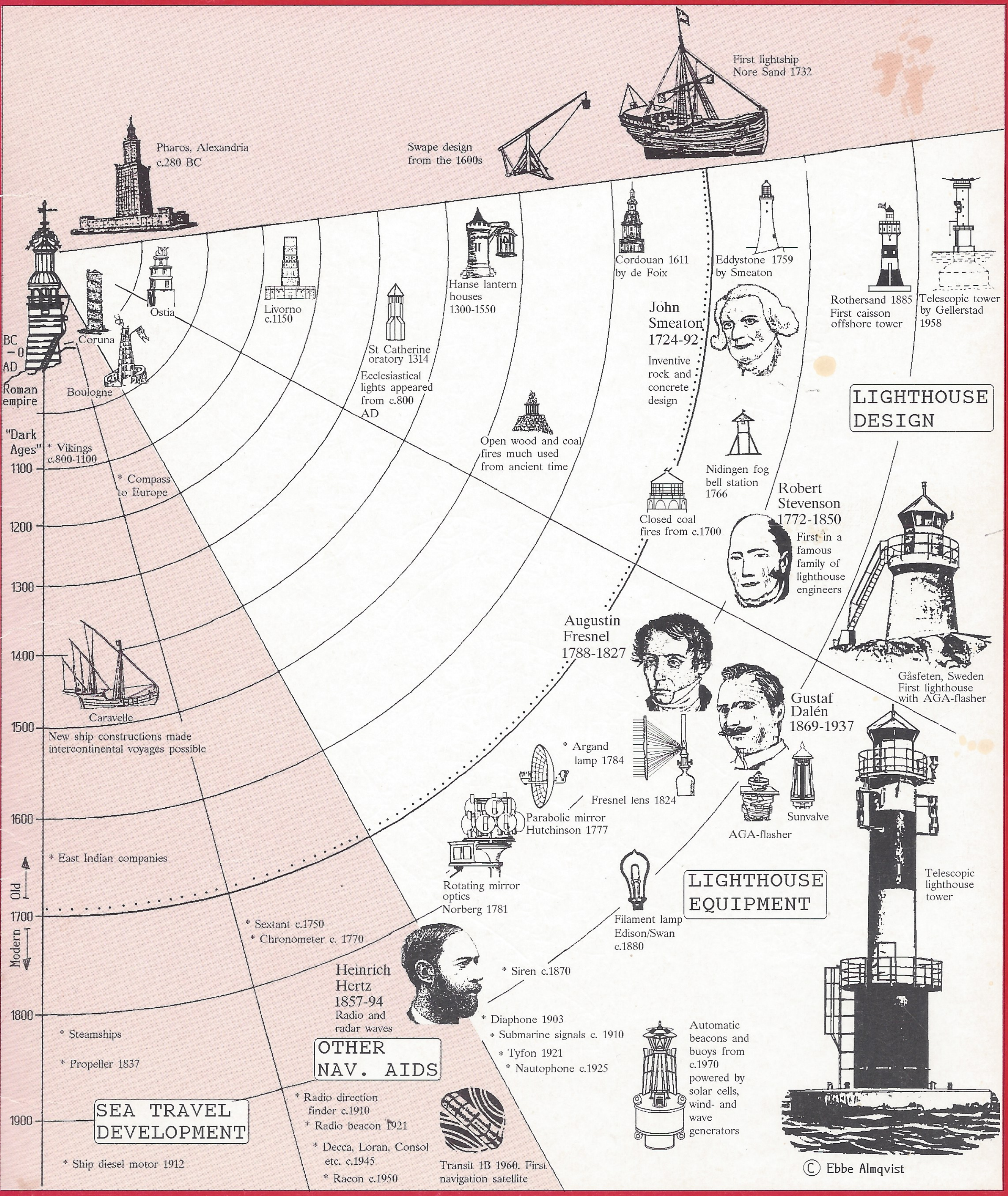
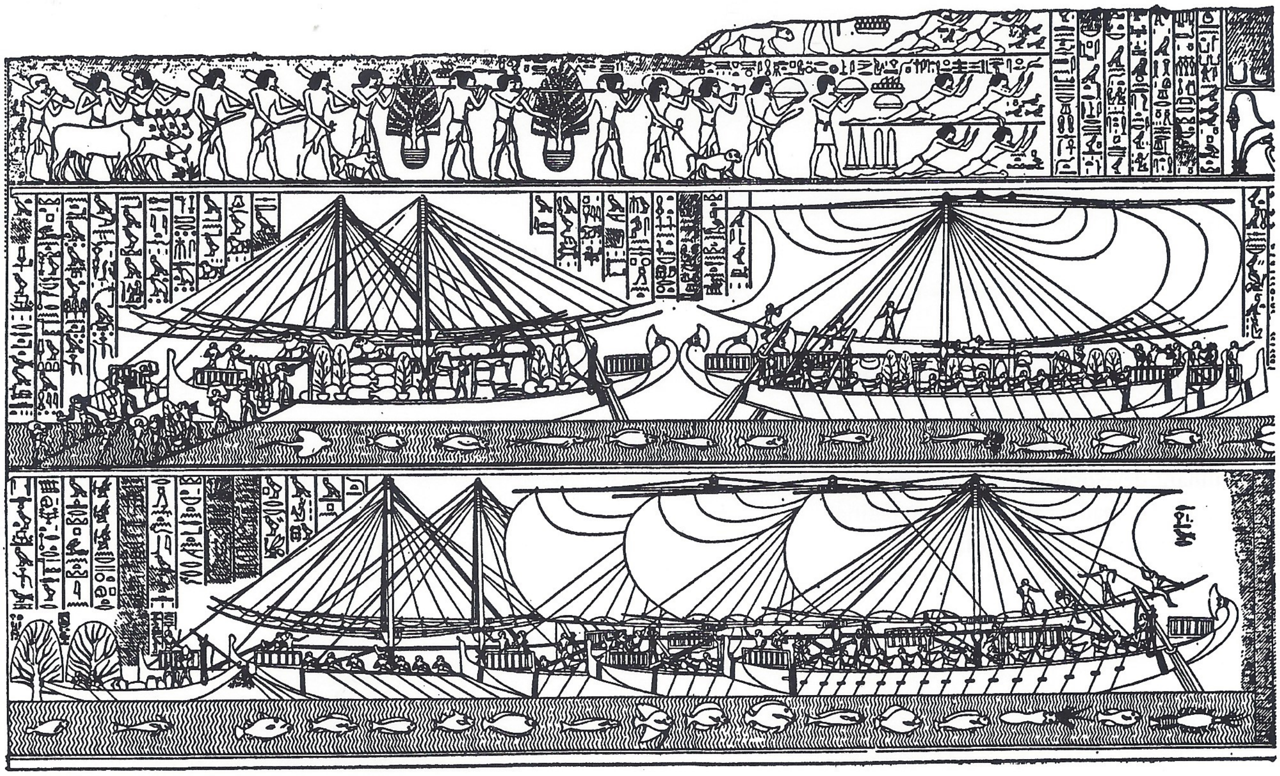
MILESTONES IN LIGHTHOUSE ENGINEERING

by Ebbe Almqvist
Kenneth Sutton-Jones



Contents

The origin and history of lighthouses has many interesting aspects at the inception and development of sea trade. Many excellent books and articles give a detailed view of this subject. (See the ref. list.) The aim of this résumé is to trace the broad lines of development and point to the impelling forces behind the technological steps toward the unattended lighthouse.



1. Queen Hatsheput's fleet of seagoing ships at Punt in Red Sea c. 1500 B.C. Wall carving at Deir-el-Bahari tomb temple in Egypt.

The early development of sea trade and aids to navigation

Sea trade development
Throughout the history of man the sea has offered a powerful means of communication. The first boats made of planks instead of bonded reed or dugout logs, were probably made by the Egyptians of the 4th millennium B.C.

We do not know where sailing first originated because, in early days, lack of communication with distant lands hid development from Western knowledge. On the Nile and Euphrates rivers, sailing originated about 5000 years ago, when Egyptians and Babylonians established trading routes.

The earliest surviving written record of open-sea sailing, stimulating shipping and trade is from 2700 B.C. when a fleet of forty ships brought cedar wood from Phoenicia (Lebanon) to Pharaoh Snefru. Regular trade, was carried on between Crete and Egypt before 2500 B.C. At first the Egyptian seamen stayed on or near the Nile leaving to Crete to establish the first sea empire (c. 1800 B.C.).

The Mediterranean and Black sea areas were colonised by these early sea empires, probably because of the need for trading posts. First to venture out were the Phoenicians, on the North African coast in about 1000 B.C. They moved out through the Strait of Gibraltar to the Spanish trade city Tartessus (Tarsis), where they set up a harbour at Gades (Cadiz). The Phoenicians were now able to get the metals they needed, i.e. silver from Iberia (Spain) and tin from mines in Cornwall, England, first by local Spanish carriers, then in their own vessels.

About 800 B.C. the Greeks settled in Syracuse and colonised areas on the Black Sea coast. By c. 700 B.C. they also had visited the tin mines of Cornwall via Rhone and Seine rivers. They were the dominant sea power until the destruction of their fleet in the Peloponnesian war (434–401 B.C.). Ca 340 B.C. Phyteas of Massilia (Marseilles) sailed through the Strait of Gibraltar to the British isles and to the "island of Thule" (Iceland, Shetland or Norway). First Rhodes and then Alexandria, founded by Alexander the Great in 332 B.C. became sea trade centres. This was before the rise of Rome made seamen of the Italian people who, up till then, had been very much land based. They got their exercise when defeating the Carthagian fleet in 146 B.C. and within 75 years Rome conquered and then ruled the whole Mediterranean.

The early aids to navigation
Sea voyages by boat required skills in navigation. Whilst sailing off the coast natural navigational guides such as characteristic land formations, islands, promontories, boulders and trees etc. were used as landmarks. These soon proved to be insufficient. Man-made guides, such as towers, beacons or exaggeration of the shape of natural landmarks were introduced. The first written aid to coastal navigation was the pilot document (periplus). These showed the tracks to be steered between ports with the help of detailed observations inherited from generations of sailors. Directions of currents and wind were also shown. The oldest surviving pilot documents are from the fourth century B.C., describing routes, leadline, landmarks, anchorages, currents and port entrances. Another very simple but useful aid also carried by ancient mariners was the leadline for measuring the water depth.

