

WHAT KIND OF A WAVE IS HOKUSAI'S *GREAT WAVE OFF KANAGAWA*?

by

JULYAN H. E. CARTWRIGHT^{1,*} AND HISAMI NAKAMURA^{2,*}

¹*Instituto Andaluz de Ciencias de la Tierra, CSIC–Universidad de Granada,
Campus Fuentenueva, E-18071 Granada, Spain*

²*Chuo University, 742-1 Higashi Nakano, Hachioji, Tokyo 192-0393, Japan*

The great wave off Kanagawa by Katsushika Hokusai is probably the most famous image in Japanese art. It depicts three boats in heavy seas on the point of encountering the eponymous wave, while Mount Fuji is glimpsed in the distance. The print is today often reproduced as the artistic depiction of a tsunami. Did Hokusai really have a tsunami in mind when he composed this work? We examine that hypothesis together with the alternatives, by discussing the image itself and the circumstances surrounding its composition, and by evaluating the wave in terms of the fluid dynamics of breaking waves and in particular of the species termed plunging breakers, of which *The great wave* is a member, and conclude that it is more probable that Hokusai intended to depict an exceptionally large storm wave. There is a great deal of scientific interest at present in such abnormally high waves, which are often termed freak or rogue waves.

Keywords: Hokusai; fractal; freak wave; plunging breaker; tsunami; oshiokuri

The great wave off Kanagawa, reproduced in figure 1, has become probably the image of Japanese art best known throughout the world.¹ In the humanities, it has inspired both music (Debussy's *La Mer*), and literature (Rilke's poem *Der Berg*),² as well as many later compositions. The work has also aroused scientific interest. In his book *The fractal geometry of nature*,³ Mandelbrot cites *The great wave off Kanagawa* as an example of self similarity; Hokusai's image depicts well the fractal nature of breaking waves,⁴ which is seen in the ocean itself.⁵ Although he was not looking to achieve photorealism, and in some of his work he depicts scientifically impossible situations, the scene we are shown here appears quite plausible. Besides, other Hokusai prints depict further aspects of fluid motion, as well as faithful representations of plants and animals; Hokusai's ability to observe nature is evident. It is clear, then, that although this is of course an artistic interpretation of a wave, many people view Hokusai's work in representationalist terms. The authors of the works cited above—musical, literary and scientific—viewed the scene as a storm. Recently, however, one finds the image being presented in the media, on the Internet, on T-shirts, and even in science textbooks, as an example of a tsunami. Here, then, we ask what kind of wave this is, by first examining Hokusai's life and work, and then by analysing the wave and its provenance.

*julyan@lec.csic.es; nakamurahisami@nifmail.jp



Figure 1. *The great wave off Kanagawa*. How many impressions Hokusai made is not known; the various editions also show detail differences in colours and in elements of the design, as a result of wear in the woodblocks. As the original woodblock prints are more than 180 years old, the colour also varies from copy to copy according to its state of preservation; in some instances the clouds and spray are barely discernible, and the colour of the sky at the top varies from yellow to pink. (Online version in colour.)

Katsushika Hokusai⁶ was born in 1760 in Edo—present-day Tokyo—where, except for short periods, he lived his whole life. He dedicated himself to art, portraying scenes ranging from nature to cityscapes, in watercolours as well as in woodblock prints. He is today almost undoubtedly the most world-renowned Japanese artist,⁷ although within Japan itself he is not generally accorded such eminence, in part because the *ukiyo-e* (pictures of the floating world) art movement of which he was a member was popular rather than high-status art, and also because he chose to portray less typically Japanese subjects in his work; possibly it is the very non-Japaneseness of his art that gives him his worldwide appeal. Hokusai was an apprentice of *ukiyo-e* artist Katsukawa Shunsho, but his work also incorporates influences from the traditional Japanese Kano school and from Chinese and Dutch landscape painting.⁸ During his lifetime Japan was practically a closed country with the only contact with the West being through Dutch traders permitted to live far from Tokyo on an artificial island, Dejima, in Nagasaki harbour; the country was reopened in the decade after his death and his works began to gain wide recognition by Westerners.

The great wave off Kanagawa is one of a beautiful series of views of Mount Fuji printed from woodcuts. The set, originally published in 1831–33, is entitled *Fugaku Sanjurokkei*, meaning ‘Thirty-six views of Fuji’, although in the end Hokusai made 46 views from different viewpoints, mainly from present-day metropolitan Tokyo but some from as far out as Nagano and Aichi. In this, the most world-famous of the series,⁹ we see Fuji through the waves from a viewpoint offshore, together with several boats battling the waves; we may suppose that we are viewing the scene from a similar boat, or else are looking through a telescope.

