 1487 to 1570 to meet the growing demand for Antwerp-based shore/coastline mapping. In 1569, Mercator published his famous rectangular grid of lines of latitude and longitudes. This meant his map began losing its area/distance-preserving qualities at about 23.5° north, like Eratosthenes' map: the spherical globe to flat surface map challenge. Abraham Ortelius (fig. 4B), a commercial Antwerp cartographer, had accumulated many shoreline co-ordinates and published his map of the world in 1570 (fig. 4A) along with several others in the first world atlas.

Increased higher latitude-sailing required Ortelius to apply some Earth spherical curvature to his grid so he decreased the parallel or latitudinal length gradually from the Equator to about 60% of that at the poles (fig. 4B). His map looked like an elliptical racetrack rather than a rectangle and was a more multi-purpose map, which probably increased sales. He also regularly revised and updated his atlas with copies sold in Antwerp and London and probably elsewhere. In his reconstruction, Brazil fitted poorly into the Gulf of Guinea; however, the southwest and northwest African shoreline trends (fig. 4C) fitted well with their South American equivalents (fig. 4C) and the northwest African shoreline with that of the eastern USA. Ortelius' fit of Ireland/Britain against southern Greenland was impressive without the intervening Iceland, and Spain did not fit against Labrador. The northwest of Norway and East Greenland fit, given sparse co-ordinate data near the Atlantic pole of rotation, was surprisingly good; however, he could only make his map lie on a flat table if he chose a west-east Europe-Asia/Africa boundary and made a cut along it, from the coast of northern Africa/Mediterranean and then guided his cut using his excellent drainage mapping to the Persian Gulf and then follow the shoreline east to the Pacific as in figure 4C. His cut opened a large, eastwards trending and widening, irregular 'V'-shaped gap.

The author has no evidence Ortelius made such a physical reconstruction, nor did he know he was essentially copying Eratosthenes by probably cutting along Dicaearchus' Diaphragma shear. Neither could he have known of Carey's twentieth-century Tethys gap, resulting from his 'V'-shaped cut. He had only two years to provide some evidence as he died just two years later in 1598. There was another method. His atlas also showed he had to remove Iceland from between the Greenland and Norway fit to be able to state in 1596: 'it was as if the Americas were torn apart from Africa/Europe'.

Ortelius included the scholar Gudbrandur Thorláksson's (1541–1627 CE) wonderfully detailed and illustrated 1585 map of the linear volcanoes and lava-fields of Iceland (figs 4D and 4E) in his atlas of 1595 (Ortelius & Vedel 1595). Since Viking settlement of Iceland in 870 CE (after 'Thule' of Pytheas 310 BCE), a complete record of active volcanoes has been maintained. Hekla (fig. 4D, inset) is a 5.5-km-long volcanic fracture volcano which is active along its length during major eruptions. Hekla is almost 1,500 m high, 100 km east of Reykjavik and has erupted more than 20 times between 1104 and 2000 CE, and Thorláksson may have seen it erupt as depicted on his map. Figure 4D shows the red dashed line of Reykjanes Ridge (now the onshore extensional, separating part of the Atlantic Ocean Ridge and its red dotted continuation to the north). The activity at the Hecla section in c.1585 therefore postdates the initial continental breakup in the area between Greenland and the Scottish Hebrides, which enabled Ortelius to leave Iceland out of his mental reconstruction of the North Atlantic when making his simple statement of 1596. It appears Ortelius knew over three centuries earlier than Carey, that the oceanic ridge was probably the then current focus of separation between the continents. His cartography also told him the numerous volcanic islands emanating from the expanse of the Atlantic's volcanic seafloor were sampling the Earth's molten interior. And Thorláksson's active, linear fracture volcanoes on the Reykjanes Ridge to Hecla were uniquely located approximately midway between the granitic continental crust of Greenland and the Scottish Hebrides. Clever deductions, as he worked diligently at his trade, had guided him.