On many continents open fires were used from the earliest time for signalling and warning. Torches were displayed as semaphore signals. Nightly sailings are mentioned in the Odyssé c. 700 B.C. and tales from Troy at that time tell about false fires for misleading sailors. So there are grounds to believe that at that time there also existed a system for the nightly guidance of seamen. Primitive evidence suggests that there was a knowledge of marking a shoal-free sector in the fairway, even if it fell into disuse until the later development of international trade and maritime travel caused it to be re-introduced.

In the open sea further aids to navigation became essential. From c. 500 B.C. astronomy together with geometry and trigonometry were first used by the Greeks for navigation. Understanding the motion of the sun, stars and various meteorological factors such as wind directions, gave the early, distant navigators the possibility of finding their way back home. The planispheric astrolabe, credited to Hipparchus (150 B.C.) and Apollonius of Perga (240 B.C.), was used for determining the altitude of celestial bodies from which time and latitude could be deduced.

Early lighthouses

Very little information exists on how early lights at sea first came into use. Tradition tells us that they were used both to guide navigators and to confuse them. In the fourth century B.C., detailed sailing directions were written, covering the whole Mediterranean coast-line, but they fail to mention a single lighthouse.

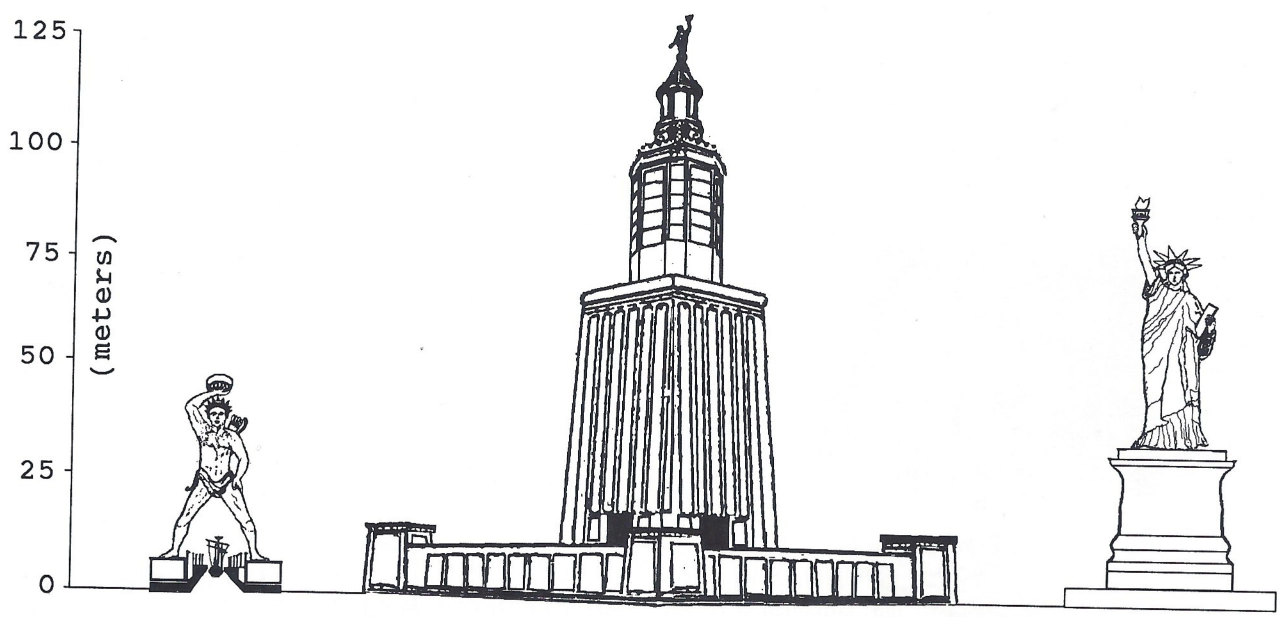
The recorded history of fire towers began when Phoenicians, Egyptians and Romans started to travel and to trade. Masonry towers were built on important headlands and as landmarks of major ports on the African, near Eastern and European shores. In Europe, fire towers first were provided in Roman Mediterranean ports, then in some ports on the Atlantic coasts of Spain, France (Gesoriacum — Bologne) and in England (Portus Dubris—(Dover).

Pharos

The Pharos erected on an island outside the harbour of Alexandria in c. 285 B.C., is the first recorded sea mark with a light. It was built on instructions of Egypt's King Ptolemy II. The tower is said to have measured over 130 metres in height. (Fig. 2.) A wood fire was kept burning all night at its top and its height has not been surpassed by any other lighthouse. It was rebuilt several times, but was finally destroyed by an earthquake in 1302 A.D. This magnificent piece of architecture was named one of the seven Wonders of the ancient world, but its exact design is not recorded. Julius Caesar (100-44 B.C.) described it as a "tower of great height, of wonderful construction" and the geographer Strabo (63 B.C.-25 A.D.) said Pharos was "admirably constructed of white marble". Another known lighthouse before the rise of the Roman Empire was at Aegea in Eastern Cilicia and this was represented on a Syrian coin before 164 B.C.

The Roman empire

During the Roman period (146 B.C. – 478 A.D.) several new ports were built following the increase in trade and shipping. Fire towers were erected to locate several

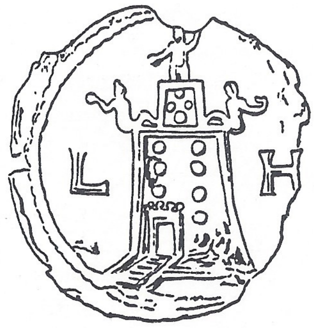


Colossus of Rhodes built c. 280 B.C. Bronze sculpture by Chares of Lindos, destroyed by an earthquake in 226 B.C.

Pharos, Alexandria c. 285 B.C. by Sostratos of Knidos. Finally destroyed by an earthquake in 1302

Statue of Liberty. New York 1886 by Bartholdi of France

2. Size of Pharos compared with other well-known sea marks.



3. Some Roman coins and medals had engravings of a lighthouse. Left: Pharos of Alexandria.

Right: Departure of an expedition from Ostia in Rome.

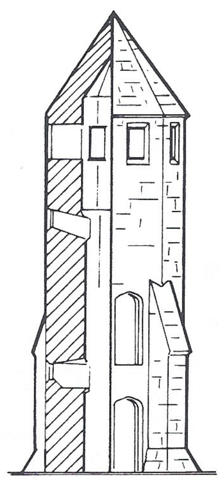
major ports. A prominent port was built in Ostia, near Rome, by Emperor Claudius about 50 A.D. — the lighthouse being erected behind a huge statue of the Emperor, and is the best known of the Roman lights. Other examples of known Roman ports with lighthouses have more vague dates recorded: Ravenna in the time of Emperor Augustus, Puteoli in the time of Emperor Antonius Pius, Centumcellae in the time of Emperor Hadrian and Leptis Magna in the time of Emperor Septimus Severus.

About 40 A.D. the Emperor Caligula brought his army through Gaul (France) to the Straits of Dover. There in 44 A.D., the triumphal tower Tour d'Ordre of Boulogne was created for the purpose of celebrating his victories. In order to combine the useful with the glorious the tower was also arranged as a lighthouse. The tower also served the purposes of defence and, on one occasion in 811 A.D., was so badly assaulted by the Vikings that Charlemagne had to have it repaired at great expense. In 1644 the Tour collapsed into the sea. The light tower at Dover on the other side of the English Channel was erected at about the same time as Tour d'Ordre.

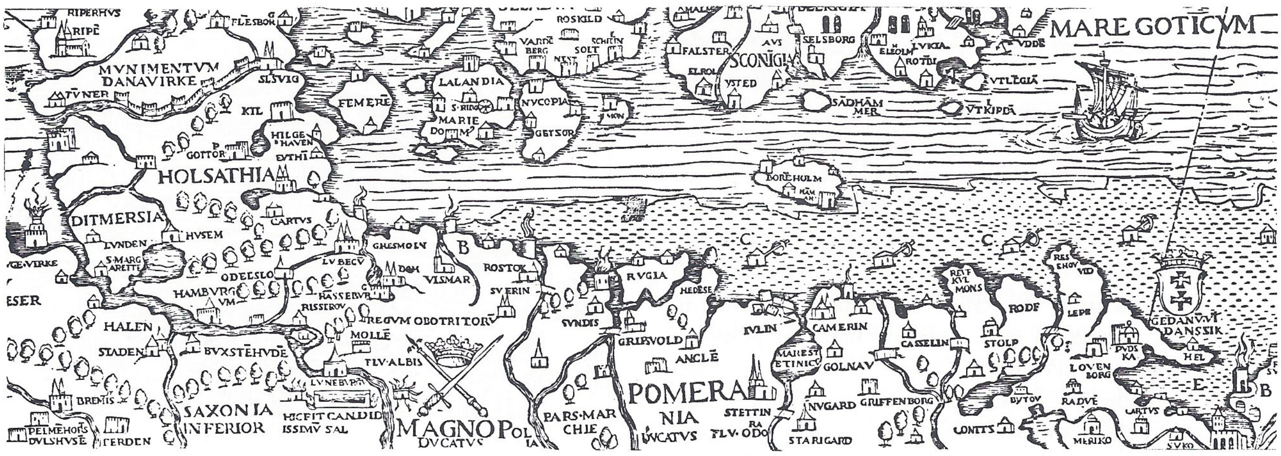
With the fall of the Roman Empire, most lighthouses were destroyed. From 600 A.D. Scandinavia began to sail the seas. This led to the start of shipbuilding and eventually to the Viking voyages 800-1100 A.D. In the ninth century, at some places on the coast of the British Isles and France, some small, local lights began to be built and maintained by individuals. Sometimes they were built and maintained by churches and chapels as a Christian duty. Monastic groups and hermits had taken to living on remote islands and promontories where their work to save ship-wrecked sailors extended to the salvage of wrecked goods and the exhibiting of candle lights in chapel windows. They were sometimes attacked by raiders and Vikings, but their work continued.

The making of profit by the raising of dues on cargo went alongside the philanthropic desire to reduce the loss of ships, cargoes and lives. Not all who erected aids to navigators did so from the same motives as the medieval hermits and monasteries. The misuse of lights to cause wrecks, which persisted until a century ago, was noticed in the 1100s by Richard Coeur-de-Lion who introduced severe punishments for pirates and people purposely causing ships to be wrecked.

