# Towards Net Zero

## Exploring the Role of Transport & the Built Environment

Dr Michael J de Smith

2022 Edition

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This 2022 edition is an update prepared in the light of the latest global data on climate change, the recent COP26 climate change conference, and the enormous impacts of the Covid19 pandemic.

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Dedicated to the memory of two eminent Cambridge academics:

*Professor Stanley A de Smith (1923-1974) – Constitutional and Administrative Law*

*Professor David J C MacKay (1967-2016) – Physics and Engineering*

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*"I saw for the first time the Earth's shape. I could easily see the shores of continents, islands, great rivers, folds of the terrain, large bodies of water. The horizon is dark blue, smoothly turning to black… the feelings which filled me I can express with one word — joy."*

*Yuri A. Gagarin, First manned space flight, April 1961*

*Cover image: © NASA (2002)*

# Acknowledgements

My thanks go to all those who have kindly read and commented on this book, and in some instances contributed pertinent images and quotes that support the text. Amongst these I must particularly thank my sister Jane Hiett; my colleague and collaborator on previous publications, Professor Paul Longley of University College London; my friend, the erudite Martin Owen; and finally, the journalist Karen Earnshaw - she is from the Marshall Islands community in the mid-Pacific and kindly assisted with materials relating to that region that are covered in the final sections of this book.

A further group of individuals to whom I owe a huge debt are my family. Travelling to Australia by sea as a child had a profound influence on my future interest in all matters geographical. There is nothing to compare with travelling to far-off lands as a child or young person. Having the opportunity to spend time with other cultures, places, people, and the landscapes of distant countries is an invaluable educational experience. So, for this "unexpected" opportunity I owe thanks to the foresight of my parents.

My father also encouraged an interest in maps and map making, and in philately. Although a marginal hobby in todays' high-tech world, the recording of events through the transmission of items of mail, in particular airmail, provides both an important part of our collective history and a unique record of momentous events and achievements.

Last but not least, I would like to thank my wife, Christine, who has not only read and advised extensively on this book, but has also tramped around many locations with me as I researched the varying aspects of this work.

Any remaining errors or omissions in the text are solely the responsibility of the author.

Michael J de Smith, PhD, FRGS, FSS
St Andrews, Scotland

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# Introduction

This book examines the past, present and future of two of the major contributors to energy consumption and global greenhouse gas emissions: transport and the built environment.

The text has been arranged into two distinct but closely related "Books", each of which is preceded by Timeline diagrams:

Book One is sub-titled "A Geospatial and Historical Perspective: How Did We Get Here?". This first Book commences with a review of mapping and map-making, how this relates to both our understanding of the World around us, and the need to find best-possible routes to reduce travel times and cost. This is then followed by an analysis of how these developments have impacted major innovations in transport and the built environment. As such it sets the scene for Book Two, which focuses on the resource usage and environmental impact of these two sectors.

The topics covered in Book One are wide-ranging: from early work on mapping the world, the land and its coastlines, to locating the best routes for transport, power and telecommunications links; and from the construction of airships and early aircraft, to the design of buildings and the exploits of pioneering aviators. The first section of Book One explains a little more about shortest paths, surfaces and how maps are produced (no mathematical expertise is required!).

The second section of Book One illustrates how some of these ideas have been applied in a range of structural engineering applications. These include applications to the design of airframes, bridges, buildings and transport infrastructure.

The third and final section of Book One takes to the air, and covers the early pioneers of heavier-than-air powered flight and the paths they took to reach their destinations within the times and parameters set by those offering large prizes for these "first flights". The most notable of these prize-winning flights took place just a century ago.

Book Two is sub-titled "An Economic and Environmental Perspective: Where are We Heading?". This second Book focuses on recent technological developments, possible solutions to some of the key environmental issues, and their likely impact over the coming decades.

In Book Two we consider what lessons from the past and present can be applied to a more sustainable future. In particular we investigate the progress towards the use electric vehicles for private and public transport and by the innovative use of hydrogen as a source of power. We also consider the potential impact of the digital economy on demand for products and services, and the possible substitution of physical communications with electronic and virtual communications.

The main sections of Book Two provide a commentary on the connections between past achievements, present-day systems and research, and future developments. Whilst technological developments provide the prospect of a more sustainable future, in the short to

medium term major changes in government policies and in individual behaviour are vital if the most extreme effects of climate change are to be avoided.