The artificial pigment Prussian blue was then newly available in Japan, and Hokusai took full advantage throughout the series of the possibilities it afforded,^{10,11} as is particularly apparent in this seascape.

In fact, the whole 'Thirty-six views' series is full of new ideas and original insights, and Hokusai's concept inspired European artists such as Monet to produce series of works on a single theme. Hokusai was at a difficult time in his life when he composed the series. He had already been through a succession of personal and family adversities in the 1820s, while he was in his sixties, when in the latter half of the decade misfortune piled upon misfortune: in 1826 he was, it seems, in pecuniary difficulties; in 1827 he suffered a medical problem that may have been a stroke; in 1828 his wife died; and in 1829 he was obliged to rescue his grandson financially. This must have reduced him to poverty and in 1830 he sent the grandson off with his father, Hokusai's son-in-law, to the country.⁸ Unfortunately this did not solve the problems: difficulties with the grandson and their financial repercussions continued during the period when he must have been working on the 'Thirty-six views' series and persisted to 1833–34. Throughout these tribulations—by which point, moreover, he was about 70 years old—he produced magnificent work, its acme being *The great wave*. The ukiyo-e movement depicted a 'floating world' (ukiyo) in which to forget about the misery of the real world (also ukiyo; the word is a pun exploiting the two meanings of *uki*: miserable or floating). Perhaps through his work Hokusai found salvation in his own particular floating world; the power and inventiveness of the work in the 'Thirty-six views' series may be ascribable to his hardships.

Here in *The great wave* Hokusai's caption in the cartouche states 'within the wave off Kanagawa', but it has become known in English as *The great wave off Kanagawa*, or some variant of this phrase; thus the first argument against the work's representing a tsunami is that he makes no mention of this idea in its title. He gives the place name as Kanagawa-oki—that is, off Kanagawa-minato—which was the port of Kanagawa adjacent to Kanagawa-juku, the once thriving Kanagawa coach station, now Higashi Kanagawa, near Yokohama railway station. Kanagawa is today subsumed in Yokohama, but in Hokusai's day the former was the more important place. The change came about two decades after *The great wave* was produced, when the United States forced the reopening of Japan to the world; Kanagawa was the port the Americans wished to be opened, but the Japanese government offered Yokohama, a small fishing village nearby, which soon grew to replace Kanagawa in both size and role. So Kanagawa-oki places the viewpoint off what is today Yokohama port, roughly 30 km south of Tokyo, from where we are looking in the image some 90 km west to Fuji.

The three boats seen in the image are *oshiokuri-bune*¹² (figure 2), fast cargo boats that were developed for the fishery trade but would carry everything from fresh and dried fish to rice, vegetables, charcoal and logs.¹³ Isabella Bird, the Victorian travel writer, described her encounter with similar boats on her arrival in Yokohama in 1878 in the following terms:

The partially triangular shape of these boats approaches that of a salmon-fisher's punt used on certain British rivers. Being floored gives them the appearance of being absolutely flat-bottomed; but, though they tilt readily, they are very safe, being heavily built and fitted together with singular precision with wooden bolts and a few copper clefts. They are SCULLED, not what we should call rowed, by two or four men with very heavy oars made of two pieces of wood working on pins placed on outrigger bars. The men scull standing and use the thigh as a rest for the oar.¹⁴

The boats that Bird is describing were probably *tenma-sen*,¹² vessels employed as tenders in the harbour that were slightly smaller than *oshiokuri*, but of similar build and propelled with the same sculling technique. *Oshiokuri*, as mentioned above, were used to transport fresh



Figure 2. Model oshiokuri in Yokohama maritime museum. As well as having oars, oshiokuri carried a dismantable mast with sails to put up in a suitable wind; they may be classed as a type of skiff. The single-oar sculling technique employed with oshiokuri was once widespread in many parts of the world,⁵⁵ but today may be encountered perhaps most notably with a Venetian gondola; in fact, the Venetians had multiple crewed sculled boats similar to oshiokuri for transporting cargo. This model oshiokuri has six oars, compared with the two or four reported by Bird and the eight of the boats meeting the great wave. The outriggers on this model are much farther apart than on the boats Hokusai drew; he depicts five closely spaced outriggers—with only four in use—on the most distant boat in *The great wave*. Could oshiokuri have been sculled with the outriggers as closely spaced as Hokusai shows? It is not clear. (Online version in colour.)