4. This coat of arms shows a holy man, St Geradine, said to have lived on the coast of Morey in the eighth or tenth century A.D., who warned vessels of danger or guided them by swinging a lantern on the shore. [7]



5. The tower of St Catherine c. 1314 on the south point of Isle of Wight. The Pope urged Walter de Godeton to establish a hermitage with a priest and a tower with a coal fire on top as atonement for his purchase of stolen cargo. The tower served its purpose for two hundred years.



6. Part of Olaus Magnus's seamap Carta Marina of 1539 showing lighthouses in Germany and Poland at Neuwerk, Travemünde, Wismar, Warnemünde, Hiddensee, Gollenberg and Pillau (from left to right).

The medieval development

With the collapse of the Roman Empire, also the advanced culture and trade developed by the Romans disappeared. The centuries c. 500-1000 A.D. are called "the Dark Ages". Shipping declined and existing ports only retained local trade. Sealights as a guide to harbours were put out due to the risk of assisting potential enemies to spring an attack. When law and order began to prevail again in the 12th century, sea trade started in new centres in two geographically separated areas. First in the Mediterranean and, a century later, along the coasts of the North Sea and the Baltic. Growing maritime commerce and new, larger ships were accompanied by more marking at sea, particularly in Northern Europe and the Baltic. These new trade centres of Europe were equipped with lighthouses mainly in harbours and river estuaries.

Maritime history of the late 11th and the 12th centuries in Southern Europe is dominated by the Crusades. When the commercial benefits of trade with the East were discovered, business took over some of the religious motivations for these traders. The first to appreciate new opportunities were the Italian maritime city republics like Genoa, Venice and Pisa. Trading concessions and the building of trading ports gave these states the monopoly of Oriental trade. These arbitrary privileges were the cause of a number of conflicts and wars.

During the mid-12th century the lighthouses of Genoa and Meloria (near Livorno) were built. The Meloria light was erected in 1157 by the Pisans, the first wave-washed tower to be built on the rocky shoal. Messina in Sicily became a great Crusader port requiring a major lighthouse like many other frequented harbours in the Mediterranean.

The sea trade in Northern Europe was managed mainly by the Hanseatic League c. 1250–1550. By 1280, various groups of Rheinish merchants were cooperating to safeguard their common interests and formed a league with Lübeck and the other German towns that dominated the Baltic trade. Connected with the League were foreign trade centres like Brugge, London, Bergen, Visby, Riga and Novgorod. The influence of the Hansa led to a number of lighthouses being established along the Scandinavian and German coasts during the 14th century. Some of these can be seen on the sea map Carta Marina of 1539, drawn by the Swedish Bishop, Olaus Magnus. (Fig. 6.) The first beacons in the Baltic were lit at Falsterbo Headland c. 1210 and at Travemünde c. 1220 on behalf of Lübeck.

7. German lighthouse from the Hansa period shown on a chart of 1572. [5]

Even if no formal link between the two sea powers is found, the first commercial codes of the early Hanseatic merchants derived from the example of Venice. They both had similar aims, namely to establish trading bases and monopolies, to secure the sea trade by suppressing piracy and to minimise losses by storm and stranding. This was accomplished by marking the seaways with beacons and lighthouses, training pilots etc.

It is probable that ships and sailors from Venice and Genoa could have met merchants from the Hansa. The most frequent points of contact were in Flanders (Antwerp, Brugge), at that time en route as new centres of European sea and river trade.

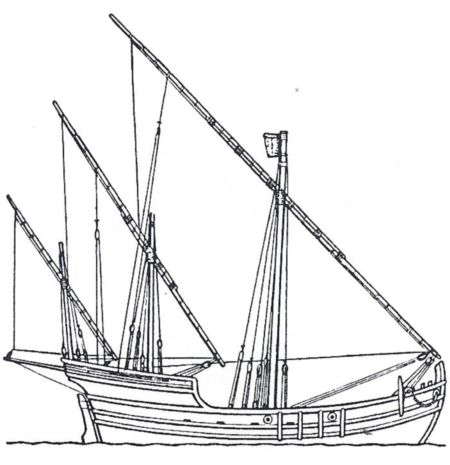
Seamarks appeared in Flanders from the 13th and

14th centuries. The marking of the coasts and inland seaways was pioneered by local Dutch seamen and fishermen and several fire towers were erected.

After several decades, the aggressive, protectionist policy of the Hansa aroused strong opposition, especially from the Danes in the second part of the 14th century. The strength of the Hansa was reduced during the 15th century when the Scandinavian and the non-German Baltic states formed unions. At that time, the Italian city states diminished in importance, leaving the role as the strongest sea power of Mediterranean to Portugal. Lisbon became the most important trade city of Europe until the conflicts with Spain over new colonies changed the picture. Spain and Holland then took the lead and new cities like Madrid, Paris, London and Amsterdam rapidly increased their trade. By the mid-16th century, the Dutch had won control of the freight trade from the Baltic to the west. England had lagged far behind the Dutch as a seafaring nation. This could also be seen when studying the sea marking.

Before Trinity House was founded in 1514 to provide pilots and guide sailors, British coastal lights were of ecclesiastical or charity origin. By the end of Queen Elisabeth I's reign (1603) British maritime development had increased. The building of ships and new ports gave competition for Holland as the leading trade nation. The Hanseatic League finally broke up under competition from Dutch companies and English merchants. After a century of Dutch dominance, England became the main sea power by virtue of new trade protection laws (the Navigation Act of 1651), strategic geographical position and strong technological progress.

British development of seamarking was substantial during the 17th and 18th centuries, but still the majority of new lighthouses were privately built and maintained as a reward to prominent people, who secured the right to charge a toll on passing ships. Eventually, Trinity House bought out the privately operated lights. These then formed part of a unified service to the mariner which has gained a high reputation world-wide ever since.



8. Caravelle ship with two masts and Latin sail.

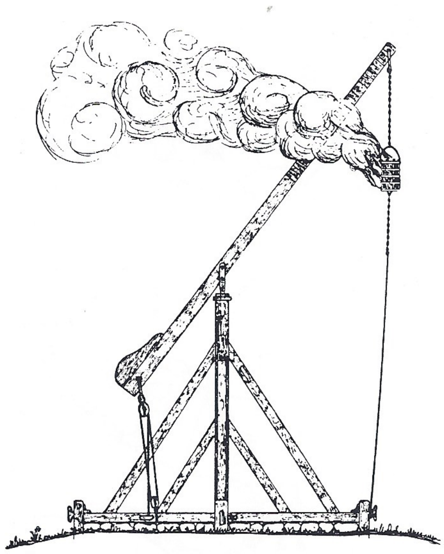
9. Olaus Magnus described lights as an aid to seamen and lights as a warning for enemies in "The History of the Nordic People" in 1555. These are his illustrations.

Wood and coal lighthouses

From the 1400s there was an increase in distant voyages. That century was the turning point for the construction of sailing ships. New continents were explored with enlarged and more reliable ships. Two or more masts, and improved rigging on ships like the Caravelle, increased the range for shipping and trade. The compass was used from the 13th century and the written travel guides of that time, called portolanos or rutters, gave necessary information of sailing around the coasts of Europe in daylight. But the now more frequent navigation in darkness created a need for a regular service at night.

In the beginning all coal and wood fires were open. Since, in a wind, the brighter part of the flame would be on the leeward side, attempts were made to enclose the fire in a glazed lantern. The cost of maintaining lighthouses was often considerable, lights tended therefore to be used only when they were needed and not throughout the year. Coastal lights were still often erected and maintained on a private initiative by churches and monasteries. Towers and beacons, military in origin, were erected along the coast in many parts of Europe. The light from these generally transmitted messages inland, as in the case of invasion by an enemy. But many of these towers and medieval castles were later on used as elevated platforms for the display of lights for navigation.

The average range of open coal fires was 10–12 km



10. Swinging pole beacon (swape). Construction c. 1625 by Jens Pedersen Grove of Denmark. [2]

during normal weather. Clouds, light fog and rain could give a longer range by reflection upwards of their reddish shine. In stormy weather open wood and coal fires could not be seen from the side where it was most required, since the windward side often remained totally unignited. This drawback called for more reliable installations.

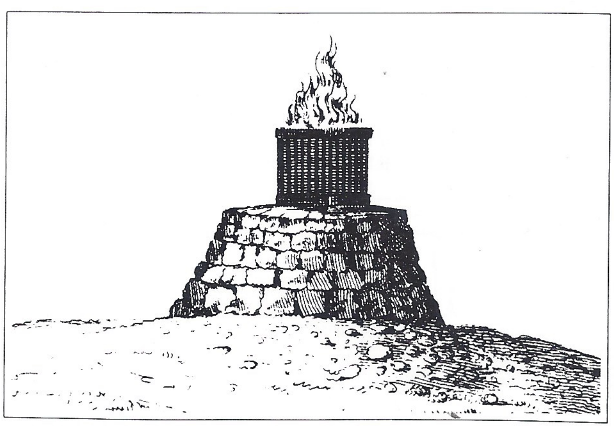
Thus old lighthouses had major drawbacks. They required constant attendance, their luminosity was uncertain and much of the light was wasted because it could not be concentrated seaward. Fire towers singly or in duplicate (as at Lizard) or even in triplicate (as at Casquets) were the means of identification and this was very costly in fuel and labour. Some lights were potentially dangerous because homing towards them on certain bearings could lead through shoals. The navigator required previous knowledge of which were the sectors it was safe to lie off the light.

As the number of lighthouses increased, it became necessary to be able to distinguish one light from another, and from industrial fires and domestic lamps. The earliest tentative efforts to obtain an intermittent light were by means of attaching a "firepan" at the end of a swaying arm and then setting the arm in movement by hand power, thereby alternately raising and lowering the light. Swinging pole-lights (swapes) (Fig. 10) were used from the 16th century. They were cheap but dangerous and could occasionally burn down. However, since they were easy to erect they survived into the 19th century.