The final section of Book Two offers a series of initial conclusions on the prospects for achieving a Net Zero position, drawing upon the previous analysis and data. Whilst in Book Two we show that there are clear paths forward, even for the problematic sectors of transport and the built environment, current evidence and trends indicate that solving some of the problems in these areas has only limited prospect of success in the short- to medium-term. The stated target of restricting global mean temperatures to at most 1.5°C above pre-industrialisation levels, seems extremely unlikely to be achieved.

Book Two is followed by a series of short Supplements. These cover a range of topics that have a direct bearing on many aspects of the previous discussions. They include: two Case Studies - one on Microstates and the other on the Chinese "Belt and Road Initiative (BRI)", sometimes referred to as the New Silk Road project. These case studies are followed by notes on the work of the International Panel on Climate Change (the IPCC), in particular highlighting some of the most recent research and conclusions, including the results from the COP26 Climate Change conference in Glasgow 2021; we then provide a Timeline table providing a temporal summary of all that has been discussed; and finally, we include Biographical details of two key academics whose work has inspired the present study.

Many organisations around the world are actively researching the options for achieving the most recent internationally agreed targets of a maximum of 1.5°C mean global temperature increase by the middle of the 21st century. Most current research suggests that a mix of solutions in terms of technology and changes in practices and behaviour are required, but are unlikely to be achieved. The independent research group, the Energy and Climate Change Intelligence Unit, reflect this view, as they summarise in their discussion note 'Why Net Zero'[1]:

> *"In many sectors of the economy, technologies exist that can bring emissions to zero. In electricity, it can be done using renewable and nuclear generation. A transport system that runs on electricity or hydrogen, well-insulated homes and industrial processes based on electricity rather than gas can all help to bring sectoral emissions to absolute zero. However, in industries such as aviation the technological options are limited; in agriculture too, it is highly unlikely that emissions will be brought to zero. Therefore, some emissions from these sectors will likely remain; and in order to offset these, an equivalent amount of $CO_2$ will need to be taken out of the atmosphere – negative emissions. Thus, the target becomes 'net zero' for the economy as a whole. "*

Readers should be aware that "Towards Net Zero" has been written from the perspective of a Western academic, living and working in Scotland, at a cool 56° North. As such the work clearly has a particular flavour that reflects these origins, and may well differ significantly from

[1] Source: eciu.net Net Zero briefing, [retrieved June 2019]

those of people living in many other regions of the world with different experiences, concerns and priorities.

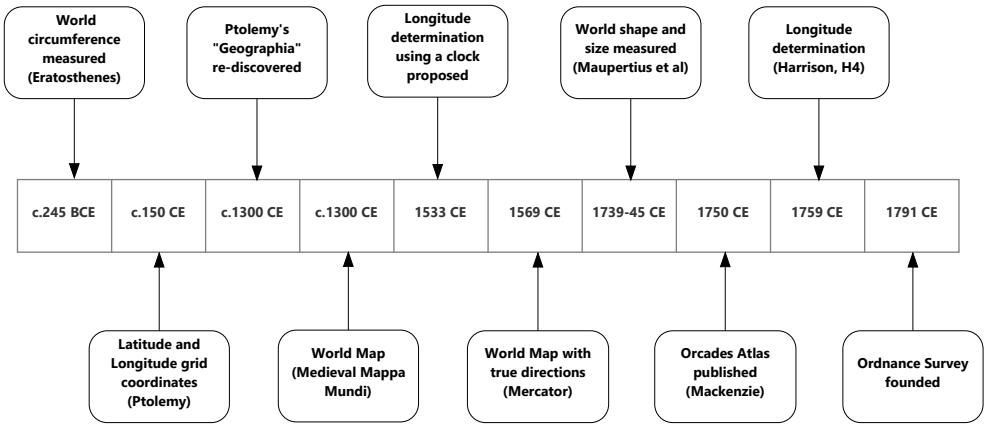
In this, the 2022 edition, much of the original 2019 data has been updated in the light of new information, the latest IPCC reports, the impacts of the global Covid19 pandemic, and the 2021 COP26 Climate Action conference held in Glasgow. The COP26 conference addressed many organizational, financial, and practical issues, but at the centre of the concerns were those summarized in the Mitigation section of the Glasgow Climate Pact published at the end of the session[2]:

> *"The Conference of the Parties (COP) … recognizes that limiting global warming to 1.5 °C requires rapid, deep and sustained reductions in global greenhouse gas emissions, including reducing global carbon dioxide emissions by 45 per cent by 2030 relative to the 2010 level and to net zero around mid-century, as well as deep reductions in other greenhouse gases; ... and Invites Parties to consider further actions to reduce by 2030 non-carbon dioxide greenhouse gas emissions, including methane;"*

[2] https://unfccc.int/sites/default/files/resource/cop26_auv_2f_cover_decision.pdf [Retrieved Nov 13th 2021]

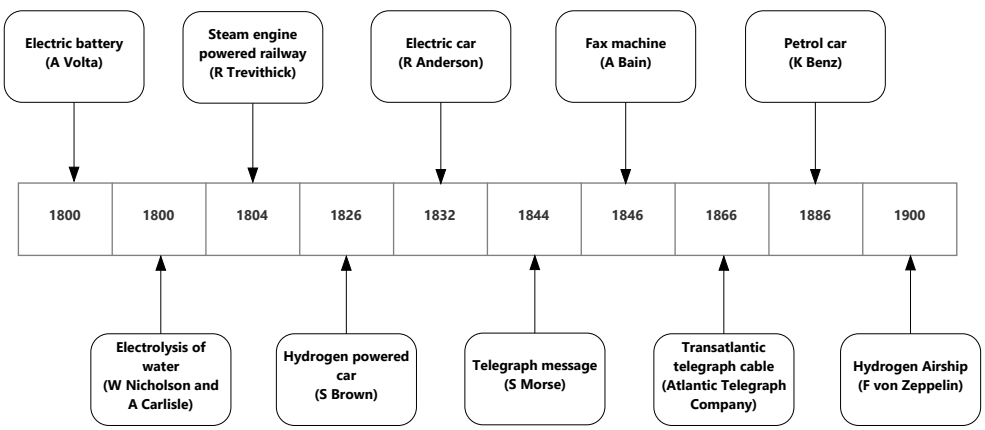
# Timelines: Book One

## Timeline 1: Mapping the World

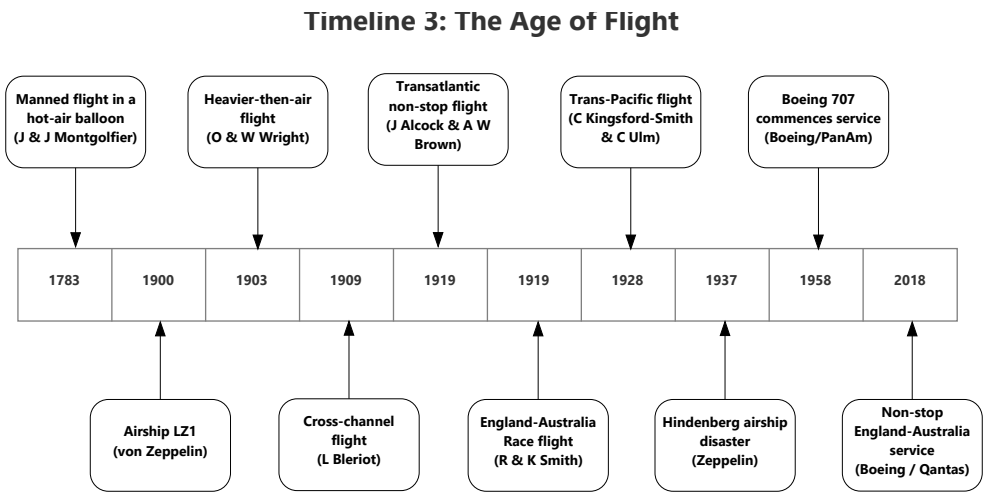



BCE: Before Current Era  CE: Current Era

## Timeline 2: 1800 to 1900 - Selected Key Inventions



# Timelines: Book One




Please see the Supplementary Materials section for more details

# Book One

## A Geospatial & Historical Perspective: How Did We Get Here?

# Maps, Lines and Surfaces

*World map, or Mappa Mundi, c.1300, Hereford Cathedral, England*

*Main map section of the largest medieval World Map to survive intact. It is drawn on calf skin (vellum) with Jerusalem as the centre, the Red Sea and Persian Gulf shown in red at the top right, the "Mare Medi Teranea" (Mediterranean) highlighted in dark brown. England, Scotland, Wales and Ireland are shown in the lower left* [3]