fish, typically tuna for sushi and bonito for sashimi, to Tokyo from the fishing ports lining the bays nearby; tuna and bonito were and are caught in Sagami Bay during their spring and autumn migrations. In Hokusai's day, oshiokuri were licensed craft permitting them to pass a checkpoint at Uruga, at the tip of Miura Peninsula between Sagami Bay and Tokyo Bay, without control, so that their cargo should arrive at market as quickly as possible.¹⁵ Once they left their home port, oshiokuri might not return for as long as 10 days but would travel to and fro between a rendezvous point at sea where they would meet the fishing boats and the fish market, for which purposes the crew would carry a rice cooker and *mushiro* or rush mats to eat and sleep in the oshiokuri.¹⁶ Owing to the perishable nature of the cargo, speed was essential—the trip would take five hours with a tail wind carrying 50 tuna, about three tons, from Misaki in Miura, 50 km south of Tokyo, for example¹⁵—for this reason, as we can observe, in these oshiokuri there are eight scullers and two relief crew members per boat. The boats are seen heading away from Tokyo. Have they been surprised by the waves on their way back from Tokyo—they generally carried rice and miscellaneous goods on the return journey¹⁵—or have they been forced to come about to head into the waves while on their way there? We can glimpse what might be some bagged cargo in the hold of one boat; rice would of course have been bagged, but dried fish also might have been placed inside a bag. Some oshiokuri even transported species such as squid and mackerel live to the fish market, using a fish tank installed in the hold that communicated with the sea;¹⁶ we cannot see any signs of such a tank in these boats, though, and tuna and bonito are probably too large to have been carried in this way. It is possible that what we view is not the cargo itself but mats on which to place it, or even the bed mats or indeed the sails that oshiokuri carried. If what we see is just empty bags or mats in the hold, the oshiokuri may be heading to meet the fishing boats at a purchase point somewhere offshore to collect their catch. The blue garments that the crew are dressed in are *samue*, work apparel typically worn in spring and autumn. The blue version was worn in spring, and sometimes in autumn too. However, generally the autumn variety would be brown or black. Such seasonal references are rather important in Japanese culture; we may note the example of *kigo*—terms denoting the season—in haiku poetry.

The dark colour of the sky around Mount Fuji probably indicates that this is early morning, with the sun rising behind us in the east just beginning to illuminate snow-capped Fuji, still enveloped in darkness, while the sky higher up has a golden glow reflecting the sunlight.

The clouds seen above Fuji seem to be cumulonimbus, which from their apparent size must lie between us and Fuji, and we are seeing Fuji in the distance beneath the cloud base. Although there is cumulonimbus storm cloud between us and Fuji, we can see the mountain, so there is no rain, and the weather at Fuji must be rather better than where we are, as the mountain—3776 m high—is free of clouds. The yellow-pink sky above the grey cumulonimbus might be higher cirrostratus clouds with the low early morning sunlight shining on them from below. The German naturalist Philipp Franz von Siebold visited Tokyo in the 1820s (Siebold lived in Japan before the opening of the country to the West; he was associated with the Dutch trade delegation and may possibly have met and commissioned some work from Hokusai during his stay in Tokyo); he noted the visibility of Fuji from the distance of Tokyo in the early morning:

Mt Fuji we have seen during our stay in Edo was truly wonderful. Especially in the cool hour of the morning, when the vision is clear, this soaring pyramid seems as if it is very close ... but unfortunately it lasts only for a short time. Soon, as the day warms up, a grey-white veil covers the head, and the white curling hair gradually conceals itself behind the fog, covering up the great work of vulcanism.¹⁷

The waves come from the south, from the left in the image; it is traditional in Japanese painting that the sudden appearance of something extraordinary or unexpected is represented by an object depicted on the left or moving from left to right, as the eye proceeds from right to left, in accordance with Japanese writing.¹⁸ We can use the boats—oshiokuri were commonly 12–15 m in length—and the sailors in them to estimate the size of the wave they are encountering, but first we must note that Hokusai stretched the vertical scale in the image by about 30%, as is clear from comparing the slope of the flanks of Fuji as depicted in *The great wave off Kanagawa* with photographic views of the volcano, as in figure 3.¹⁹ If we rescale the image to give the natural slope, as we have done in figure 4, and compare the size of the wave with the farthest boat and its crew, which is the only one visible over its entire length and seems to be at about the same distance from us as the bulk of the wave, we can estimate the wave height as approximately 10–12 m.