SW CAREY (1911–2002) SPHERICAL MAPPING OF CONTINENTAL DRIFT, 1958

Samuel Warren Carey (1911–2002), Professor of Geology at the University of Tasmania from 1946 until 1976, was recognised internationally as a controversial expert in global tectonics. An early believer of continental drift, many of his ideas were formed during field work carried out in the (then) Territories of New Guinea and Papua (Carey 1938, 1954, 1955; Baillie 2021). Carey was unaware of the work of Ortelius and Eratosthenes. In the opening paragraph of his 1958 symposium paper, Carey paid tribute to Alfred Wegener's 1912–1929 work on continental drift: 'Wegener worked out the broad outlines of continental drift….. but my picture of the assembly does not differ greatly…. and others have improved on details, but apart from the dissociation of Pangaea into Laurasia and Gondwana [fig. 5C] … the fundamental picture is much as Wegener saw it.' (Carey 1958, p. 177).

The third cartographically accurate map, at the time of reconstruction, was made by Carey in 1958 (fig. 5). Carey (fig. 5A) used two spherical methods. In the first he formed plastic sheets over a 30-inch (75-cm) globe (fig. 5B), and in the second he made stereographic projections (figs 5D, 5E) of the 'land hemisphere'. In both methods he matched opposing shelf edges, the 200 m isobath (fig. 5D) generally somewhat further seaward than the shorelines of Ortelius, and at the 2,000 m isobath if available (fig. 5E) closer to the actual break-zone of continental separation. These and other continental outlines were fitted to South America/Africa to form a complete jigsaw puzzle (fig. 5C). The unshown hemisphere (or reverse) was the Pacific Ocean. Apart from the South Pole and the resulting Arctic and Tropical circles, the flat plan, stereographic projection surface was lacking a cover 'picture' of a regional geologic map to confirm geology across adjacent pieces of the jigsaw puzzle reassembly (fig. 5C). The direct tracing fit at the shelf edge left a gap (fig. 5B) between southern South America and Africa which was comparable to the yellow area on the stereographic projection (fig. 5D), and likewise smaller yellow area to the northwest match, but both represented considerable advances over Ortelius and intervening sketches, such as those of Wegener.


TYPVS ORBIS TERRARVM
TERRA AVSTRALIS NONDVM COGNITA
QVID EI POTEST VIDERI MAGNVM IN REBVS HVMANIS, CVI AETERNITAS OMNIS, TOTIVSQVE MVNDI NOTA SIT MAGNITVDO. CICERO:
A
B
C
ISLANDIA
D
Sand Iokul.
Arnafelds Iokul.
Getlands Iokul.
Skialbred.
Kluka.
Hekla
SKALHOLT
Mydals Iokul.
Porlarks haffn
AVLVOS
E

As expected, the same South America/Africa match at the 2,000 m isobath (fig. 5E) was close to perfect and constituted the ultimate proof of continental drift; only the sediments of the post-drift Nile delta falsely infringed.

The cumulative reconstruction of the modern seven continents and smaller blocks left two large areas or 'gaps' (or yellow areas), the large TETHYS and smaller ARCTIC oceans in figure 5C indicating to Carey they were real and were either true oceans at the time of reconstruction on the present radius Earth or the Earth had expanded appreciably during the drift phase to the present. Carey devoted the last 11 pages of his symposium paper (Carey 1958, pp. 339–349) to explaining his reasoning for expansion, an endeavour which he pursued up to his death in 2002. More recent data are supportive of elements of his stance and will be considered in a forthcoming paper.

Carey (1955) wrote that one clear result of the orocline analysis is the recognition of the Tethyan Shear System (fig. 6A). What did he mean by an orocline? Many would have recognised folded rocks in vertical road cuttings, maybe metres in dimensions. These are generally formed by 'local' compression. However, Carey was interested in the very large folds in the horizontal surface plane, like folded mountain ranges, best appreciated from high above. Often, they involve a shearing component and can have dimensions of a thousand or more kilometres, indicating a globe-encircling deformation, a geologically distinctive feature, an ideal jigsaw picture on all continents it covered.

Figure 6A shows the deformational bends of folded mountain belts and anticlockwise rotated blocks, consistent with left-shear-offsets, shown in red. He described those offsets during the symposium in 1956: 'South America has been moved 1,000 km east with respect to North America. Africa has been moved east some 1,100 km with respect to Europe. Australia has been moved more than 3,000 km with respect to Indo-China' (Carey 1958, p. 340) (and a further 5,000 km with respect to Tonga/New Zealand). Effectively the Tethyan Shear was an east-west roller bearing between the two hemispheres, the Northern 'Laurasia' lagging the Southern 'Gondwana', which was relatively advancing.