[3] https://www.themappamundi.co.uk/mappa-mundi/

*World map, or Mappamundi, c.1450, Bibliotech Estense, Modena.*

*This much later and more recognisable circular World Map shows the Mediterranean, parts of Europe and North Africa in some detail, the Red Sea again in red in the centre of the map, but other regions are 'speculative'. The network of lines is indicative of directions to/from key locations, notably Catalonia (hence this is known as a type of "Catalan" chart from the Catalan-Mallorca school)*[4]

[4] https://edl.beniculturali.it/beu/850013654

## Cartography, Baselines and Triangulation

The early World maps illustrated above are a long way from accurate representations of the shape and size of land areas, their coastlines and the seas and oceans known at the time. Their authors were also unaware of far better World maps dating from the Hellenic era and developed further by Islamic scholars centuries later. No World maps survive of this much earlier work of the Alexandrian geographers, Eratosthenes of Cyrene (c.297 BCE – c.195 BCE) and Claudius Ptolemy (c.100 CE – c.170 CE). However, even at this time these scholars had a world view based on a perfectly spherical Earth with Eratosthenes providing the first estimate of the circumference of the Earth (at approximately 28,600 miles or 46,100kms). This figure is remarkably close to the currently accepted mean value (24,880 miles or 40,040 kms).

Ptolemy built on the work of Eratosthenes and others to produce his eight volume "Geographia". Volume 1 explained his methods of cartography, introducing the idea of using a well-defined grid to locate the positions of known towns and geographical features such as mountains. Volumes 2 to 7 provided a gazetteer, listing locations known at the time with their estimated latitudes North of the Equator (based on the height of the sun at midday on mid-summer's day) and longitude, based on their position to the East of a nominal zero meridian that he placed in the Canary Islands. Volume 8 included a map of the known world and possibly many regional maps. Although no originals remain of Ptolemy's World Map, reconstructions from the 1400s onward show a surprising degree of accuracy in the mapped representations.

The earliest surviving terrestrial globe dates from 1492, the same year as Columbus sailed to discover the New World. However, it was not until the late 16th century that serious efforts were made to produce accurate World maps and terrestrial globes. These early map- and globe-makers or 'cartographers' drew their inspiration from the discoveries of Dutch navigators and explorers of the 16th and 17th centuries. They soon realised that in order to produce accurate maps and globes improved methods of measurement and computation were needed. This led to a series of innovations, notably the use of very carefully measured baselines [5] to support surveys that relied on extending a series of triangles across landscapes in order to fix specific locations precisely. In 1533 Dutchman Gemma Frisius was the first to describe this technique, known as *triangulation*, a procedure which is still in use today. And in 1553 he was also the first to propose the use of an accurate clock to determine longitude. The latter task was not realised for another two centuries when in 1759 John Harrison completed his final precision marine timepiece (or *chronometer*) that is today known as Harrison's chronometer #4, or H4.

By the early part of the 18th century the method of accurate measurement using baselines and triangulation was well-established. One of the hottest topics in science at that time was whether the Earth was truly spherical, as Eratosthenes believed, or a slightly different shape as contemporary scientists believed. Knowing the size and shape

[5] A baseline is a precisely measured straight line on the Earth's surface that provides a fixed side to triangles extended from the ends of the line with known measured angles. Further triangles may be extended from the initial triangle to create a network of triangles, or a "triangulation", enabling large areas to be mapped accurately

of the Earth was to prove of great importance, and formed the foundation stone of much research by French scientists throughout the century. English scientists, led by Sir Isaac Newton and Edmond Halley, insisted that the Earth was a bit flatter at the poles (oblate, like a grapefruit) whilst French astronomers, led by J J Cassini, disagreed and believed it was slightly pointed (prolate, rather like a lemon). A landmark project to resolve the question took place in the years 1735-9. The French Academie des Sciences sent two teams to measure parts of the Earth's surface North and South of the equator and to compare these measurements with the values expected for a perfectly spherical Earth. The team heading North was led by Pierre-Louis Moreau de Maupertius and included several French astronomers and the famous Swedish scientist, Anders Celsius. They went to the Arctic Circle (66 degrees North) in modern-day Finland, and established a carefully measured baseline of 8.9 miles (14.3 kms) on the frozen river Torne (Tornionjoki).