We should at this point interpose that of course artists have the prerogative to distort one aspect or another of their artwork with respect to life. It is a mistake, however, to imagine that they habitually do so haphazardly. Recently there has been a deal of work demonstrating the congruency of artworks with the scenes that their creators saw, and showing that one can even obtain scientific data from an artwork. Van Gogh's *Moonrise* is consistent with the view he would have had of the Moon at 21:08 on 13 July 1889 from the place he was situated while painting it.²⁰ Monet's paintings of the Houses of Parliament in London are shown to be accurate observations of the scene he had in February–March 1900 when he composed the series, and contain useful information on levels of atmospheric pollution.²¹ And a study of the colours of sunsets in paintings from 1500 to 1900 by many artists, including works by John Singleton Copley, Alexander Cozens, Friedrich Caspar David, Edgar Degas, Breton Jules, Gustav Klimt, Claude Lorrain, Joseph Mallord and William Turner, shows that they provide significant information on the influence of major volcanic eruptions on particle concentrations in the atmosphere in the sixteenth to nineteenth centuries.²² Although it is true that some Japanese artists aimed at an aesthetic, philosophical or poetical experience rather than a realistic record of nature, Hokusai did not number himself among them. In the afterword to an 1834 collection of his work *Fugaku Hyakkei* (*One hundred views of Mount Fuji*) that he signed 'Gakyo Rojin Manji' ('Manji the old man mad about art')—he was then 74 years old—he wrote:



Figure 3. Mount Fuji seen from a boat some 3 km off Bayside Marina in Negishi Bay, Yokohama, close to the probable viewpoint for *The great wave off Kanagawa*, but in more clement weather. If we imagine the state of the sea as in the Hokusai image, and mentally remove the development on the coast, we can see that waves could easily obscure all land except Mount Fuji, as in Hokusai's image. (Image courtesy of Yoshio Miyajima.) (Online version in colour.)



Figure 4. *The great wave off Kanagawa* rescaled vertically by 30% to give Mount Fuji its natural slope. (Online version in colour.)

Since the age of six, I had a habit of sketching from life. From fifty onwards I began producing a fair amount of art work, but nothing I did before the age of seventy was worthy of attention. At seventy-three, I began to grasp the structures of birds and beasts, insects and fish, and of the way plants grow. If only I go on trying, I will surely understand them

still better by the time I am eighty, so that by ninety I will have penetrated to their essential nature. At one hundred, I hope I may have a divine understanding of them, while at one hundred and ten I may have reached the stage where every dot and every stroke I paint will be alive. May men of great age and virtue see that I am not hoping for too much!²³

If we substitute 'science' for 'art', the above quote could come from a scientist; clearly, he did see his art as depicting nature itself. Hokusai died in 1849 at the age of 88 years. We should note that when he writes of his age he is using the traditional Buddhist manner of counting his years, in which one is born at the age of one year, so his cut-off of 70 is 69 in Western terms. His 'Thirty-six views' series appeared in 1831 when he was 71 years old, although it is not known with certainty how much earlier he had composed each work, so it is not clear whether he includes *The great wave* among the work whose worth he is dismissing. In general, little is known of how or when Hokusai set about a particular work; however, we do know, from an 1833 advertisement for *One hundred views of Mount Fuji*, that he kept a sketchbook in which he drew scenes from life during his travels, from which he later composed woodblock prints.²⁴ Although we disagree with his radical deprecation of his earlier work, we can comprehend his meaning: Hokusai reached his zenith in his last decades. Might some of the dissatisfaction he expresses above be related to problems with perspective in his work? Hokusai seems never to have understood perspective scientifically. In *The great wave*, there are no absolute markers for depth in the picture, so there are fewer possibilities for such perspective issues; the only places where perspective distortions can be seen are in two of the oshiokuri. Although Hokusai introduces different horizontal and vertical scalings, he clearly intends to depict a scene from nature, so we may legitimately analyse that scene and ask what sort of wave we are seeing.

Let us suppose for the moment that *The great wave off Kanagawa* depicts a tsunami. Hokusai would undoubtedly have been familiar with tsunami. The inhabitants of Tokyo certainly heard of the 1792 eruption of Unzen Fugendake in Kyushu, followed by the collapse of a flank of the mountain into the sea, resulting in a huge tsunami known as Shimabara Taihen Higo Meiwaku that claimed 15 000 lives.²⁵ Hokusai would assuredly have been aware of this and other tsunami that took place in different parts of Japan, but there does not seem to be any evidence as to whether or not he experienced one in person. However, had he encountered one, it would have been on a trip away from Tokyo, because there does not seem to have been a tsunami in the Tokyo area during his lifetime.²⁶ Moreover, tsunami that have struck the Kanagawa area, and within Tokyo Bay as a whole, have not been of great size. Although large tsunami can strike, and have struck, the nearby Pacific coast, they suffer attenuation on entering the relatively narrow bay and arrive at Tokyo with a relatively small amplitude; the maximum runup recorded at Tokyo seems to have been 2 m in the 1703 Genroku tsunami at Shinagawa—much smaller than the wave in *The great wave*.²⁶ Hokusai certainly may have heard about a tsunami arriving with full force on the Pacific coast, rather than in a diminished state within Tokyo Bay. It is known that he did stay in Chiba on the Pacific coast for some time in 1806,²⁷ at least, and sailors there may have told him of such events. It is not known how well acquainted Hokusai was with nautical life, and we have no information on whether he took a trip by oshiokuri in Tokyo Bay to produce *The great wave*. But as *The great wave* is almost certainly too large to be a historical tsunami off Kanagawa in Tokyo Bay, if it does show a tsunami we must consider that Hokusai is transposing an event that took place on the Pacific coast.