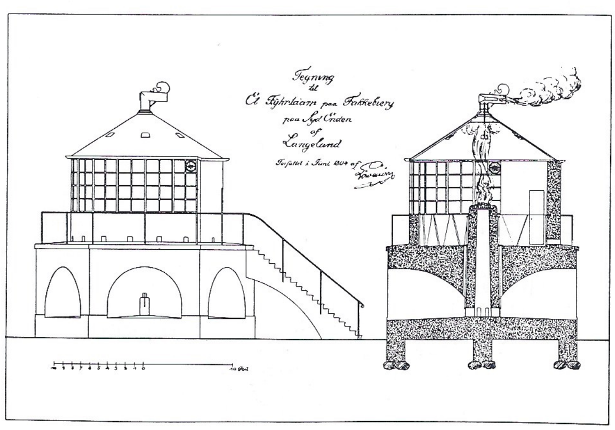
Although masonry stone towers with coal fires were expensive to build they were superior over the swape. Larger braziers could be used, thereby increasing the light intensity, and fires could be attended more efficiently. In addition to this, they also made very good day marks. (Fig. 11.) In some places during the 17th century, coal fires behind glass windows were introduced. Coal from English mines had begun to be used in large quantities as a fuel in blast furnaces, and the first English lighthouse to use mined coal was probably Dungeness in 1616.

In the last part of the 18th century, the famous English lighthouse architect John Smeaton (1724–92) and the Swedish engineer Anders Polheimer (1746–1811), among others, constructed special covered coal-lights. (Fig. 12.) The fire was enclosed in a lantern provided with sheets of glass. Ingenious funnel devices for obtaining artificial and adjustable draught gave a smokefree, white and extremely powerful flame, which made these lights superior to all others at the time. Still; a century after these innovations, some seamen wanted to keep fires instead of the new, feeble light sources which could be mistaken amongst domestic and similar lights.

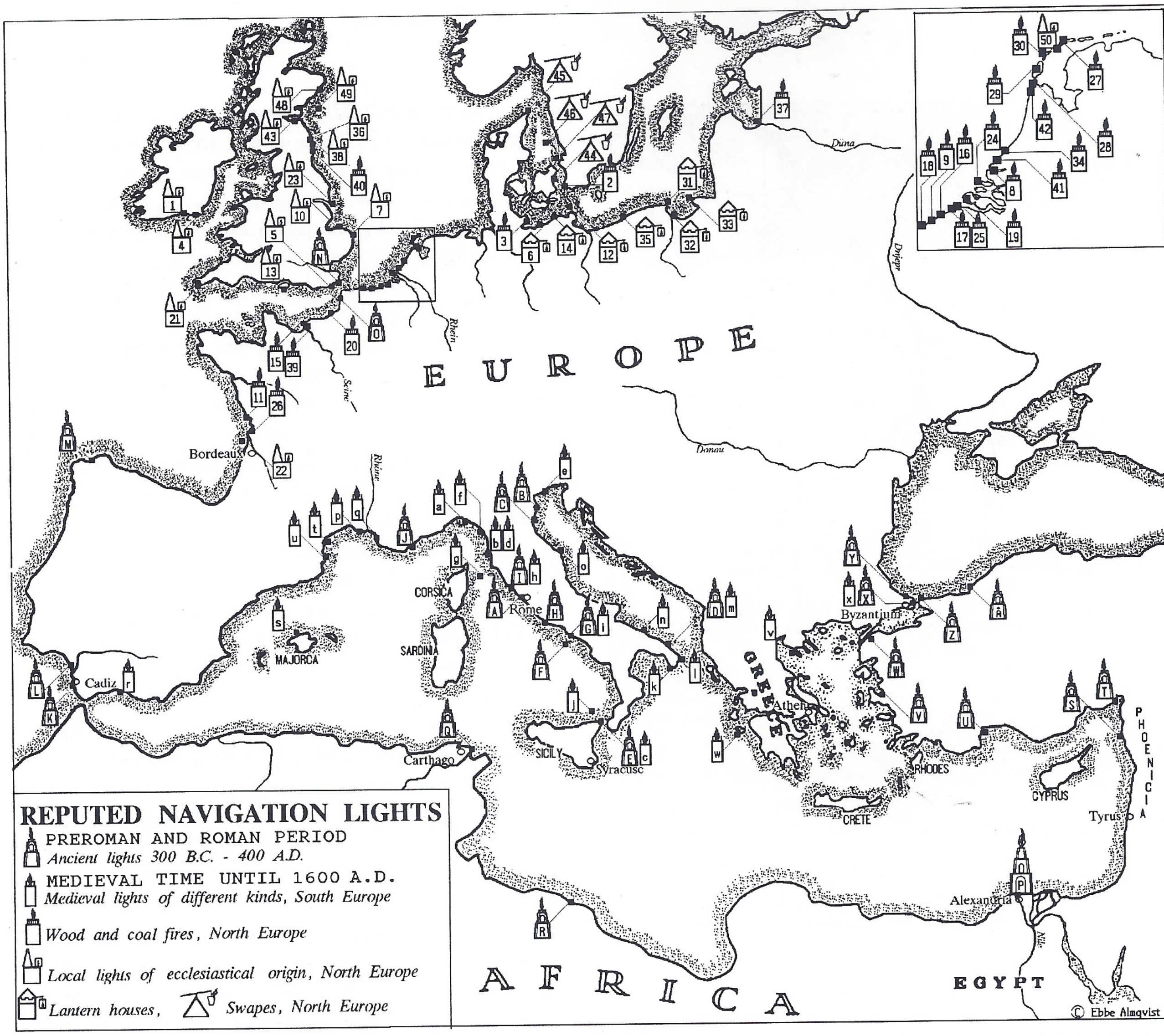
Many names of engineers such as Smeaton and Polheimer could be mentioned amongst excellent pioneers of modern lighthouse design and construction, which from the 18th century developed into a highly specialised branch of engineering. Of all the names associated with this phase of enterprise, the Scottish Stevenson family stands pre-eminent. Since 1787 the control of Scottish coastal and offshore lights was taken over by



11. Open coal fire at Kullen, Sweden 1791. Sketch by Anders Polheimer.



12. Enclosed coal fire with draught system from below at Fakkebjerg. Denmark 1804. [2]



Reputed navigation lights 300 B.C. – AD 1600

Pre-Roman and Roman period 300 B.C. – c. AD 400

ITALY

A. Ostia c. 50 AD
B. Pomposo
C. Classis
D. Brindisium
E. Messina c. 35 AD
F. Capreae
G. Putoeli
H. Terracina
I. Centumcellae c. 120 AD
J. Forum Julii

SPAIN

K. Gades (Cadiz) BC
L. Turris Caepionis c. 100 BC
M. La Coruna BC or c. 100 AD

BRITAIN

Dover c. 50 AD

FRANCE

Boulogne 44 AD

NORTH AFRICA

P. Pharos c. 280 BC
Q. Carthago
R. Leptis Magna

SYRIA, TURKEY

S. Laodicea
T. Aegea c. 200 BC
U. Antalya
V. Smyrna
W. Abydos
X. Bysantium 2nd c. AD
Y. Timaea 1st c. AD
Z. Chrystopolis 2nd c. AD
Å. Heracleia Pontica

Medieval lights – AD 1600, Mediterennean and Black Sea

ITALY

a. Genua 1130
b. Meloria 1157
c. Messina c. 1190
d. Livorno 1163
e. Venedig 1312
f. Tino
g. Pianosa
h. Civitavecchia
i. Naples
j. Lipari
k. Sant Andrea
l. Otranto
m. Brindisi
n. Bari
o. Ancona

FRANCE

p. Aigues Mortes c1244
q. Marseille

SPAIN

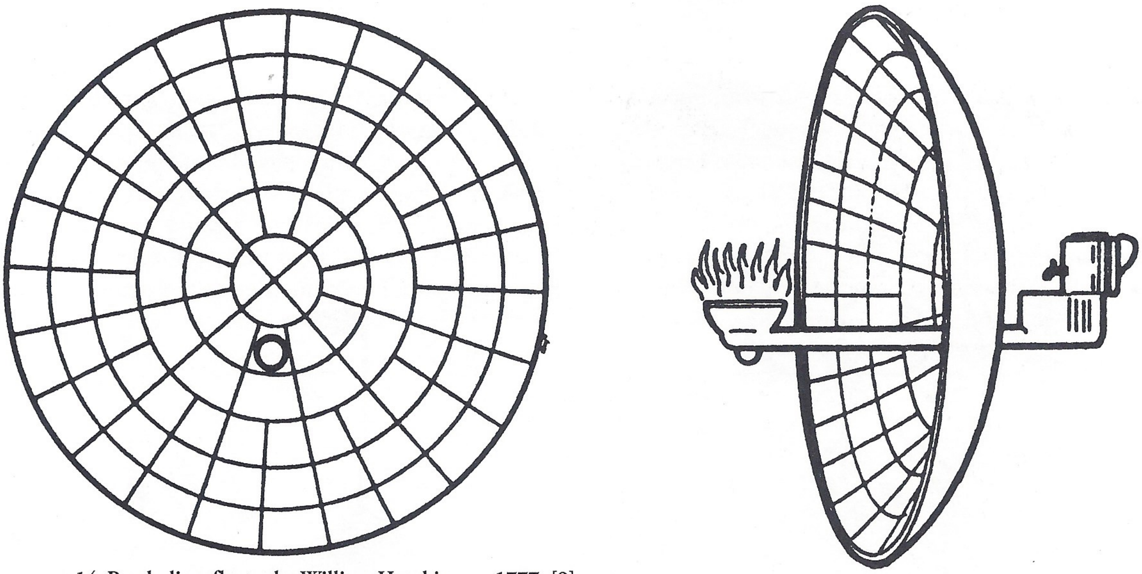
r. Malaga
s. Soller
t. Collioure
u. Port Vendres