Using a frozen surface ensured that the baseline measured was extremely close to being level, smooth, and hence enabled the length of a straight path to be measured with great precision. This work, coupled with detailed astronomical observations, enabled the length of one degree of latitude (i.e., a North-South arc) to be estimated very precisely at the Arctic Circle. The measurements confirmed that one degree of latitude at the Arctic Circle was slightly longer than one degree measured in Paris. This proved conclusively that the Earth was oblate (flattened at the poles) rather than prolate. A second team was sent to the region of Quito, in modern-day Ecuador, to perform similar measurements (1735-1739). Together with the findings from Finland

these led to the first modern definition of the Earth's shape, in 1743, as a squashed sphere or *ellipsoid*. This shape has a semi-major axis (effectively the radius at the equator) of 6,397,300 metres (i.e., around 6400 kilometres or 3975 miles) and flattening factor: 1/216.8, or about 0.5%, quite close to the values we use today. These measurements also led to the *definition* of a metre at the time as one ten millionth of the distance along a line of longitude from the North Pole, through Paris, to the Equator, i.e. defined as being 10,000kms or 40,000kms circumference through the poles (it has since been refined several times).

Following somewhat in the footsteps of Maupertius, early in the winter of 1744 on a bright cold morning, an ambitious young schoolmaster named Murdoch (Murdo) Mackenzie stepped onto the frozen surface of a small lake close to his home. The lake in question was the Loch of Stenness and is situated on the largest of the Orkney Islands, off the north coast of the Scottish mainland. This event marked the start of a very significant, but little-known development in our understanding of map making, coastal charts and the development of the science of hydrography. Like Maupertius, Mackenzie was embarking upon a lengthy programme of very careful measurements.

Mackenzie's endeavour was an opportunist private venture, funded by subscriptions from the Hudson Bay Company, London merchants, insurance businesses, friends and wealthy patrons[6]. As such, it was a very 'modern' plan, and we can imagine similar ideas being proposed

[6] See further the beautifully produced book by Fleet, Wilkes and Withers (2016) *Scotland: Mapping the Islands*; the two articles by Diana Webster on Mackenzie; and the present author's book "Understanding Mathematics". All are listed in the References section of this book

and considered today — perhaps crowd-funded! It was to take him four years to complete, make his name and a reasonable fortune, and ultimately gain him election to the Royal Society.

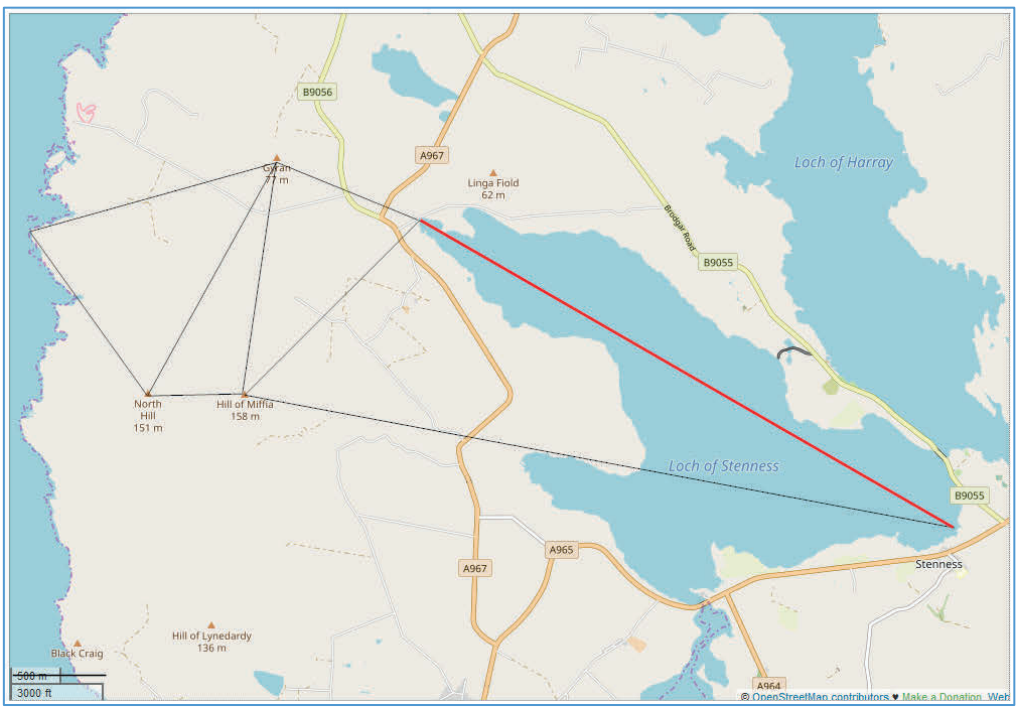
Onto the ice he dragged a box containing a long metal chain, many lengths of rope and a large number of coloured wooden poles. He made a smooth hole in the ice and inserted the end of one of the poles as his first marker. He then tied a length of rope to the bottom of the pole and set out across the ice. After a short distance he repeated the process, inserting the next pole and heading off again in the same direction, to produce as straight a line of poles and rope as he could. He probably spent much of the day working his way across the smooth ice surface, covering a distance of nearly four miles. When he finished, and was happy that all the poles were in line, he returned to the start, and picked up the iron chain (probably on the next day!). In this endeavour we can safely surmise that he was following the procedures of Maupertius, whose methods and findings had been reported throughout Europe a few years earlier. There is no record of what the chain looked like, but almost certainly it was of the type invented by Edmund Gunter in 1620, constructed from 100 links and 22 yards (66ft) in overall length[7].