Wherever the event is occurring, a tsunami would have to be near to shore to break as it is doing; out at sea a tsunami does not have this aspect but is just an unnoticeable small-amplitude swell with a very long wavelength. Only in the shallows is a tsunami a bore; that is,

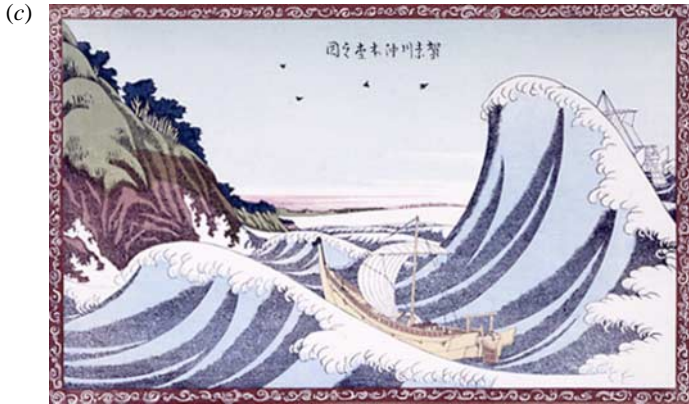


Figure 5. (Caption opposite.)

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Figure 5 (opposite). Precursors of *The great wave off Kanagawa*. (a) *Spring view of Enoshima*, from 1794–1798. (b) *Oshiokuri riding the waves*, from 1806–08, when Hokusai is known to have stayed in Kisarazu, Chiba. Here sailors wearing the brown samue usual in autumn are sculling standing, as described by Isabella Bird, rather than crouching in anticipation of the wave as in *The great wave*. (c) *Honmoku, off Kanagawa*. Here we are at Honmoku point, in Byobu-ga-ura, present-day Negishi Bay, Yokohama, not far from the viewpoint of *The great wave*, but we are looking in the opposite direction, across Tokyo Bay to Chiba, and Fuji is behind us. Just one sailor in blue samue is visible. This image from 1812 seems very exaggerated, with the oshiokuri in full sail heading straight for shore while the enormous wave is about to hit her abeam. In strictly scientific terms the latter two images are notably less plausible than that shown in *The great wave*, and they do not have the powerful artistic impact of the later work. (Online version in colour.)

a step with a steep wave front and an almost flat back. For this reason tsunami were generally unnoticed by Japanese sailors, who might only discover that one had passed on arriving back at port to find it devastated; it is possible that this may be the origin of the very word *tsunami*, meaning a wave (*nami*) hitting a harbour (*tsu*).²⁸ These sailors are clearly aware of this wave—they are meeting it head-on so as not to be capsized by it, and are crouching down over their oars for better stability rather than standing as described by Isabella Bird—so if it is a tsunami we must be nearer the shore than we suppose. Moreover, at the right there appears the trailing slope of another large wave, implying that this wave is just one of a train of waves of relatively short wavelength.

Although tsunami are long-wavelength, low-amplitude waves out at sea, as the water shallows near the shore a variety of subsidiary waveforms can develop. The 2004 Indian Ocean tsunami in particular provided many observations of such different tsunami phenomena. Most photographs and videos were taken from the shore, so they do not have a similar perspective to that shown in *The great wave*, and they generally show variously smooth or turbulent wave fronts in the form of a bore, with a steep front forming a step in the water level, the sea surface being much higher overall for some distance behind, in accordance with what we have discussed above. However, a sequence of photographs taken from yachts moored off the coast and analysed by Ward & Day²⁹ (see their Fig. 16) shows unusual standing waves that developed on top of this higher sea surface that bear a resemblance to Hokusai's waves, being of short period, steep and forming a regular series. In most cases these waves, having been produced by a piling up of water close to shore, broke seawards, but landward-breaking waves are seen in a few instances.