GREECE, TURKEY

v. Cassandra
w. Strofadrhes
x. Constantinople

Medieval lights – AD 1600, North Europe

1.	Youghol IR	1190
2.	Falsterbo S	c.1210
3.	Travemünde D	c.1220
4.	Hook Head IR	1245 (810)
5.	Winchelsea GB	1261
6.	Lieps D	1266
7.	Yarmounth GB	1277
8.	Brielle NL	1280
9.	Nieuwport B	1284
10.	Hunstanton GB	13th c.
11.	Arundel F	13th c.
12.	Hiddensee D	1306
13.	St Catherine GB	1314
14.	Warnemnde D	1348
15.	Harfleur F	c.1364
16.	Ostende B	b.1366
17.	Blankenberg B	b.1366
18.	Dunkirk F	b.1366
19.	Westkapelle NL	1370
20.	Dieppe F	1389
21.	St Michaels M GB	14th c.
22.	Cordouan F	c.1400 (806)
23.	Spurn Point GB	1427
24.	Goeree NL	c.1440
25.	Heyst NL	c.1440
26.	La Rochelle F	1445
27.	Terschelling NL	1462
28.	Huisduinen NL	c.1462
29.	Texel NL	c.1462
30.	Vlieland NL	c.1462
31.	Hela P	1482
32.	Weichelsmünde P	1482
33.	Pillau P	1526
34.	Schweningen NL	b.1531
35.	Gollenberg D	b.1532
36.	North Shields GB	1536
37.	Riga Est	1536
38.	Newcastle GB	1540
39.	Le Havre F	1540
40.	Tynemouth GB	1550
41.	Ter Heide NL	b.1550
42.	Petten NL	c.1550
43.	Leith GB	b.1552
44.	Dragör DK	1560
45.	Skagen DK	1561
46.	Anholt DK	1561
47.	Kullen S	1563
48.	Aberdeen GB	1566
49.	Bell Rock GB	1500s
50.	Brandaris NL	1593



14. **Parabolic reflector by William Hutchinsson 1777. [9]**

the Northern Commissioners. Stevensons were employed to handle lighthouse engineering projects over a period of nearly 200 years. Six Stevensons were deeply involved in the construction of altogether 81 lighthouses, and played some part in the most inventive period in the development of optics and apparatus generally.

Optical development

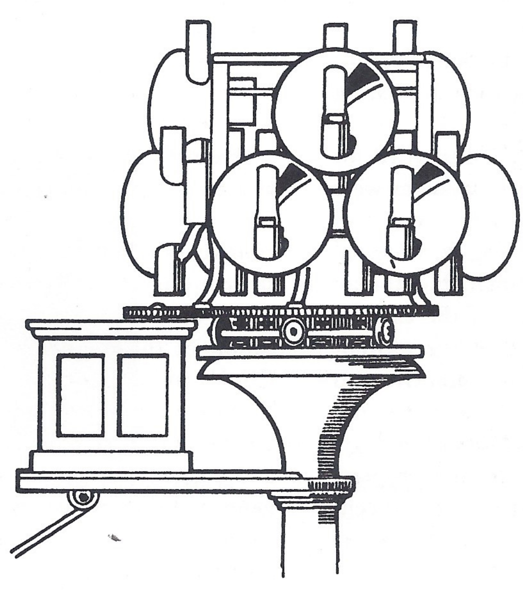
When the plan was adopted of employing rape-oil lamps and reinforcing the light my means of polished metal reflectors, a gigantic step forward began. Candles and flames using oil were too feeble light sources before the concentrated beam was invented.

The earliest use of metal reflectors seems to have taken place in the Baltic in 1532, at the lighthouse of Gollenberg, which had a single lamp with a metal reflector. More definitive are the records from Landsort in Sweden where a lamp with a metal reflector designed by Johan Daniel Braun was used between 1669–1677, until the tower burned down — then to be replaced by a coal fire. Örskär 1687 had five large parabolic metal reflectors with six oil lamps each, the first lighthouse in the world where the illuminating power was reinforced by some kind of additional apparatus. It was not efficient however, as too many ex-focal lamps spread the light and covered the reflectors by smoke.

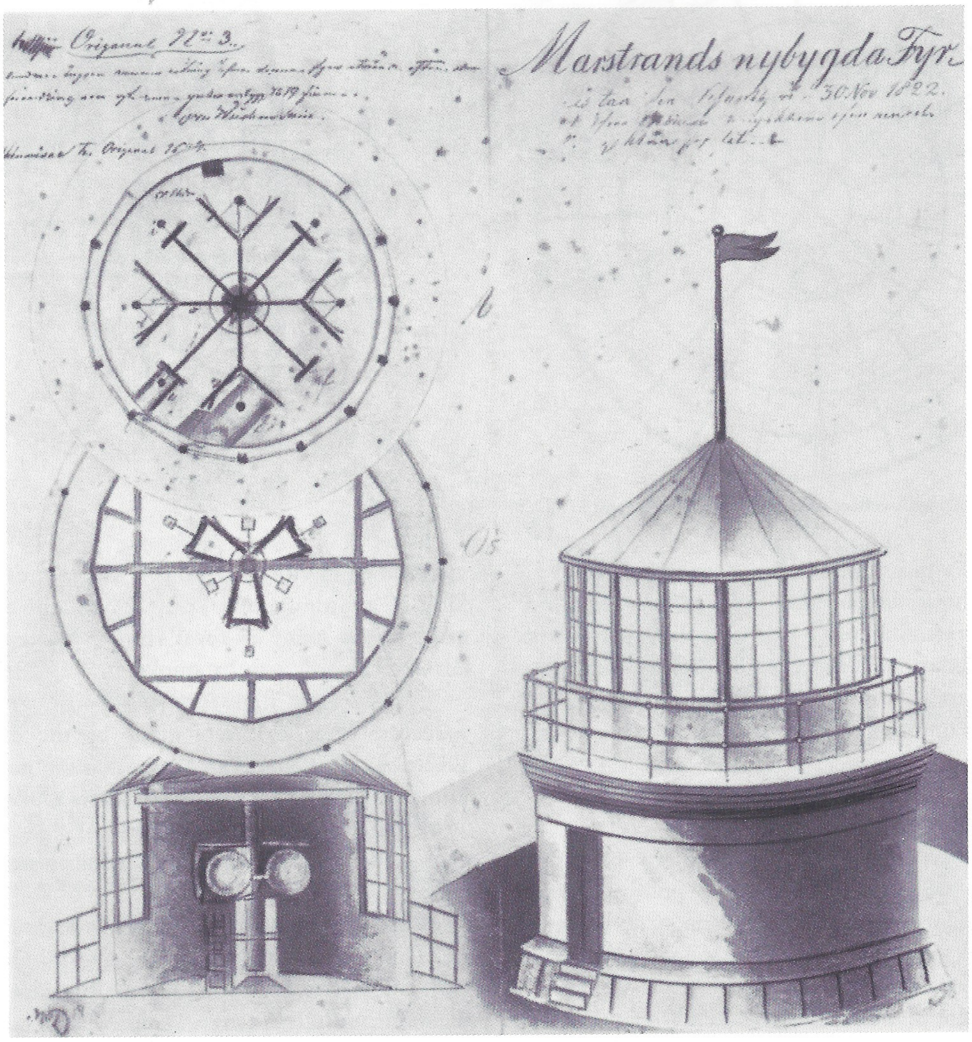
1763–77 the first scientifically designed parabolic reflectors (Fig. 14) were made by the dockmaster in Liverpool, William Hutchinson. These had facets containing pieces of silvered glass set in a plaster parabola. With parabolic reflectors the use of a small sized light source was essential in order to concentrate the reflected rays.

When the reflectors were rotated, flashes were produced. This fact was realised by the Swede, Jonas Nordberg (1711–1783), who came up with the idea of arranging parabolic reflectors on a stand which was rotated by means of clockwork. (Fig. 15.) Now it became possible to obtain periods of alternate light and darkness which could be combined in many different ways so as to form characteristic flashes.

Following experiments in the lighthouses at Korsö (1757) and at Örskär (1768) with reflectors rotated backwards and forwards by hand driven mechanisms the system was adopted in full. The first revolving beam lighthouse in



15. **Rotating catoptric (mirror) system. [9]**



16. Carlsten lighthouse near Marstrand Sweden. Drawing form 1820 shows the first revolving light in the world established by Jonas Nordberg in 1781.

the world began service in 1781 at Carlsten on the West Coast of Sweden. It had a slowly rotating catoptric (only reflectors) system including three wick lamps with two reflectors each. (Fig. 16.)

Lighthouses based on the Nordberg's system were erected in 1784 at Dieppe and in 1785 at Liverpool. In France in 1790, J.C. Borda and Joseph Teulère equipped the famous Cordouan lighthouse with a rotating array of 24 Argand lamps with reflectors.

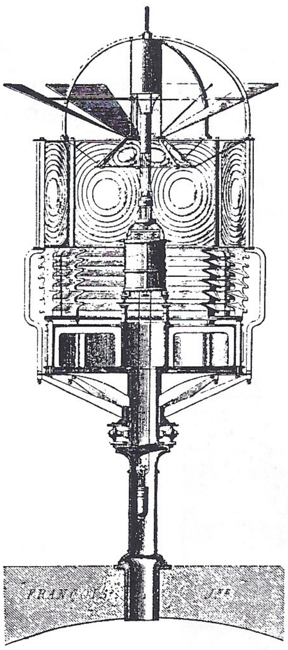
Until the 19th century, only reflectors were used for directing the light beams. These **catoptric** systems were limited by the practical problems caused by the size of the mirrors and thus the great weight. Augustin Fresnel (1788–1827), a member of the French Lighthouse Commission, realised the shortcomings of the existing catoptric method. Great improvements in the technology were made by his invention of the **dioptric** and **catadioptric** lens systems which took his name and revolutionized the lighthouse illumination technology. The dioptric system employs only the refractive property of glass to make the equivalent of a large lens by concentric rings of small prisms and a catadioptric system uses both reflection and refraction.

The apparatus Fresnel constructed for intensifying and directing light consists of narrow polished lens elements of glass. Similar optics to Fresnel's system were investigated and designed by Buffon in 1748 and the French mathematician Antoine de Condercet suggested making separate rings instead of a single lens in 1773, but neither of them turned their theories into practice. In England, David Brewster claimed to have preceded Fresnel by ten years as the inventor of the "polyzonal" lens.

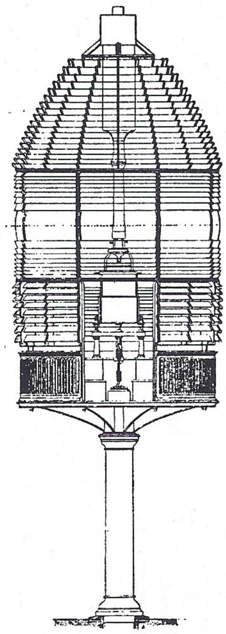
Fresnel's system was very simple. It may be described as a bull's eye, around which are disposed a number of concentric rings of glass. The advantage was a light, thin construction which absorbed only 1/10 of the light passing through it, compared to the old parabolic systems which absorbed half the light. The first practical application of the Fresnel lens took place in the tower of Cordouan in 1823.

