Hafgerdingar: a mystery from the *King's Mirror* explained

Waldemar H. Lehn
Electrical and Computer Engineering, University of Manitoba, 504 Engineering Building, 15 Gillson Street, Winnipeg, Manitoba R3T 5V6, Canada (lehn@ee.umanitoba.ca)
Irmgard I. Schroeder
60 Thatcher Drive, Winnipeg, Manitoba R3T 2L3, Canada

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ABSTRACT. The medieval *King's Mirror* describes Iceland and Greenland with a scientific accuracy that is remarkable. One of the very few exceptions is the *hafgerdingar* in the Greenland Sea. The term translates as 'sea hedges,' within which a mariner may become trapped at great peril. Many have believed that a real event was being described, although none of the proposed explanations has been totally satisfactory. The most common view currently is based on Steenstrup (1871), who explained the phenomenon as a tidal wave following a submarine earthquake. A simpler and more consistent theory is developed here: that the *hafgerdingar* are an optical phenomenon, specifically, a superior mirage. Such mirages, quite common in the polar regions, can produce an appearance fully consistent with the original description, as illustrated by several photographs and a computer simulation. Even the peril to seafarers has been corroborated, in the sense that such a mirage is frequently followed by a storm.

Contents

Introduction

The remarkable thirteenth-century manuscript known as the *King's Mirror* contains accounts of Iceland and Greenland that are rational and accurate to a degree not usually found in writings of the time. There are only four anomalies in the Iceland and Greenland accounts, anomalous in the sense that they portray fantastic descriptions apparently based on superstition or invention. The authors propose to examine these anomalies and to show that they also can be interpreted as rational observations of natural phenomena. Then the entire accounts of these two regions become consistently accurate scientific descriptions.

The *King's Mirror* survives as a number of manuscripts and fragments, from which complete renderings of the lost original have been assembled (Larson 1917: 65; Brenner 1881: x–xvi; Keyser and others 1848: xiii–xvi). Two almost complete manuscript copies survive in the Arna-Magnæan Collection. The oldest, written around 1280, a few decades after the composition of the original, is known as the Norwegian main manuscript, and designated AM243B (Whitaker 1985; Jónsson 1921). The other is AM243A, a younger Icelandic copy dating from the fifteenth century (Brenner 1881: x).

These two manuscripts differ in the sequencing of the 11 chapters that describe Iceland, Ireland, and Greenland. The older one contains four chapters on Iceland, followed by two on Ireland and five on Greenland. This sequence is preserved in printed editions such as Brenner (1881) and Jónsson (1920). The younger version places the Irish chapters first, followed by those on Iceland and Greenland. This is the order that appears in the Christiania edition (Keyser and others 1848) and in Larson's 1917 English translation.

The sequence becomes of interest when one examines the contents of these 11 chapters. They are largely free of superstition; rather, they are based on common sense, logic, and keen observation. The exception is the Irish chapters. In contrast to the rational tone of the rest of the work, these are almost entirely mythical, beginning with a discussion of the holy soil of Ireland and continuing with miraculous objects like floating islands that heal the sick. The Irish section has been much studied in an effort to identify its source (Meyer 1910; Young 1938). It seems generally agreed that the author of the *King's Mirror* was not using personal experience or first-hand accounts when he wrote about Ireland. Finnur Jónsson (1921) concluded that the author copied the Irish material from other sources,[1] while he obtained the accurate material about Iceland and Greenland from seafarers who had actually been there and had first-hand experience that tallied with his own. Whitaker (1985), on the other hand, referred to linguistic studies indicating that the Irish account is almost certainly an interpolation. In this sense the sequence of AM243A is the most logical, because it separates the fantastic from the factual sections. One could speculate whether the Icelandic copyist reorganised the chapters to emphasise the qualitative distinction between them. In any case, the Irish sections will be disregarded in this discussion of the veracity of the *King's Mirror*.