By laying the chain alongside the rope and stretching it taut, Mackenzie was able to measure a very long straight line (a *baseline*) with considerable accuracy. When he finished, he had covered a total distance of 3¾ miles (300 chains). From the two ends of his baseline, he

[7] This is the origin of the unit of measure "one chain" and is the length of a cricket pitch (between the wickets). 10 chains by 10 chains defines an area measure (220 yards x 220 yards) known as an acre. 80 chains equal one mile (8 furlongs or 1760 yards).

could see the tops of nearby hills, mountains and islands. He then used a device invented in its current form about 20 years earlier, known as a theodolite, which he had been loaned by the Royal Navy. This consisted of a telescope mounted above a carefully graduated circle. With this he was able to measure a whole series of angles to these various notable points from each end of his baseline (Figure-1).

*Figure-1 Baseline and triangulation, Loch of Stenness, Orkney*




And to be certain of their position, he constructed piles of stones and occasionally lit fires on the hilltops, to ensure his results were as accurate as he could make them. From each of these measured points, he could make sightings to additional high points, along the coastline, or on other

islands, extending his original baseline on the ice using simple triangles and ratios to determine how far apart each point was to a considerable degree of accuracy. It is important to note that the triangles needed to be constructed as close to equal-sided (equilateral) as possible, to minimize direct and cumulative measurement and computational errors.

Mackenzie's objective was not to make a precise land survey, although that was a partial result of his work. And his use of measured baselines and triangles was not new. But what was original was his interest in accurately charting the coastline — recording and mapping the detailed shape of the inlets, bays, off-shore rocks, the depths off-shore, the tides and the currents. For, as he wrote in his original promotional map (one of the earliest published marketing campaigns):

> *"On this small Island alone [North Ronaldsay] about twenty British and Dutch vessels have been lost within the last 30 or 40 years many of them with very Valuable Cargoes, besides a much greater number on other Parts of that Coast; most of which might have been prevented by such a Chart of these Islands as is here proposed."*

This text is engraved in the upper right corner of the map shown in Figure-2. As can be seen from his original Orkney chart, there are no lines of latitude or longitude on the charts – these did not appear in a consistent manner until an agreed global Prime Meridian was established at Greenwich in 1884. Most of the Orkney maps and his subsequent coastal charts simply show a compass rose, with lines indicating true North and magnetic North with the date and variation

from true North this represents. The results of his meticulous efforts were published in 1750 in a single volume of eight large-format charts and associated notes, known as The Orcades Atlas.