Now sharp horizontal pencil beams could be produced by optical systems large enough for powerful lights and rugged enough to withstand the heat such lights generated. Fresnel assembled lenses and prisms in panels to rotate around a single lamp in order to produce several beams. Augustin Fresnel died in 1827 aged only 39. In the mid-19th century his systems were improved to a far greater degree than Fresnel ever contemplated by two British men, Alan Stevenson and James Timmins Chance of Birmingham. They perfected the catadioptric (mirrored and refracted) system in which extra prism sections acted as mirrors to return the light wasted upwards and back into the light source. The vertical collection of light was thereby increased and distributed as required.

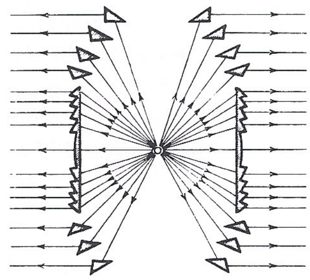
Equipment such as dioptric lens panels was first constructed in Paris by Leonor Fresnel (Augustin's brother). Leonor Fresnel was employed in 1831 by Messr Cookson, of Newcastle in England who also started development of Fresnel lenses. They built lenses for fifteen British lighthouses until 1845 when their work was discontinued. At that time Letourneau & Lepaute in Paris were the dominating manufacturer of lighthouse optics.



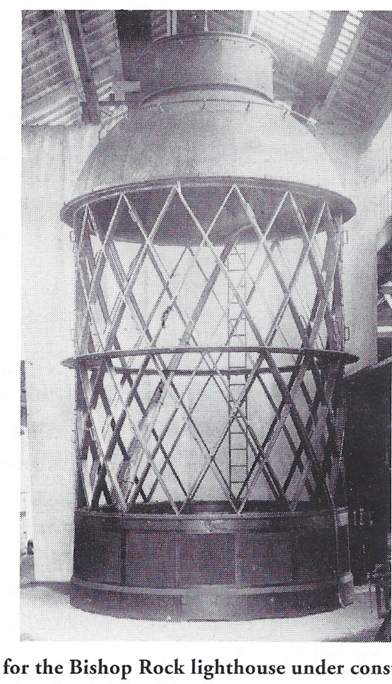
Fresnel's first lens system installed at Cordouan 1823



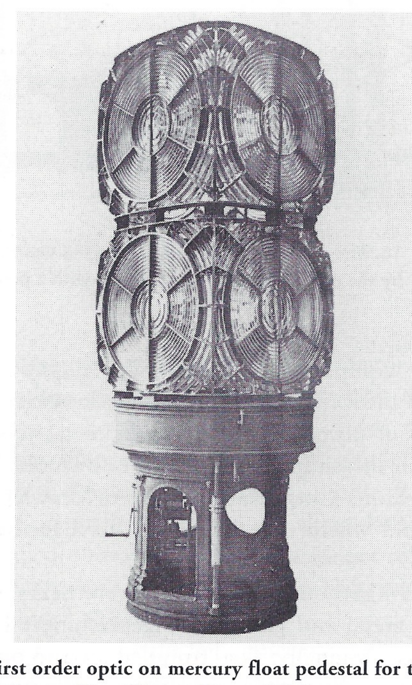
Catadioptric Fresnel lens for fixed light.



Principle of catadioptric lens system.



Lantern for the Bishop Rock lighthouse under construction in Chance Bros. factory 1892.

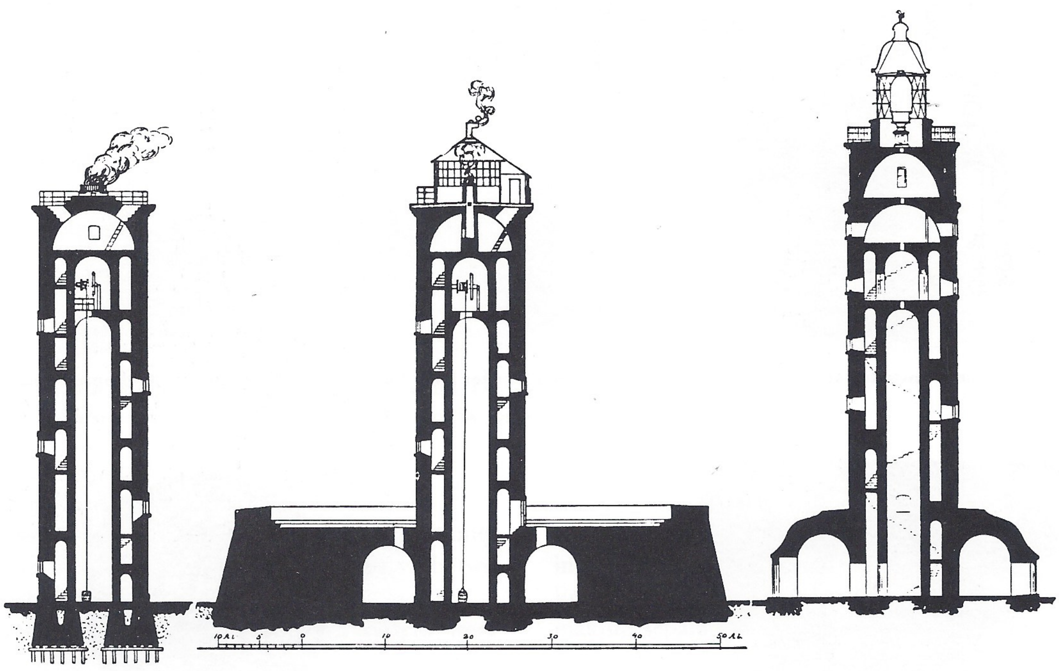


Biform first order optic on mercury float pedestal for the Fastnet Rock lighthouse, Eire (Chance Bros., 1906)

17. Different lighthouse optics from the 19th century.

Lens grinding and polishing was pioneered in France and was much advanced in 1840 when the grinding and polishing of pot-produced glass was employed. In these early days the only glass for prisms was made at the St Gobain and Prémontré glassworks in France. In 1824, Robert Lucas Chance purchased a crown glass factory near Birmingham in England and founded Chance Brothers. In 1850, Chance Brothers began making optical lens glass assisted by the French experts, Tabouret and Bontemps. They specialised in lens manufacture and kept close contact with the Stevenson family. Some years later James Timmins Chance and his colleague and successor Dr. John Hopkinson took up the manufacturing of special lighthouse lenses. Soon they found that they had to make the allied equipment for accurate mounting of the optics in order to stay in business. Chance Brothers then became the only manufacturer of lighthouse optics in England. They also made the entire lighthouse equipment, including the engine-generator plants and intricate switch-gear when electricity became the means of power. They also built metal towers and powerful air driven foghorns. The firm was sold in 1955, becoming Stone-Chance and moved to Crawley in Sussex, England where they continued for a further thirty years.

The old lighthouse optic arrays were heavy, and the weight of metal and glass rotating machinery could be five tonnes. Originally, they trundled around on rollers, but now the idea of floating them on mercury was developed. It originated from the French lighthouse expert M. Bourdelles in 1890 and was perfected by Dr. John Hopkinson in Chance's team. The beams could then be rotated faster by the usual weight-driven or spring driven clockwork, and the spacing of the lens panels determined the sequence of flashes. Later, the heat from the fuel of the lamp was used to vaporise into gas for consumption in a mantle producing enhanced luminance. In smaller apparatus the rising heat was employed for rotating occulting screens around a stationary lens (common in Norway).



18. The open coal light of Anholt 1788 was transformed to a closed coal light in 1809–14 and by the end of the century equipped with a petroleum burner and a rotating Fresnel lens. [2]

The development of modern lighthouses and lightships

The lighthouse and beacon design were largely influenced by the prevailing lighting system. The old beacon towers for coal fires were stocky, sturdy buildings. The covered lanterns had an ash-shoot down the middle as well as draft flues and a stairway built inside the wall. Such beacon-houses were 8 to 12 metres in diameter.

Lighthouse towers from the early 18th century were often made of wood, but these could be washed away in severe storms. The decisive advance in lighthouse construction was the invention by the Englishman John Smeaton. He designed the first lighthouse made of interlocking masonry blocks on the Eddystone Rock in England in 1759. (Fig. 19.) Later on, he was the first after the Romans to develop a cement that could set in water. Following the success of Smeaton's innovations, a large number of lighthouses were built in the open sea. Interlocking masonry blocks remained the principal material for lighthouses until they were replaced by concrete and steel.

The development of lanterns enclosing mirrors and lenses in conjunction with various lightsources during the 19th century gave rise to varying types of lighthouses. As Argand lamps developed into multiple wick burners for use in lighthouses, the size of optics grew into apparatus of "mammoth" dimensions and weight, culminating in such as were installed at Bishop Rock (southwest of Isles of Scilly), Bull Rock (off Western Eire), etc., where the optics measured 3.5 m in diameter and 6 m in height. This coupled with its pedestal and rotating machinery, weighed over 10 tonnes and needed a lantern exceeding 6 m in diameter and 10 m in height! This epoch in the lighthouse development was known as the "Era of magnificence". Such equipment required a tower of masonry and, if built upon a rock at sea, was usually of interlocking granite blockwork.

The incandescent mantle "PV" burner introduced in 1912 had the effect of slightly reducing the size of optical apparatus in most cases. But, when electrical illuminants emerged, it was customary to make the filament size fit the original optical apparatus. This resulted in certain excesses in performance until it was realised that smaller apparatus, which required a lighter structure, would suffice.

Tubular iron towers, some in open-work form, took the place of many heavy structures, particularly when a pile substructure was required in mud, sand, swamp or coral. Open-work steel towers, particularly for beacons are installed universally, but are fairly inconspicuous, whereas the modern, unattended lighthouse of the 20th century is of modular glass-reinforced plastic and, pigmented in its Daymark Colours, is particularly conspicuous by day. Its light, although as powerful as many of the former "mammoth" types, needs no separate outer lantern and measures overall less than a cubic metre.