The scientific accuracy of the *King's Mirror* has been widely discussed. Whitaker (1985) examined the discussion of life in Greenland, finding 'a remarkably high standard of veracity for a medieval text.' Fridtjof Nansen (1911: II, 242ff) mentioned the correctness of the identification of marine life in the North Atlantic. In 1921, Nordgård published a study in which he identified all 32 of the creatures described. Whitaker (1986) reviewed these descriptions, revising some of Nordgård's conclusions and identifying 26 species.

Two animal species and one natural phenomenon remain unsatisfactorily explained. To the modern reader these mysteries are out of place, because, unlike all of the other descriptions, they border on the supernatural. The *hafgufa*, often translated as 'kraken,' is said to reside in the Iceland Sea, while in the Greenland Sea one can find the *hafstramb* and *margygr* (merman and mermaid), and the *hafgerdingar*. In a series of papers, the authors will examine these exceptions to accepted knowledge, track their historical development, give the current interpretation, and propose a new one.

Hafgerdingar

This paper examines the *hafgerdingar*. Of all the mysteries of the *King's Mirror*, this one carries the least historical baggage. There are very few medieval references to it, and there is only one widely known previous theory to explain it. Although not entirely satisfactory, this theory appears in most textbooks.

The following description is quoted from Larson (1917: 137–138). The original word for the phenomenon is given in brackets. Larson's text contains only his English translation of it.

> Now there is still another marvel in the seas of Greenland, the facts of which I do not know precisely. It is called 'sea hedges' [*hafgerdingar*], and it has the appearance as if all the waves and tempests of the ocean have been collected into three great heaps, out of which three billows are formed. These hedge in the entire sea, so that no opening can be seen anywhere; they are higher than lofty mountains and resemble steep, overhanging cliffs. In a few cases only have the men been known to escape who were upon the seas when such a thing occurred. But the stories of these happenings must have arisen from the fact that God has always preserved some of those who have been placed in these perils, and their accounts have afterwards spread abroad, passing from man to man. It may be that the tales are told as the first ones related them, or the stories may have grown larger or shrunk somewhat. Consequently, we have to speak cautiously about this matter, for of late we have met but very few who have escaped this peril and are able to give us tidings about it.

This description of the *hafgerdingar* is the only known one in existence. However the word itself appears in other places, without definition. The most important reference occurs in several sources that describe the colonisation of Greenland. In *Grænlendinga Saga* (Jones 1986), the word is associated with an implied disaster at sea. The saga relates how, in 986 AD, Erik led a fleet of 25 ships to found the first colony. The settlers must have encountered severe difficulties at sea, because only 14 of the ships arrived safely in Greenland. During the voyage, aboard the ship owned by Herjolf, a Christian passenger was moved to compose the *Hafgerdingadrápa*. The surviving lines of this poem, while containing no description of what occurred, suggest that the author was in fear for his life. Neither does *Grænlendinga Saga* make any mention of what actually happened.

The *Landnámabók* is more specific (Benediktsson 1974). As before, a Christian travelling on Herjolf's ship composed the *drápa*. Two versions of the story (*Hauksbók*: 81v; *Thorðarbók*: 8r) flatly state that Herjolf came into *hafgerdingar*: 'Herjólfr...er fór till Graenlands ok kom i hafgerdingar' (*Hauksbók*). Curiously, another version (*Sturlubók*) does not contain this line, possibly because the author did not understand or believe it. Jones (1986: 11), on the basis of corroborating evidence, considered *Hauksbók* to be more accurate than *Sturlubók* in the description of the Norse discovery of Iceland; perhaps the former is more accurate here as well. It does seem clear that an unusual and hazardous event occurred during the passage to Greenland.

The only other reference from the medieval period is a heading in the *Bishops' Saga* (*Biskupa Sögur*) (Vigfússon and others 1857: 483), where it is called 'Frá hafgerdíngum.' It appears within the story of Godmund, Bishop of Hólar from 1203 to 1237. In 1202 Godmund made a voyage from Iceland to Norway, during which his ship was subjected to a series of violent storms. In the section under the above heading, there is a description of one particularly large wave, the onslaught of which the ship barely survived: '. . . so big a wave that they thought their death was certain . . .' (Vigfusson and Powell 1905: I, 614). Whereas the word *hafgerdingar* does not appear in the text itself, it seems reasonable that this is the event to which the heading refers. Although a single rogue wave does not quite fit the *King's Mirror*'s description, the account does illustrate that the concept remained in the minds of mariners in the thirteenth century.