*Figure-2 The Island of North Ronaldsay, Orkney (© Orkney Archive)*

The reason that there was so much interest in Mackenzie's proposal was the extreme danger to shipping that used the Pentland Firth at the time. This is the narrow waterway between the Scottish mainland and the Orkney Isles, and provides a vital route between North America and Northern Europe. A combination of some of the fastest tidal flows in the

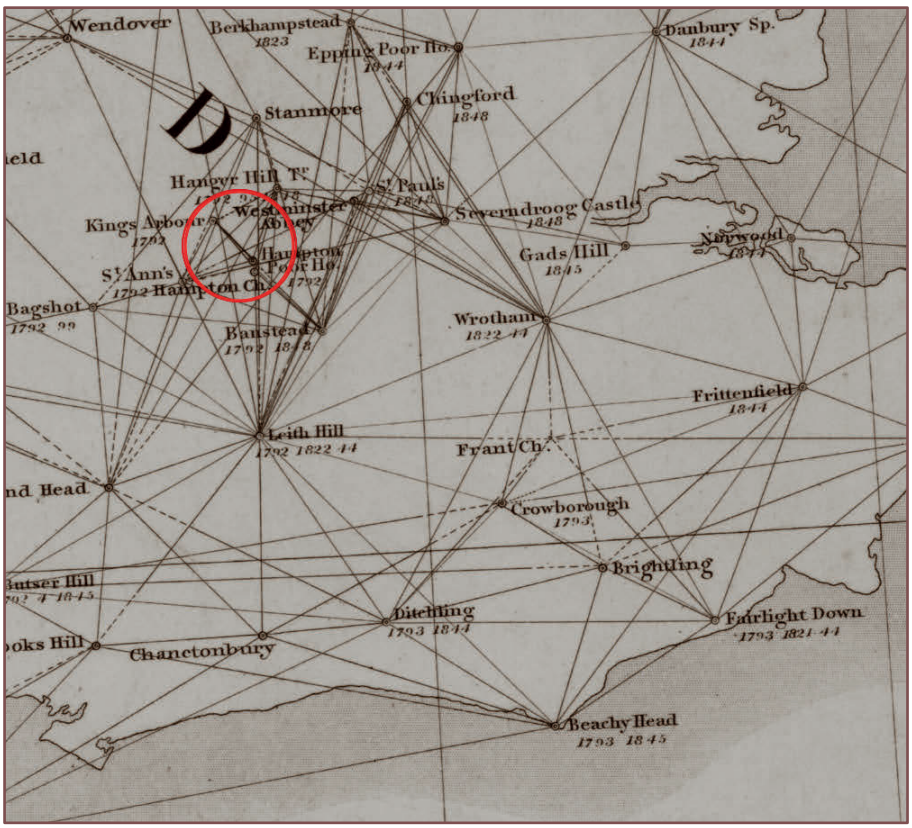
world (up to 16knots, or 30km/hr, 18m/hr), strong winds, submerged rocks and very rough seas, combine to make this waterway extremely treacherous to all but the most able navigators. However, as we shall see later in this book, these strong currents can also provide a valuable resource for clean power generation.

Mackenzie is the person most responsible for the development of accurate annotated maps of coastlines throughout the world, essential for the safety of vessels and the defence of island realms. It was also timely, as in 1745 the British Royal Navy was trying to capture the rebel pretender to the Scottish throne, Bonnie Prince Charlie. The lack of good charts of the Scottish and Irish coastlines resulted in lengthy and fruitless searching, with the prince eventually escaping to Skye and thence to France. The Royal Navy, highly impressed with Mackenzie's Orcades Atlas, commissioned him to produce detailed charts of the entire west coast of Britain and Ireland, as far south as Bristol. The creation of these charts occupied the next 30 years of Mackenzie's life.

In parallel with Mackenzie's work, in 1747, a separate exercise to survey and map of the Scottish Highlands was commissioned by the British government. This was designed, in part, to assist in the building of new "military" roads in the Highlands, a programme of works that had been initiated following the first Jacobite uprising of 1715. The engineer and surveyor, William Roy, was asked to undertake this task and did so over the next 8 years. His work in Scotland was of great importance in opening up the Highlands and in the understanding of how remote mountainous regions could be surveyed and mapped. Roy's work

ultimately led to his appointment to lead the project to measure an accurate baseline at Hounslow Heath in 1784 (remeasured in 1791/2) between Hampton Poor House and Kings Arbour. Roy's baseline was central to the establishment in 1791 of the Ordnance Survey and the initial "Principal Triangulation of Great Britain" (Figure-3).

*Figure-3 Principal Triangulation of Great Britain - extract*[8]




Roy's baseline is in the left centre of this map extract where the two named end locations can be seen. The baseline was measured as 27,404

[8] Source: NLS, Maps Department https://maps.nls.uk (Ordnance Survey 1856)