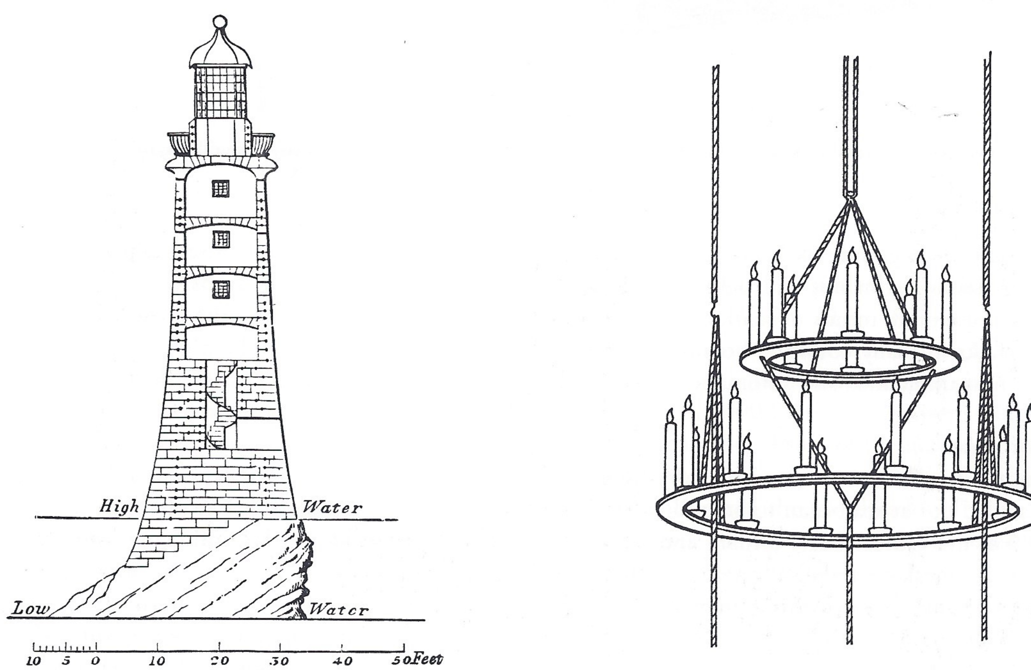
Lightvessels

The requirements for introducing lightships and lightfloats arose firstly because sandbanks of shallow seas and river estuaries shifted and were moved by tides and winds. This created difficulties for the seafarers, especially at low tide. Also the technology for erecting towers in sandbanks was in its infancy.

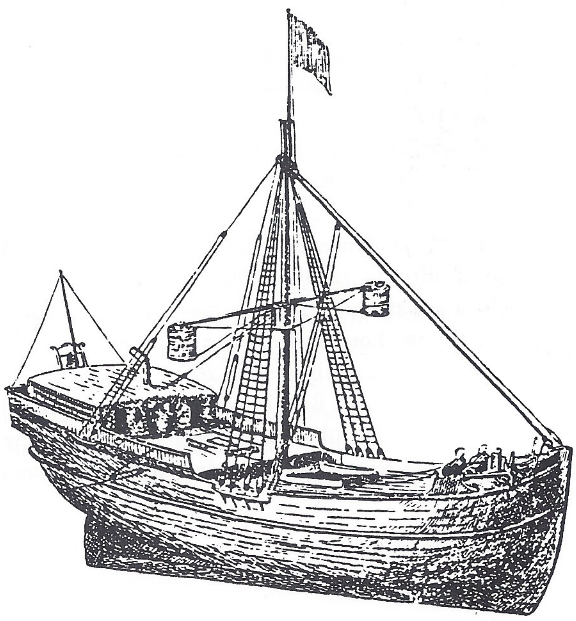
There is some evidence that lightvessels were used in Dutch waters already in the 15th century. The first known lightship was moored at the Nore in 1732, marking the fairway into London from the Thames estuary. It had two lanterns and a fog bell. (Fig. 20.)

The next lightships in Britain were moored at several stations around 1788 and these earliest lightships were converted cargo vessels. Sturdy wooden ships were then specially designed, with oil burning reflector lights fitted to gimbals so they were unaffected by the rolling and pitching of the ship. Later on, reeds and sirens sounded by compressed air were also installed. At first, ships with a single mast carried a single fixed light. Then, for identification, two or three lantern masts were installed. However, lightships were not considered a stable enough mark until chain cables had been invented and introduced. (1820)

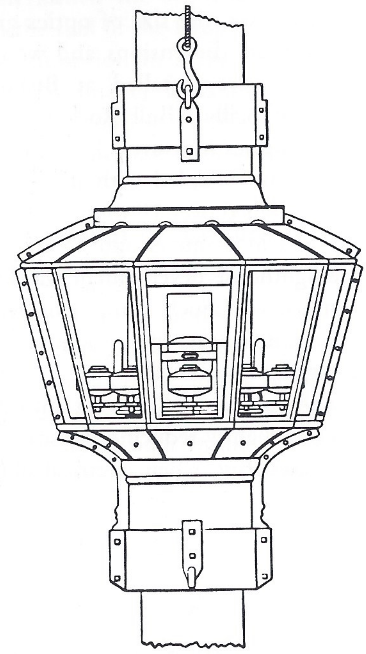
In order to increase the light efficiency and replace costly lightships (which needed a crew of 10–15 people) the last part of the 19th century saw foundations being laid in cylindrical caissons wherever the bedrock could be reached. On such a deep and secure foundation the top structure



19. The Eddystone tower by John Smeaton and the light source employed. [4], [9]



20. The first recorded lightship at Nore Sand in the Thames estuary 1732.



21. Lightship lantern encircling the mast by Robert Stevenson 1807. It had ten oil lamps. [3]

could be built either by granite blocks or of metal lattices. However, even today, lightships and lightfloats continue to be the most economic means of marking fairways and shifting sandbanks in many countries because these ships and floats are now unmanned and automatic.

Caisson lighthouses

The first caisson structure to be constructed ashore, floated and installed out at sea began to be built at Rothersand in 1880 at the Outer Weser estuary and seaway to Bremerhaven. Bremerhaven was selected, because it was the home port of the large North German Lloyd Atlantic liners, but the river mouth is hemmed in by shoals and sandbanks. This required improvement to the waterways and lightships were not considered appropriate. A caisson was installed, but whilst filling it with sand it moved, turned and drifted away to swampy ground where it sank. After many enormous difficulties and incidents, which required a lot of talent and money, a new caisson was secured. The lights at Rothersand were first shown in 1885. (Fig. 22.) It was then connected to a submarine electric cable in 1895.

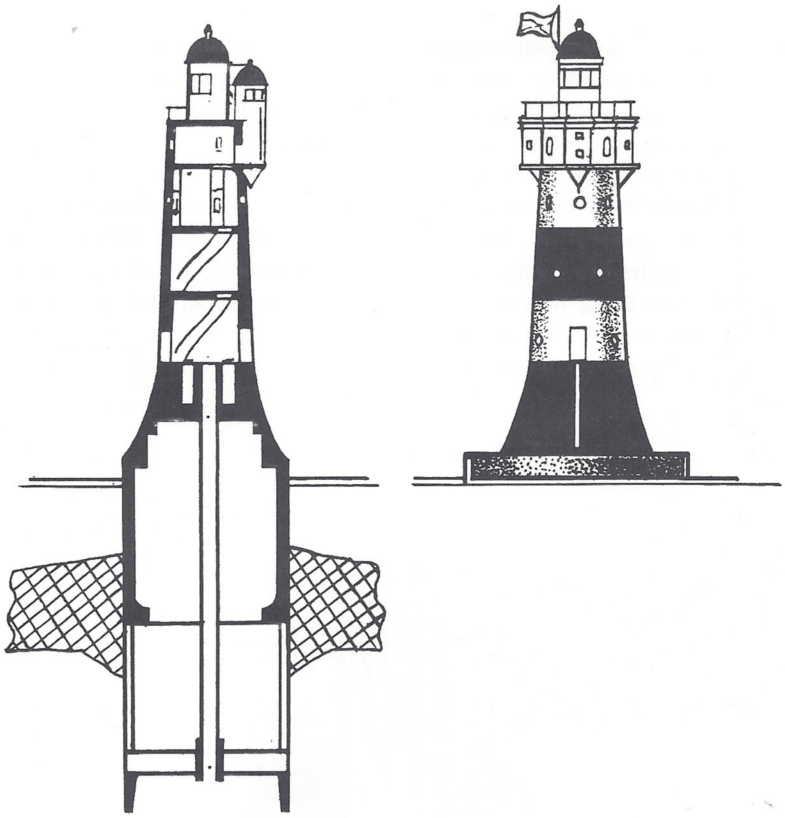
Illuminant development
The unattended lighthouse

Hand in hand with the development of the optical apparatus have been improvements in regard to the illuminants and the methods of producing a brilliant, clear flame.

Up to a couple of thousand years B.C., fire was the prevailing light source, but extra light was created by using torches of wooden sticks dipped in fat. The Egyptians invented the oil lamps with a wick and these were then commonly used by the Greek and Roman peoples.

Oil lamps began to be used in lighthouses during the 16th century. Crude and refined oils of vegetable and animal origin such as sperm oil (from whale) or colza oil (from wild-cabbage) were first used. Both were very expensive so the maintenance of a light was costly. Later on, cheaper alternatives like olive oil, oil from seeds, seal oil, herring oil and lard oil came into use until, in the middle of the 19th century, petroleum became available. In many locations where coal or wood fires were impractical the only alternative was using candles. Wax candles were used from the 15th century, but they were rare and expensive to be used everywhere. Only churches, which were rich at that time, could use them regularly. The cheaper tallow candle was used from the same time, but has a bad smell and smoked. Wax candles were replaced by the cheaper stearin candles patented by the French chemist Chevreul in 1825. The first three Eddystone towers utilised chandeliers with up to 60 candles as their light sources. (Fig. 19.)