Existing interpretations

Nansen (1911: II, 244) believed that the description of the *hafgerdingar* was based on observation of a natural phenomenon. He tentatively suggested two possibilities. The huge waves may have been caused by submarine earthquakes, which are not unusual around Iceland. But Nansen found it 'curious' that the *King's Mirror* placed them in the Greenland Sea. Then he proposed that they were possibly caused by capsizing icebergs near the Greenland coast. However, the generally accepted explanation, cited by almost every author who had mentioned the phenomenon (Jones 1986: 146), was put forth by Steenstrup in 1871. He agreed that the *King's Mirror* described a naturally occurring event not confined to any specific location. As modern examples of such events, he discussed in great detail two European tidal waves that covered wide stretches of the sea: one in the North Sea in 1858, the other in the Atlantic in 1755. The latter followed a violent earthquake that shook Cadiz two hours earlier, where the tidal wave reached a height of 18 m (60 ft).

This disturbance was experienced as far away as the West Indies. On the basis of eyewitness accounts, which typically described three to five enormous billows crashing against the shore, he concluded that the three great billows of the *King's Mirror*'s *hafgerdingar* were the sequential waves spreading from a submarine earthquake. He noted the typical behaviour of such disturbances, that they are limited to regions near the shore, and that the sea farther out remains calm and unruffled.[2] It is difficult to reconcile this behaviour with 'These hedge in the entire sea.' Steenstrup also did not appear to distinguish between the Iceland and Greenland seas.

From the cases listed by Steenstrup, one may conclude that large tidal waves in Europe have been quite infrequent, perhaps a few per century. Yet he claimed that this rare *hafgerdingar* event coincidentally occurred exactly during Eirik's voyage, up against the south coast of Greenland.

Benediktsson (1981) made the case that the *Hafgerdinga Drápa* was composed some 100 years after the colonisation. How can this be explained? If one accepts the *Hauksbók* version, a *hafgerdingar* event did occur, and made a big impression. The story certainly remained current for a long time: Benediktsson estimated that the Herjolf story was first written down in approximately 1200.

Thus, there are contradictory interpretations that a) the memory of the *hafgerdingar* was vivid enough to inspire the poem a century later, and b) the seafarers with Godmund in 1202 had forgotten every tradition about the *hafgerdingar* except for its extreme danger to ship and crew (Steenstrup made this point). A more serious problem is the basic nature of the tsunami, which is brought into existence by a shallow shelving sea floor. The tsunami is not felt in the open sea. It is doubtful that the *King's Mirror* meant the *hafgerdingar* would be experienced only in the immediate vicinity of a shore. The description seems to describe something that occurs in the open sea: the ship is surrounded. It would have been easier for the story to remain vividly in memory, later to inspire the author of the *Drápa*, if there had been repeated sightings of the phenomenon throughout the intervening years. The present authors propose to show that this would indeed have been possible.

Before proceeding, two modern reports that invoked the concept of *hafgerdingar* should be mentioned. One was provided by a shipwreck on the Greenland coast in 1895 (Nathorst 1895; Hammer 1916). The royal Greenland trading ship *Hvidbjørnen*, commanded by R. Hammer, was destroyed by ice near Kap Thorvaldsen, under conditions that strongly indicated a submarine earthquake. The ship was anchored near shore in the lee of a small island, which it had reached by sailing along a strip of open water between the shore and a wide strip of pack ice. On 12 April a very large swell began disturbing the ice. This was considered highly unusual because such an ice pack, extending many miles from shore, would be expected to damp out any swell almost completely. Yet there was enough energy present to produce an indescribably violent swell, advancing in opposition to the north wind, which lasted most of the day. It tore the ship loose from its moorings and finally destroyed it. Hammer was convinced, and there appears to be no argument against his conclusion, that the swell was caused by a submarine earthquake, indeed, the crew felt several shocks after they abandoned the ship. However Hammer's suggestion that he had experienced the *hafgerdingar* was questioned by Nathorst, who, as the authors do, placed the *hafgerdingar* of the *King's Mirror* in the open sea. In other words, Hammer's account fit Steenstrup's description very well, but Steenstrup's phenomena are not *hafgerdingar*.