The Mediterranean oroclines were geologically illustrated best exactly where Eratosthenes may have noticed their topographic expression, in the western Mediterranean (fig. 6B). Carey combined rock-type description from legends of the component, regional European geologic maps and constructed a 'relative timing of events', grey and black, oldest (pre-drift, industrial revolution coals of northern Europe), through pink, purple and blue, the Tethys and drift margin rocks, and the author moved the orange unit from the middle to the top of the section (youngest compression and sheared oroclines – see fig. 6B, right). Carey then 'unwound' or unfolded and essentially straightened to the recent pre-orange shape and removed the above 1,000–8,000 km of Tethyan Shear (fig. 6C). The folded core of some oroclines, such as the Ligurian Orocline in northwest Italy, can almost coincide with Poles of Rotation at centre left of figure 6B, which can be derived from Eratosthenes – that is, the northern Tyrrhenian and Adriatic seas opening. Both orocline and pole were probably created in environments of regional force acting on rocks with greater ability to flow or break (Carey 1954).

The explanation of the formation of the Tethyan Shear became the cornerstone of what was known as Carey's 'New Global Tectonics' (tectonics in Greek means 'building') in 1960 and by 1970 was altered to what we now call 'Plate Tectonics'.

Carey at Yale 1959–1960

There was very little headway with the science of continental drift in the nineteenth century. So little in fact that Allan Krill (2011) presented an essay on mid-nineteenth–early twentieth-century geologists as a contest between those against continental drift (i.e., 'Fixists') versus those for continental drift (i.e., 'Mobilists') as if it was a boxing match, and this makes very entertaining reading. Then Krill discovered SW Carey which caused him to add Carey in Chapter 10 in his revised book (Krill 2014, p. 252), in part as follows:

'10. From Continental Drift to Plate Tectonics

S Warren Carey's wake-up call to North American geologists (1959–1960)

After Chester Longwell retired as Professor of Geology at Yale and moved to California in 1955, the remaining professors at Yale University were less negative towards continental drift. Yale then made a curious contribution to the transition from continental drift to plate tectonics. In his autobiography, John Rodgers related how this came about:

> *'Sam Carey warrants a digression. He was a very innovative geologist, a maverick indeed and consciously so, with some very good ideas and others that most of the rest of us considered crazy. When I took my first sabbatical year (1959–1960) to go to Europe, Yale therefore had my salary to appoint a Visiting Professor. After careful consideration and consultation, and largely on the basis of a very innovative early article of his, we invited Professor Carey. Moreover, he made trips all over the United States and Canada, lecturing everywhere in his inimitable now-you-see-it-now-you-don't style (he had put himself through college by working as a magician) and North American geology has never been the same since. For he ended, once and for all, the condescending dismissal of the idea of Continental Drift that had characterized North American geologists. He also helped to lay the foundation for the theory of plate tectonics, "the new global tectonics" as it was called at the time, which revolutionized tectonic thinking during the 1960s. About 1955 Carey apparently*

FIGURE 4 — **A** Map from Ortelius *et al.* (1570); **B** Engraving of Ortelius open source from Wikipedia; **C** Reconstruction of Ortelius' map undertaken by the author; **D** Map of Iceland by Thorláksson, red dotted line showing the on-shore mid-Atlantic Ridge; **E** Close up of Thorláksson's map showing the Hecla volcanic fracture, red indicates lava.