One could speculate, then, that the waves depicted in Hokusai's *Great wave* might represent an anecdote told to him by sailors about a tsunami seen from offshore, including in particular surviving a series of standing waves that developed on the back of a tsunami bore, either off Kanagawa or else off the Pacific coast where such waves could be much larger. Yet a further factor to consider is that Hokusai's wave is also localized laterally; it seems to rise in the foreground and to end in the middle ground at about the distance of the farthest boat. A tsunami would behave like this only if the bathymetry of the ocean at that point were such that the depth increased suddenly beyond the middle distance—a very specific and atypical situation, although we should note that the sea depth in Tokyo Bay does increase very quickly with distance off the Kanagawa coast. For this to be a tsunami, then, the shore must be very close to the edge of the picture; in that case, we imagine that Hokusai would have included it, as he did in other instances, for example in figure 5. In summary, although *The great wave off Kanagawa* is unlike almost all waves developed in the course of a tsunami, it is not possible from a pictorial analysis alone to rule out the tsunami hypothesis.

Although Hokusai certainly could have portrayed a tsunami, it is not probable that he would have wanted to depict a phenomenon associated in Japan with such human tragedy;²⁸

Hokusai's intention in the 'Thirty-six views' series seems to have been to contrast secular life with the sacred mountain of Fuji.³⁰ In *The great wave off Kanagawa* his artistic interest has been said to lie in employing a perspective that emphasizes the height of the waves and the distance to Fuji.³¹ It is also noted that he repeats the pattern of Fuji in the waves themselves:³² in fact, the wave in the foreground in front of *The great wave* appears like Fuji viewed from another, more famous viewpoint, from the southern Shizuoka side, with Ken-ga-mine, the highest peak of Fuji, on the left, and Hoeizan, a feature formed by the eruption of 1707, on the right.

Hokusai produced several precursors on the theme of his *The great wave*; we show a sequence of them in figure 5. The earliest, *Spring view of Enoshima*, from 1794–98, shows a wave breaking at the beach near the island of Enoshima, while *Oshiokuri riding the waves*, from 1806–08, and *Honmoku, off Kanagawa*, from 1812, have enormous waves about to hit boats, and manifest the evolution of his idea over a span of decades. Hokusai gives us an insight into how he saw waves in his *Ryakuga Haya-oshie* (1812),³³ a species of textbook on how to copy shapes from nature. In the book he teaches that repeated patterns on different scales—what is now termed self similarity—can be found in nature; in figure 6 we reproduce the page where he shows that the figure of a rabbit, like the pattern of a wave, can be obtained by using a compass to draw arcs of circles of various radii.

The fractal nature of wave breaking that, as Mandelbrot noted,³ is so well depicted by Hokusai, has been demonstrated in a dynamical model of breaking waves⁴ and confirmed in observations of the ocean itself.⁵ The wave shown in *The great wave* is a type of breaking wave termed a plunging breaker. Breaking waves at sea—white horses or whitecaps—can be observed to break in various ways. A plunging breaker encloses a tube of air within a layer of water that rolls over to splash into the water in front of the wave, whereas the other form of breaking wave, a spilling breaker, breaks at its crest and so-called white water—the broken portion of wave, a white foam of water entraining air bubbles—slides down the face of the wave.^{34–37} In the foreground Hokusai shows a spilling breaker in the wave reminiscent of Fuji. A single wave can show both behaviours at once along its length, as we illustrate in figure 7. Hokusai depicts a further aspect of wave breaking—and here he builds on a tradition in Japanese art going back centuries—in the fingers and spray into which the wave is disintegrating. The fingers split into claw-like forms and pinch off into drops of spray at their tips. This fingering and drop formation is visible when one looks in detail at a plunging breaker, as we show in figure 7.³⁸

It is a considerable achievement on Hokusai's part that he was able to see and depict all this structure in *The great wave* before photography, and more than a century and a half before science confirmed it. This insight into the essential structure of waves surely encapsulates Hokusai's greatness: he concentrates on one aspect of what he sees, while discarding inessential details. Although a photographic image may be extremely beautiful, realistic and detailed, it is just a reproduction of nature, devoid of any further insight into the scene that has been captured. Hokusai has a different attitude in his art, discarding unnecessary details that distract the attention from the deep and fundamental aspects of a scene so that we can concentrate on what he wishes to show us and appreciate it in a new and different light. In this way his work is very similar to how some scientists seek to understand nature by implementing Occam's razor in constructing a minimal model of a phenomenon, made, as Einstein put it, 'as simple as possible, but not simpler'.

The alternative to a tsunami is that the wave shown in *The great wave* is from a storm. The cumulonimbus cloud seen in the image is consistent with the viewpoint's being at the edge of a storm system; we must be only at the periphery because we can see Fuji beneath the cloud.