The second reference was a theory put forth by Lindvall (1905). He theorised that the *hafgerdingar* were produced by riptides, which can disturb the open sea over large areas. He observed one such disturbance himself, off Reykjanes. He claimed that similar ones occurred near the Faroes and the Vestmannaejyar. Nansen (1911: II, 150–154) also mentioned strong currents and whirlpools in the sea, especially the well-known *Moskenström* in the Lofoten Islands, but he did not associate them with the *hafgerdingar*. Thus Lindvall disagreed with Steenstrup in two ways. He indicated, first, that *hafgerdingar* were a phenomenon of the open sea, and, second, that they occurred in certain places. While the authors agree with Lindvall for the first, they must agree with Steenstrup for the second: the *hafgerdingar* phenomenon is not geographically limited.

Interpretation as a mirage

The *King's Mirror* placed the *hafgerdingar* out in the open sea, where even a powerful tsunami causes only a mild change in elevation as it passes under a ship. The disastrous effects of the tsunami are limited to coastal regions. The authors propose that the phenomenon is an optical effect, produced by an atmosphere that often presages a violent storm. The effect in question is the superior mirage.

In his book about his whaling voyage to the Greenland Sea in 1822, William Scoresby Jr (1823: 163) provided fascinating descriptions of many mirages. On 16 July, when he calculated his position to be 72°33′N, 19°9′W, his ship was in the Greenland Sea about 100 km (62 miles) off the Greenland coast. In his account of 'the optical phenomena of unequal refraction,' he described a striking mirage that he observed that day: 'At one period (about 10 PM of the 16th) the phenomenon was so universal, that the space in which the ship navigated seemed to be one vast circular area, bounded by a mural precipice, of great elevation, of basaltic ice.'

On page 169 of his book, he summarised several of his observations: '. . . it [the sea ice] presents the appearance of a vast amphitheatre, which is so disposed, that every observer, whatever may be his position, imagines himself to be in the centre of it.'

Fig. 1. *Hafgerdingar* photographed from Iceland.

Fig. 2. *Hafgerdingar* on Lake Winnipeg.

Although Scoresby appears to have had no knowledge about the *King's Mirror*, his description immediately brings to mind the *hafgerdingar*. Modern photographs of the phenomenon look just like the image painted by Scoresby's words. Several examples follow.

Figure 1 is an example photographed from the south coast of Iceland on 25 July 1976. In the direction of view, which is toward the southeast, there is nothing but open sea for 400 km (250 miles). A ship is visible on the normal horizon, while above it is the gray barrier of the *hafgerdingar*. The 'hedge' or 'fence' has a visual height of 6 arcminutes. The ship subtends between 2 and 3 arcminutes vertically; if one assumes that its mast height is in the range of 7–10 m (23–32 ft), its distance from the camera is of the order of 10 km (6.2 miles). The barrier, clearly beyond the ship, is thus quite distant, probably 15–20 km (9.3–12.4 miles) from the camera. Weather conditions at the time were calm and mild, so that the *hafgerdingar* did not appear to be immediately threatening.

Figure 2 shows *hafgerdingar* observed over the frozen surface of Lake Winnipeg on 17 April 1980, a calm day on which the temperature over land reached 20°C (the following day was extremely windy, a point that may be of interest later). Along the direction of view, the far shore is 30 km (18.6 miles) away, too far to be seen if the atmosphere is normal. The fence has a height of 9.5 arcminutes, and its upper edge stands at an elevation angle of about 10 arcminutes. Two target structures on the ice give some reference points. They are each 1.52 m (5 ft) high, and their distances from the camera are 0.61 km (0.38 mile) and 1.11 km (0.69 mile), respectively. The barrier appears to rise a few kilometres beyond the more distant target, that is, 3 or more km from the observer. Such *hafgerdingar*, giving the appearance of boiling wave activity, would appear quite threatening on the open sea.