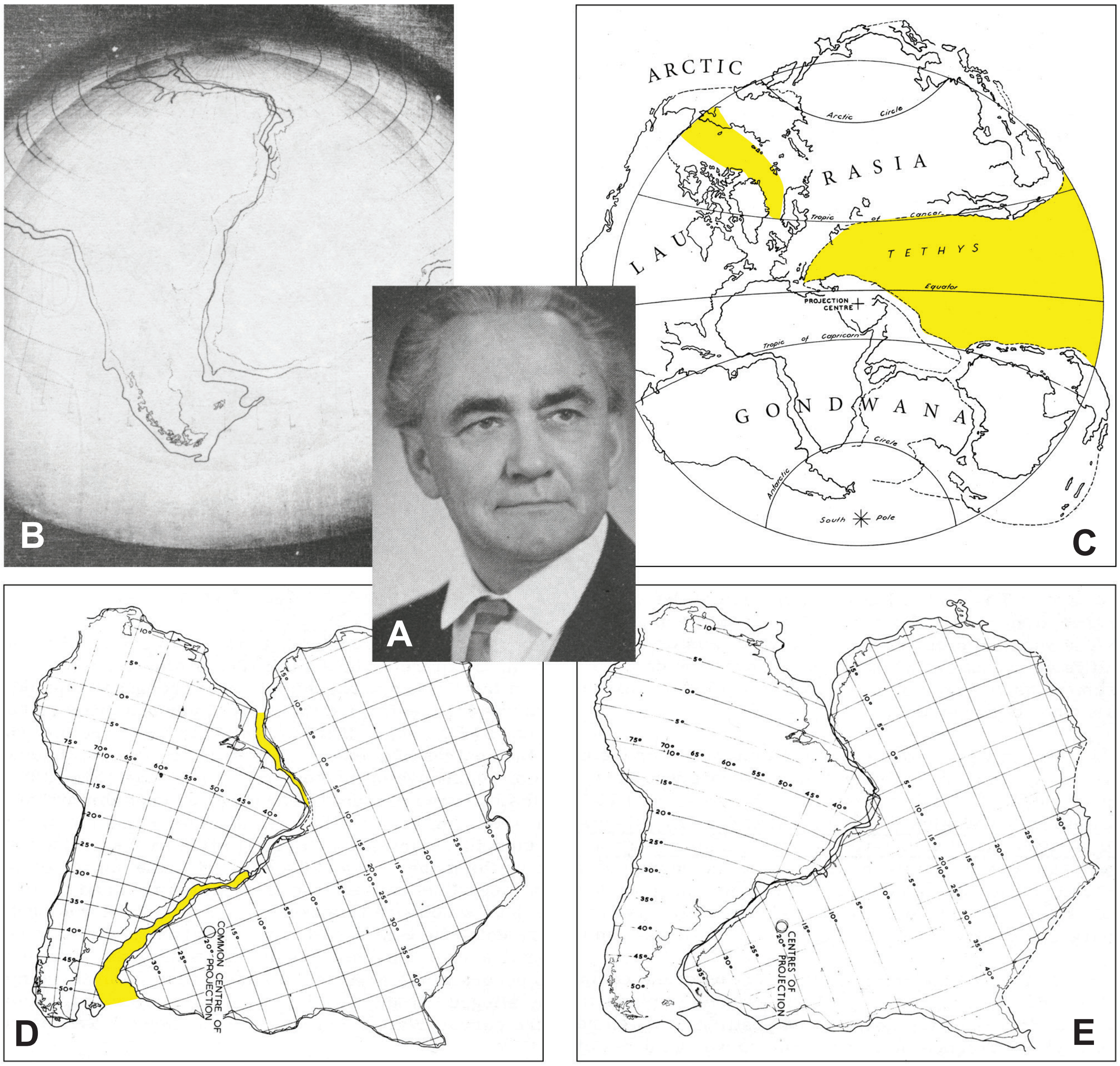


FIGURE 5 — Carey's reconstruction of continental drift. **A** SW Carey aged 65 (from Carey 1976); **B** Plastic sheet formed over a 30-inch globe; **C** Dissociation of Pangaea into Laurasia and Gondwana, yellow shows the Tethyan and Arctic gaps; **D** Stereographic projection at 200 m of continental edges, yellow shows gap; **E** Stereographic projections at 2,000 m edge showing almost perfect fit.

anticipated the new global tectonics in a manuscript that was rejected for publication as too speculative; I haven't seen it, but I'm told that it included both the creation of new crust at the mid-ocean ridges, forming the oceans, and its destruction or at least swallowing at belts of compression, where new mountain ranges are built. But curiously, in later years he reneged on the latter and recognized only the creation of new crust, and he became a strong advocate of the theory of an expanding Earth, going so far as to claim that its radius has about doubled in the last five hundred million years, implying of course that its volume has nearly octupled and therefore that its density then was nearly eight times what it is at present. It is this aspect of the theory that makes most of us unwilling to accept it, preferring to balance the creation of new crust, on which we agree with Carey, by the destruction of old crust, on which we disagree.