Figure 6. Hokusai's *Ryakuga Haya-oshie* of 1812 shows that he had an intuitive grasp of the presence of self similarity in nature that leads to what today are known as fractals. In the page reproduced here he demonstrates that drawing arcs of circles of various radii allows one to replicate the form of breaking waves and of a rabbit.³³

We can glean from the image quite a significant amount of information on the season: the crew of the oshiokuri are wearing samue, so it is spring or autumn; the samue are blue, so it is probably spring although it might be autumn; and Fuji is snow-capped, with an appreciable



Figure 7. Breaking waves. (a) A breaking wave captured at an instant not dissimilar to that seen in *The great wave off Kanagawa*. In the foreground it is not yet breaking; near to the surfer it is a spilling breaker; and in the background it is a plunging breaker like that in *The great wave*. This is a wind-produced wave much smaller than the wave depicted in *The great wave*, but we can see that Hokusai, working before photography, captured very well the shape of a breaking wave and had noted the way in which the wave breaks up into fingers that pinch off into drops at their tips. (b) A close-up view of a plunging breaker shows that the fingering can even produce claw-like forms similar to those in *The great wave*. (Online version in colour.)

covering of snow. Today this snow cover is seen on Fuji before May and after October, and we can tell that the situation in about 1830 was not dissimilar, as the range of snow cover on the peak depicted by Hokusai throughout the ‘Thirty-six views’ series is similar to what is seen throughout the year today. The snow rules out the scene’s being associated with the tropical cyclones called typhoons. In the Tokyo region, the typhoon season is generally from the end of July to the beginning of October, during which months there is little or no snow on Fuji. If set in spring or autumn, the scene would correspond most closely to the passage of a so-called bomb cyclone, an extratropical maritime, cold-season cyclone that can develop extremely rapidly into an intense storm that can sink shipping.³⁹ In Japan these cyclones are associated with the Kuroshio, the warm current that flows east south of the Japanese islands, and with so-called El Niño years in which that series of climatic changes is operating.⁴⁰ A study of wave heights in and around Tokyo Bay discloses that extreme waves tend to come from the south, as here, and that the largest waves appear from March to May (when bomb cyclones may occur) and in August or September (during typhoons).⁴¹ The publication *Guide*

to the Port of Yokohama provides a few more data: it states that in bad weather conditions it is 'possible for waves 5.5 m–6.0 m high to occur once every 10–20 minutes'.⁴² If the viewpoint of the image is as Hokusai sets it, near the port of Yokohama within Tokyo Bay, the wave shown in *The great wave off Kanagawa* is not, then, a typical storm wave; a 10–12 m wave as depicted here would be exceptional even in the worst storm. Abnormally large waves like this were long thought to be mythical events—yarns told by sailors—but recently it has become clear that so-called freak or rogue waves, a wave or series of two or three waves much larger than the others around them, do exist. Ocean waves in general are maintained by the wind and have a spectrum of heights; a common definition for a freak wave is one with maximum height H_{\max} greater than twice the maximum significant wave height, this latter ($H_{1/3}$) being defined as the average height of the highest third of the waves in a sample, so for a freak wave $H_{\max} > 2H_{1/3}$. A study of wave heights in Tokyo Bay estimated the maximum significant wave height, $H_{1/3}$, to be 5.6 m in the worst storm between 1952 and 1971; there were much larger maximum significant wave heights, from 9 m to 13 m, outside the bay.⁴¹ In a typical storm a 10–12 m wave in Tokyo Bay would then assuredly meet the criterion to be considered a freak wave.

Like the fractal nature of waves we discussed above, both freak waves and tsunami are only now beginning to be understood scientifically, because they are both essentially nonlinear phenomena. Tsunami are waves of such a long wavelength that for them the ocean is shallow water and nonlinear effects are very important,⁴³ whereas freak waves can result from the interaction of nonlinear waves or solitons. Linear waves when superposed add together linearly, so that their combined amplitude is the sum of the amplitudes of the components, but for nonlinear waves this is no longer true, and when two solitons coincide the combined height may be far greater than the sum; this has been postulated as a possible mechanism for the occurrence of freak waves.^{44–46} In Hokusai's image we see the trailing slope of another large wave at the right of the picture, as if perhaps there is a group of freak waves, and at the left behind the great wave we glimpse a smaller wave that might be one of those colliding to produce the freak wave. Although he produced the image long before there existed any scientific understanding of freak waves, and Hokusai may well have exaggerated the wave height for artistic effect, it is possible that he could have painted *The great wave off Kanagawa* after hearing sailors tell of such a monster. Certainly, such tales were current at the time: for example, a popular story of the era, *Funaosa Nikki (A captain's diary)*, written in 1822, recounts the miraculous survival of Captain Jukichi, who was rescued by an English ship heading for the USA after his boat had been driven across the Pacific and wrecked by storm winds and waves.⁴⁷ Under Japan's seclusionist government, such adventure stories were top secret, but Jukichi went about exhibiting goods he had brought back from America to raise funds for a memorial to his dead crew.