Fig. 3. *Hafgerdingar* on Lake Winnipeg. The tree-covered point of land is 3.7 km (2.3 miles) away from the camera.

To appreciate the reaction of Norse mariners to this apparition, consider Figure 3. This is a photograph of Drunken Point on the west shore of Lake Winnipeg. The tallest trees rise 12 m (39 ft) above the lake level,[3] and in this case the *hafgerdingar* are almost as high as these treetops. If a typical Norse ship were located near the point, the *hafgerdingar* would rise as high as the top of the mast.[4] The approach of such a wave would certainly engulf the ship. The visual effect will be discussed further in the following paragraphs.

A brief explanation of the underlying physics of the mirage is as follows (Pernter and Exner 1922: 84–188; Greenler 1980: 151–177; Minnaert 1993: 58–86). A mirage of this type is seen when a strong, well-defined temperature inversion surrounds the observer. This can happen when warm air moves over cold water or ice. The air is thus cooled from below, producing an atmosphere in which the temperature increases with elevation (this is the inversion — a reversal of the normal decrease of temperature with height). Because the lowest layer is the coldest, it is also the most dense. Successive layers above it have decreasing densities. This creates a stable, layered atmosphere in which there is no inherent tendency toward mixing of the layers. The situation can last for hours. Consider the effect when a distant object is observed from a low vantage point, such as the deck of a Norse ship. The line of sight will be nearly horizontal, more or less parallel to the atmospheric layers. The light rays that make up the view through such an atmosphere are refracted downward (towards the denser medium) as they proceed (Lehn 1985; Lehn and Legal 1998). Therefore each ray will describe an arc, concave downwards, on its path to the observer.

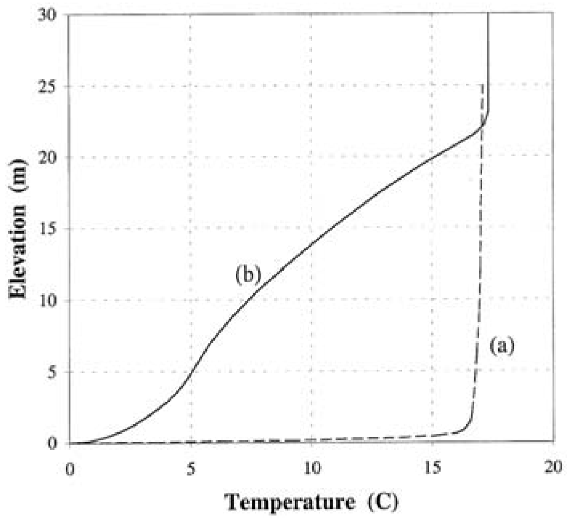

Fig. 4. Temperature profiles. (a) Profile in Region I, from the observer out to 3.7 km (2.3 miles). (b) Profile in Region II, beyond 3.7 km (2.3 miles).

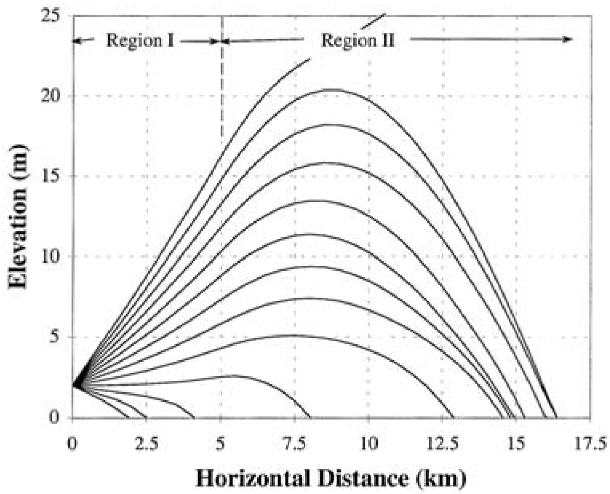

Fig. 5. Ray paths in the atmosphere described in Figure 4. Elevation is measured from the curved surface of the Earth. The ray curvature is suitably compensated so that the Earth can be portrayed as flat.