In any case, the best thing that I ever did for North American geology was to go away for a year, so that Carey could spend the year here.' (Rodgers 2001, pp. 194–195)

Carey's early adopters, 1972

The author joined Esso in 1970 and in 1972 Carey and I attended the first continental drift conference at Princeton, the first since 1956. Carey was re-acquainted with Lewis Weeks who in 1959 had advised the Broken Hill Proprietary Company to apply for oil exploration and production rights to the Gippsland Basin region, southeast Australia. Weeks confirmed Carey's Gippsland Basin structural predictions

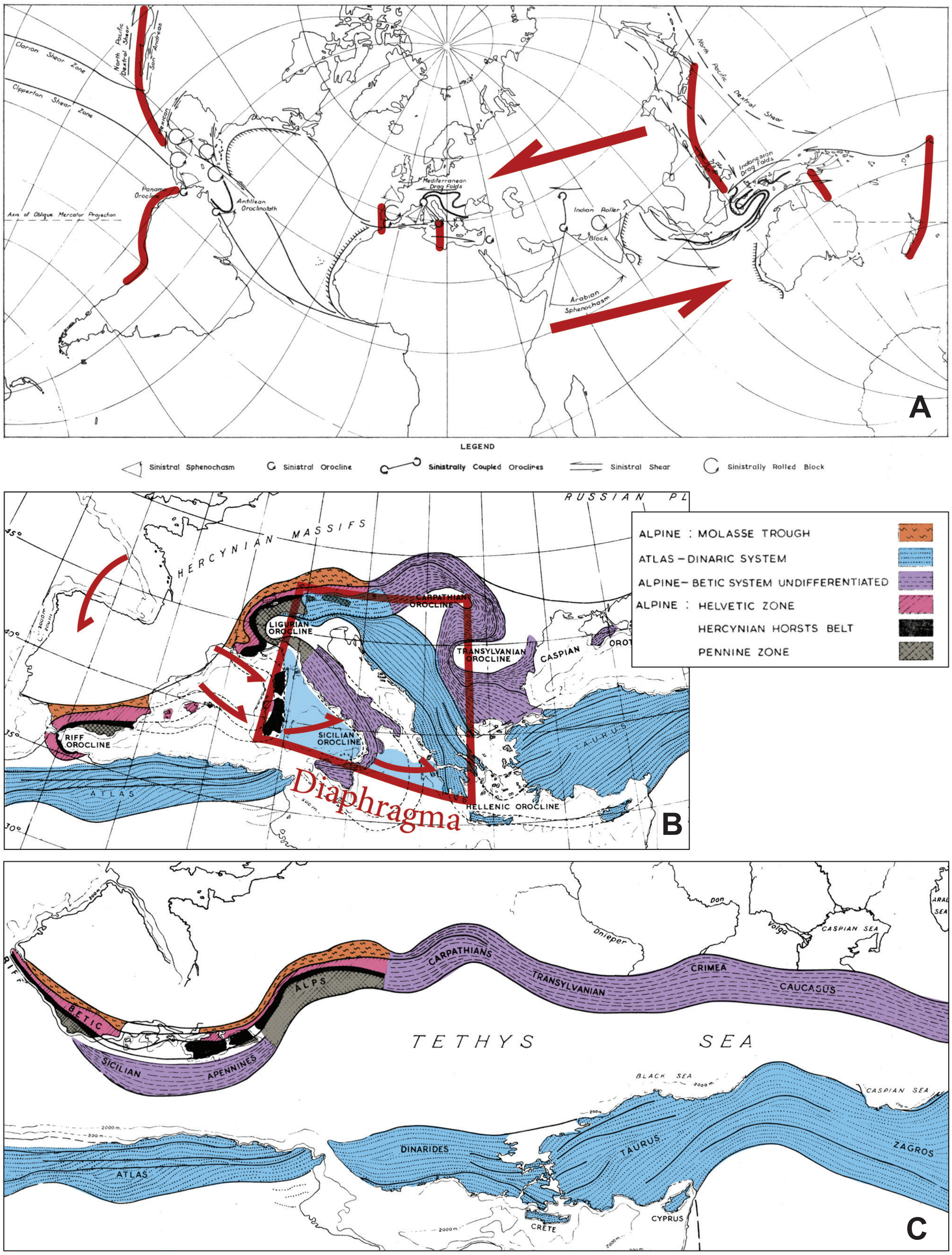


FIGURE 6 — Map of oroclines as described by Carey (1955). **A** Location of Tethyan Shear with arrows showing relative movement (Carey 1958, p.252); **B** Close-up showing oroclines at the bend at northwest Italy, legend gives geologic age, oldest at bottom (Carey 1958, p. 252);; **C** Straightening of folds in 6B to show the pre-Tethyan Shear (Carey 1958, p.253).