The smoke from the fires, candles, and oil lamps used as illuminants in lighthouses quickly blackened the panes of glass protecting the fire from wind and water. Aimé Argand (1755–1803), a Swiss physicist made the oil lamp smokeless in 1784. His invention, using different kinds of oils, was revolutionary. By means of a hollow cylindrical wick and a glass chimney, air was drawn up through the middle of the burner, which resulted in a cleaner, more reliable and much brighter flame with less smoke. (Fig. 23.) Powerful multiwick mechanical bur-



22. Rothersand, the first offshore caisson lighthouse 1885. [9]

ners with up to ten concentric wicks were developed and wick lighting became accepted for almost 100 years as the principal form of lighthouse illumination. With the Fresnel lens, it was possible to concentrate the light source and, by mounting the lens panels on a rotating carriage, produce a flashing code. This was a great step forward in the pursuit of maritime safety.

Advances in the process of refining petroleum led to "earthoil" being employed for lighthouse purposes. The Argand burner was much used in conjunction with paraffin, which in time, became the cheapest and most efficient illuminant known.

In some countries other types of oil fuels were adopted. In Germany compressed oil-gas, water gas and Blau liquefied gas were utilised. The advantage of Blau gas was that it could be transported in steel cylinders at about 100 atm. pressure compared to 10 atm. for oil-gas. Different types of oil vapour lamps were developed by Matthews, French, Pintsch, and Diamond which differed only slightly in details of construction.

Coal gas (town gas) was the first gas to be used as an illuminant in a lighthouse at Salvatore, Trieste in 1818. (Fig. 24.) John Wigham introduced a gas system in 1865 at Howth Baily, Dublin, complete with miniature gas works. Julius Pintsch (1810–1884) in Berlin, first developed oil-gas lights for railway carriages and then entered the marine light field with his gas system. He founded a new company, which still continues as Pintsch-Bamag. Pintsch oil-gas was first used for light carried on a buoy in 1878, unattended for 1 month.

The Pillau lighthouse in Poland became the world's first unattended lighthouse with Pintsch gas delivered through a one kilometer long pipeline. An automatic occulter, worked by the gas passing from the reservoir to the burner, was introduced in 1883. This type of flasher could give intermittent bursts of light which could be discriminated from lights ashore, but not give a special signature. More than 400 Pintsch buoys were sold in 15 years.

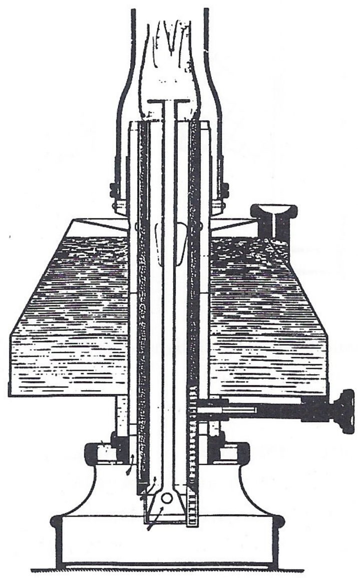
The invention in 1885, of the incandescent gas mantle by the 27 year old Carl Auer von Welsbach (1858–1929) in Vienna, changed the possibilities of using gas lighting in lighthouses. He used a silk mantle coated with chemicals to obtain a very bright flame. First it was used for gas, but after some years, it was used with oil vaporised in the burner. Lights with a mantle could exceed 1 Million candlepower, but the cost of maintaining the light was comparatively low owing to low oil consumption. By employing petroleum incandescent light mantles as a source in large lighthouses (instead of employing petroleum lamps with wicks), considerable increase of the lighting power was obtained.

The next major advance in illuminant sources was the invention of the Pressurised Vapour Burner (PVB) with incandescent mantle by Arthur Kitson 1901. The PVB system used the light mineral oil as in the wick lights but, by pressurising the oil and heating it to a vapour in tubes above the burner, sufficient heat was produced to ignite a collodionised silken mantle. This was positioned over the burner, giving a very bright flame which, in its developed form, gave up to six times the illumination compared with a wick burner. It was at this stage that developed versions of Kitson's PV burner were invented, notably by David Hood of Trinity House and Chance Brothers.

Optics and illuminants were now developed to satisfactory levels. But, fixed light could still be confused with a ship's mast light. Even a flashing light had a risk to be mistaken for the twinkling of a brilliant star. Therefore, special flashing characteristics must be developed. In 1811, Robert Stevenson (1772–1850) developed an intermittent mechanical flashing apparatus. This was for mirror optics with two cylindrical screens, which were vertically movable. It did not come into use anywhere else due to large size and some malfunctioning.

The group-flashing light was invented by Dr. John Hopkinsson in 1875. During the 1870s Sir William Thomson (lord Kelvin) was urging the authorities to adopt a system of short and long flashes representing the dots and dashes of the Morse code to each lighthouse. This would proclaim the identity. He reported that he found "the authorities exceedingly heavy to move" where new ideas were involved, and welcomed Stevensons policy of speeding up the revolutions of older apparatus in order to obtain flashing characters.

The "Zenith" in the design of attended apparatus for use with kerosene oil emerged in the latter part of the 19th century with massive optical systems in "Biform" (one optic and burner superimposed upon a second, identical optic). These were of up to 1330 mm focus, mounted upon a mechanical carriage with a weight driven machine, all inside a lantern 10 m in height and up to 6 m diameter. The lantern was most ingeniously designed by Sir James Douglass — an eminent engineer of Trinity House. Rising heat from the burners caused air to be drawn into the double wall of the lantern base — past the glazing — (thus quelling condensation) and up into a high double-roofed dome, through a large roof ventilator, to the air outside. Douglass was also responsible for building many of the tower-rock lighthouses, including the present Eddystone, Wolf Rock, Smalls Rock and Bishop Rock in the British Isles, and some overseas.



23. Argand lamp. [10]

Towards the unattended lighthouse

The middle of the 19th century was the beginning of "the golden age of sail" when large, elegant Clipper ships were constructed and became employed in intercontinental trade. But, very soon however, Clippers had to give way to steam ships, first driven by coal and then oil. Sea traffic increased tremendously when fast and reliable sea transport of goods could give accurate time schedules. Due to this prospering of sea trade due to faster, steam driven ships, a great expansion of the lighthouse system was required . The approximative number of coastal and leading lights in the world had increased slowly from 40 in 1600 to 80 in 1700 and 200 in 1800. Now the increase was extensive, from 500 coastal lights in 1840 to about 8000 in 1900 and 12000 at the outbreak of World War I in 1914.

Sweden, whose coastline has numerous waterways along it, required a large number of lights. It was necessary to obtain a safe and complete lighthouse system, including new leading lights with recognisable light characters, at the least possible cost. Therefore, the Swedish Lighthouse Department made endeavours to obtain reliable, automatic light systems which could be left without inspection for a considerable period. This started a chain of unique developments which in the end improved marine safety all over the world.

First Carl Gustaf von Otter, in 1865, constructed a flashing apparatus in order to obtain different light characteristics, using the expensive lens systems already employed for fixed lights. It was a system of Venetian blind-type rotable shutters which, by means of clockwork, opened and closed at fixed times. This allowed the light to show or be occluded. This apparatus was further developed in co-operation with G.W. Lyth in 1875–78. A similar apparatus by Lyth, had a mantle which was periodically raised and lowered, thereby causing a dark period at certain fixed times. The aim was to give a lighthouse its special light characteristic by an agreed code.

A single, large lighthouse reflector driven by clockwork and which rotates rapidly around its focus, (thus creating very short flash periods), was designed in the 1870s by John Höjer (1849–1908). He later played an important role as a mentor and motivator for the development of the AGA system.

Movements could cause a surge in the supply of oil in vaporised oil lamps resulting in excess carbon deposit. In 1881 C.R. Nyberg and Lyth had a solution to this problem. They designed an oil-gas buoy lamp system which did not require attention more frequently than every tenth day. In 1889, a similar lamp for kerosene was developed. In 1882, L.F. Lindberg constructed an intermittence apparatus which consisted of light screens. These were made to rotate around a flame by means of the heat from the lamp. All these earliest designs for characteristic and automatic lights were employed abroad. By 1914 in Sweden, 200 leading lights were equipped with Lyth's kerosene lamp and Lindberg's rotator.

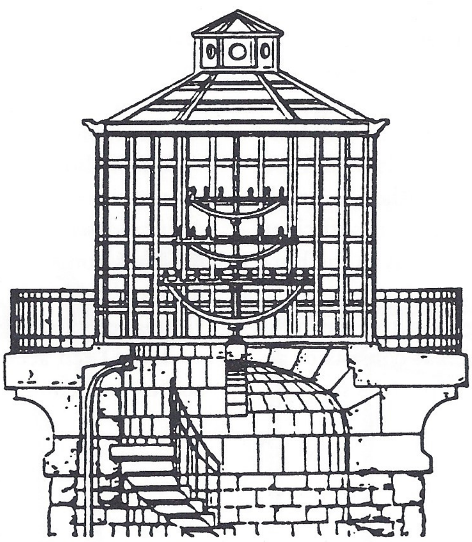
Acetylene light

The history of acetylene as an illuminant in navigation commenced almost simultaneously in Canada and Sweden in 1904. In that year, Leopold Willson (known as the inventor of the acetylene process, 1892) conceived the idea of automatically generating acetylene gas in a buoy. In conjunction with this he employed the best type of light apparatus then available, namely the Pintsch buoy lantern with Fresnel lens. Acetylene produces 5–10 times higher illumination than an equal volume of oil gas.

The immense increase in light power over the older forms of floating aids using oil or oil gas, together with the longer period of uninterrupted operation available, caused the Canadian government, after a short test period, to adopt the Willson buoy as a standard. By 1911, more than 250 buoys with carbide generators for making acetylene were in use in Canada, but no other country adopted the method. The old Pintsch system was discarded. Attempts to use compressed acetylene in Pintsch buoys in Canada and South America resulted in terrible explosive accidents.

At the time Willson was working on his carbide generator type buoy the AGA system was developed in Sweden. Two Frenchmen George Claude and Albert Hess had, in 1896, discovered a method of storing and transporting compressed acetylene gas by dissolving it in acetone held in steel cylinders. In this form the powerful acetylene light began to be employed in lighthouses in different countries. John Höjer, at that time in charge of the Swedish lighthouse engineering, started trials with the French ”acetylene dissous”. There were, however some problems. The light source was good, but as the flame burned continuously, the expense was too great and no other light character than fixed light could be obtained. In addition, the acetylene cylinders could not be used without danger of exploding.

The long-sought for ideal of a fully satisfactory



24. Coal gas used as the illuminant in Salvatore lighthouse. Trieste 1818.