For example, a ray originating from the surface of the sea would pass to the eye of an observer in an arc rather than a straight line, and enter the eye as if coming from an elevated point. Because the eye always assumes that light travels in straight lines, it then interprets this ray as arising from an elevated point. In other words, the patch of sea where the ray started is perceived at some elevation well above the horizontal. In this way, the entire sea at some distance (say a few kilometres) from the ship appears to rise vertically upward. The ship is visually surrounded by a watery barrier, or sea fence.

An example calculated to illustrate the above discussion is a computer simulation of the mirage in Figure 3 (Lehn and Friesen 1992). To obtain the set of rays that the observer will see, it is customary to reverse the ray directions, and calculate them all as if emanating from the observer's eye. The image divides rather naturally into two parts: a foreground that shows the trees on Drunken Point with no visible distortion, and a background that contains the *hafgerdingar*. The atmosphere must therefore be relatively normal for the 3.7 km (2.3 miles) between the observer and the point (Region I). Beyond the point the atmosphere must undergo a transition into a second form (Region II), which contains a temperature inversion. In this model the transition distance is taken as 5 km (3.1 miles), but this could be varied because the final results are not sensitive to its value.

Figure 4 shows the temperature profiles assumed for the two regions. The first is based on a standard atmosphere, where the very lowest layers follow a rapid transition to the temperature of the ice (0°C). The second contains a 17°C inversion that bends upward rays back to the surface of the ice. Rays traversing this sequence of atmospheres follow the curved paths shown in Figure 5. Each ray that strikes the ice will be perceived as coming from an elevated point, identified by the tangent to the ray at the point where it enters the eye.

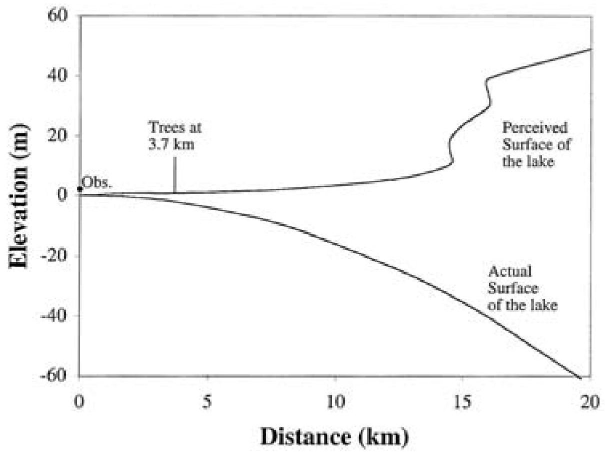

Fig. 6. Image space produced by the temperature profiles of Figure 4. Rather than falling away with distance, the surface of the lake is perceived to rise up like a cliff. The observer's eye is marked by a dot at the elevation of 2 m (6.5 ft), at zero distance.

The image space of Figure 6 can now be constructed (Fraser and Mach 1976). This is done by projecting each ray backwards along its tangent at the eye, and plotting a point at the distance where the ray meets the ice. It shows the surface of the Earth as it would be seen with straight rays (no refraction), as well as the apparent surface perceived with the curved rays. The vertical line at 3.7 km (2.3 miles) represents the tallest trees on Drunken Point. The apparent surface of the lake ice is now seen as an almost vertical cliff, higher than the tallest trees, at a distance of 16 km (10 miles) from the observer. It is worth noting that the appearance of an overhanging cliff is easily achieved by only a small change in the second temperature profile.

The height that the observer perceives for the *hafgerdingar* depends on the distance that he associates with it. If he thinks it is just behind the trees, then it will look about 12 m (39 ft) high. But in Figure 3 (clearly visible in the original slide) the lake surface is visible without distortion for some distance beyond the point, that is, the *hafgerdingar* are located significantly farther than the point. The wave is then perceived as being higher. If it is perceived to be 16 km (10 miles) away, as shown in Figure 6, then the observer thinks it is 39 m (128 ft) high. A vertical wave of either size would be deadly, but the more distant one would appear more dangerous.