made in a sketch at Weeks' Connecticut home in 1959. Presumably Carey left the map with him. Three years after, the Gippsland, Bass and Otway basins acreage had been signed and the acreage granted by the government. Carey had a sense of being left out as Weeks gained a gross overriding royalty from the deal. Carey redrew that map (fig. 7) and presented it at the ANZAAS Conference in Sydney, 1963. The regional right laterally sheared offset is shown diagrammatically in the lower left of figure 7 and by the 100 km offset of offshore Gippsland Basin bathymetry with that of East Tasmania. Carey predicted the unknown offshore extension of the basin to contain northeasterly-trending anticlinal structures like '11 and 14' onshore. Weeks was aware of the minor oil production from the onshore during WWII. The offshore anticlines were confirmed by seismic data and successful drilling and significant commercial oil and gas fields were in fact discovered from 1965. The redrawn map was given to me and lies in a pink colour on silk (fig. 7). The same map by Carey (1986) was published in the technical papers from the Second South-eastern Australia, Oil Exploration Symposium. Weeks had retired as Esso's chief geologist and was the earliest Carey adopter apart from Rogers. In 1972 at Princeton**,** Weeks led a standing ovation for Carey joined by other oil company explorers whom Carey had met in 1959–1960.

DISCUSSION

Sealstone versus orocline

Eratosthenes used the 'sealstone' for differentiating the height and distribution of mountains to establish vertical movement of rocks as an indicator of uplift (by push or compression) and he used bathymetry as a measure of the sinking of the Tyrrhenian Sea to establish horizontal movement of pull or extension. He effectively recognised the Diaphragma as a side-by-side movement with Sardinia/Italy/Greece (the Peloponnese), a separation zone on the northern side and no evidence for separation on the southern. Over two millennia later Carey used the same push and pull indicators of force (or stresses) and the Diaphragma, identical, side-by-side, movement or shear which can incorporate both push and pull; very similar methods and very similar results for the status of data at the time.

These notions of force are applicable today at the scale of continents, as Sealstone 1 was applied to the Taurus and Himalayan Mountain ranges. The sealstone method was used at the sub-continent level as a single unit of India, equal to Sealstone 2. Likewise, the Liguria/Italy/Peloponnese areas were moving sub-units covered by Sealstone 3. The Ancient Greeks used sealstones to describe the subdivision of the continents in their smaller Oikumene; we now call the same method continental drift, now we know their number, and I call Eratosthenes the first regional geologist. Ortelius' studies of Iceland, plus his accurate cartography drove him in the same direction of continental movements on his modern globe in 1596, as Carey did in 1956 (Carey 1958). Ortelius was the second regional geologist.

Geologic time

This paper has been written in chronological order to frame historic events in a logical time sequence; oldest event first and youngest last. Complicated geologic time terms to indicate relative 'ages' are unnecessary because it is still chronological, oldest rocks at the bottom of the pile and youngest at the top (unless they have been overturned.) By placing the youngest orange Mollasse (spelt 'Molasse') at the top of the legend in figure 6b, the simple stacking system of events works because the rocks were not overturned, except in local areas. However, the term Mollasse can be confusing; it refers to the coarse conglomerates deposited in front of rapidly rising and eroding mountains, a term used by Swiss geologists, not to be confused with molasses, a syrupy by-product of sugar! Geology is plagued by 'in-house terminology', yet continental drift is the over-arching natural evolution of the Earth and related, interested people should not be excluded. The colours in figure 6 appear on several geological time scales and on the legend of the UNESCO Geological Map of the World (Choubert *et al.* 1976), but are rarely used on American, British and Australian government survey maps; they want to be different while the author is trying to bring understanding of continental drift to any interested person.

Trading, shipping and mapping

Evolution of mapping was driven by, and for, shipping of spices then silk in the Indian Ocean by Mesopotamian and Persian Gulf nations in the northwestern Indian Ocean from 2400 BCE–1154 CE and by the Austronesians in Southeast Asia from Taiwan to Madagascar from c.1500 BCE–1154 CE. The reverse direction from the Atlantic by European countries eastwards via the Cape of Good Hope to the Indian Ocean from 1487 CE required finding better ways to define the shorelines or coastlines from which students of continental drift, amongst many others, can benefit.

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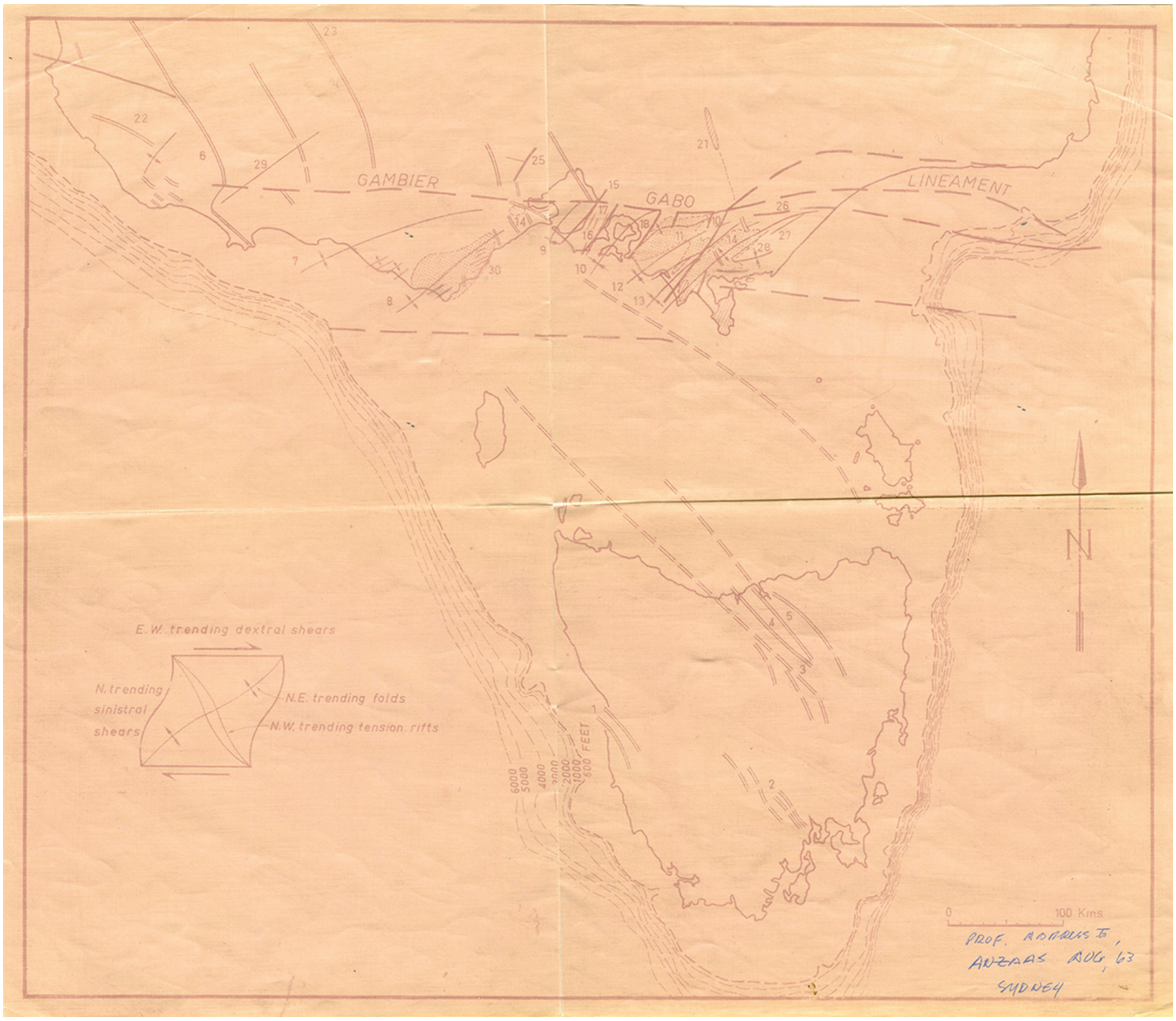

FIGURE 7 — Carey's original map he made for Lewis G Weeks in Connecticut in 1959 and presented at the ANZAAS Conference in Sydney in 1963 and subsequently given to the author in 1999. Carey published the same map in Carey (1986).

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