If a ship found itself within such an inversion on the open sea, the seafarers would see themselves surrounded on all sides, just as reported by Scoresby. The presence of other ships in the foreground would strengthen the perceived effect, because this provides a scale for the effect. In this case the foreground inversion of Figure 4(a) would not be present; the ship would be immersed in Region II, the inversion of Figure 4(b). With cold sea water rather than ice forming the base of the profile, the temperature at zero elevation might be about 4°C. The apparent surface of the sea then rises even higher than the one shown in Figure 6.

While the height of the *hafgerdingar* in Figure 3 was only 8 arcminutes, much larger ones are known. An extreme case observed on Lake Winnipeg was 30′ high. Scoresby made similar observations: his ice fences were often 20′ high, and occasionally reached a height of 30′.

The *King's Mirror* describes the *hafgerdingar* as perilous. Not only do they look threatening, they actually are; few sailors have survived to tell of them. This observation is also consistent with the mirage model. The *hafgerdingar* have indeed been correlated with approaching storms. Now one might argue that *any* voyage over the Greenland Sea is dangerous, due to the extreme rapidity with which Arctic weather can change. Scoresby (1820: I, 395–415) pointed this out, but he did not correlate the variability with unusual refractions. However, Alfred Wegener (1926) did. On the basis of his own observations (Wegener 1911), he pointed out that the superior mirage frequently precedes the passage of a cyclonic warm front. He observed this off the coast of Norway as well as on the east coast of Greenland. He found that in 87% of the cases following a superior mirage, the temperature would be higher after 24 hours. He attributed this to the passage of a cyclone.

The structure of the classic cyclone is contained in all introductory texts on meteorology. The cyclone is created when a mass of warm air intrudes northward into a large mass of cold air. At the northern extremity of the warm air, a low-pressure centre is formed. Here a curved warm front on the eastern side meets a curved cold front that follows it. The whole system rotates slowly in the anticlockwise direction as it drifts towards the east. The advancing warm air overtakes the cold air and overrides it, creating a temperature inversion whose interface has a very small slope (typically 1 : 200). Consider the experience of an observer situated south of the low-pressure centre, within the cold air on the east side of warm front. He would see an inversion the elevation of which becomes progressively lower. When this inversion is low (and strong) enough, it causes mirages of the *hafgerdingar* type. Shortly thereafter, the warm front would pass, with its attendant rise in surface temperature. If the observer is only a short distance south of the low-pressure centre, then the cold front would follow rapidly. The cold front itself usually contains strong winds, and is often preceded by a squall line containing truly dangerous winds. The atmospheric pressure rises as the cold front passes. This is exactly what Wegener observed in many instances (Koch and Wegener 1930): superior mirage followed by warming, followed by what he called a *Hochdrucksturm* (a high-pressure storm). Such an event would indeed be hazardous to seafarers, exactly as the *King's Mirror* describes.

Conclusion

The mirage model of the *hafgerdingar* agrees with the *King's Mirror* in all respects, and Steenstrup's theory can safely be abandoned. The mirage produces the apparent wall of waves surrounding a ship, a wall that could easily 'resemble steep, overhanging cliffs.' It is hazardous to seafarers because a severe storm often follows. The effect must have been observed often enough to keep the memory alive, and to permit the proper correlation with danger.

It is indeed remarkable that a medieval document has provided such an accurate factual description of a natural phenomenon. This 'marvel' has nothing to do with the overactive imagination often attributed to the author of the *King's Mirror* (or to his sources); it is a sober cold description of what seafarers actually experienced.

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Notes

1. Meyer (1910) did not agree that the sources were written; he believed that they were oral.
2. The Japanese 'tsunami' appears to have been unknown to Steenstrup; perhaps the knowledge had not yet migrated to Europe. According to the Supplement to the *Oxford English Dictionary*, the word first appeared in English usage in 1897, 26 years after Steenstrup's analysis.
3. The mirage behind Drunken Point was photographed from a distance of 3.7 km (2.3 miles) on 17 April 1980. The *hafgerdingar* subtend a vertical angle of 8 arcminutes. The top edge of the fence was measured to be 8′ above the level. The angle between the lake surface and the top of the highest trees is 9.5′.
4. Brogger and Shetelig (1971: 92) estimated that the Gokstad ship would have had a mast about 13 m (43 ft) long.

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