On weighing the evidence, we conclude that *The great wave off Kanagawa* most probably shows, not a tsunami, but oshiokuri caught out in a rough sea near Yokohama in Tokyo Bay in the early morning during a spring storm. Our opinion is that the boat is hurrying to a rendezvous point with the fishing boats to receive a cargo of fish destined for the fish market in Edo (Tokyo). Fresh bonito from Sagami Bay were especially prized, and made the best price, early in the season, which factor might make the crew willing to brave such poor weather, and fish in general could be caught in great numbers after a storm.⁴⁸ Might the men have thought the storm had abated sufficiently and put to sea from a relatively calm port, only to be betrayed? The great wave they are about to encounter is a plunging breaker, a gigantic ocean wave breaking into spray and spume, and at over 10 m in height is so large in terms of waves in Tokyo Bay that it must be considered a freak or rogue wave.

Where has the idea come from that this print is of a tsunami? We imagine that the connection may be made for a simple reason: the thinking may be that the word *tsunami* is Japanese, and Hokusai is also Japanese, ergo Hokusai's wave must be a tsunami. In such trivial ways does false information arise! The association may possibly be doing harm; this confusion of a storm wave breaking in the wind with a tsunami may be detrimental to attempts to teach people about how to recognize and protect themselves from tsunami. Our conclusion that Hokusai's image is not a tsunami is certainly not new; in fact the reverse is true: the idea that it might be a tsunami is relatively recent, dating back to the 1960s at most.⁴⁹ For the first 130 years of its existence it was seen as a storm wave by both those from the arts and those from the sciences. Nonetheless, the misconception persists and is even spreading to Japan. Given that tsunami rarely appear like Hokusai's wave, this could present a potential problem with respect to tsunami recognition and awareness. We find it worrying that those involved in tsunami planning seem to have decided to use Hokusai's wave in international tsunami warning signs; the 'Tsunami Hazard Zone' sign adopted in 2003 by the Unesco working group on international tsunami signs and symbols (<http://ioc3.unesco.org/itic/contents.php?id=71>) is clearly based on Hokusai's *Great wave*. The Unesco design does have points in its favour: it shows small waves before the bigger one that may warn people that the first two or three tsunami crests can be smaller than those following them, as is often the case, but the Hokusai-type waves in the design are ocean waves of short wavelength, nothing like the long-wavelength waves usually seen in tsunami, and in particular the design does nothing to remind people of the warning signal given by some tsunami of the sea pulling back before the first crest arrives. It is somewhat ironic that after science has abandoned the potentially misleading phrase 'tidal wave' in favour of tsunami, this Hokusai image used as a tsunami icon may cause problems with tsunami recognition that the term 'tidal wave' would not have done: notably the aspect of identifying the withdrawal of the sea like an exceptionally low tide, in many instances the first hint of a tsunami, which people may take advantage of to save their lives.

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Julyan Cartwright dedicates this work to his mother, Jean Morrell Cartwright, on the occasion of her 80th birthday; her lifelong vocation to art has nourished his interest in breaking down the barriers between the arts and sciences.

NOTES

- 1 It is difficult or impossible to give a definitive answer to the question of the best-known Japanese artwork without asking a statistically significant sample of the world population, but an Internet search using the keywords 'Japanese art' returns images of *Great wave off Kanagawa* first.
- 2 Y. Sato, 'Hayashi Tadamasu collection and Paula Modersohn-Becker' (in Japanese), *Bull. Cent. Jpn. Lang.* **16**, 51–70 (2003).
- 3 B. Mandelbrot, *The fractal geometry of nature* (W. H. Freeman, New York, 1983).
- 4 M. S. Longuet-Higgins, 'A fractal approach to breaking waves', *J. Phys. Oceanogr.* **24**, 1834–1838 (1994).
- 5 B. R. Kerman and L. Bernier, 'Multifractal representation of breaking waves on the ocean surface', *J. Geophys. Res.* **99**, 16179–16196 (1994).

- 6 Katsuhika Hokusai is a pen name, his true name being Kawamura Tetsuzo (*né* Kawamura Tokitaro). Katsushika is a place name in the province of Shimoosa—part of modern-day Chiba, although Katsushika itself now belongs to Tokyo—which signifies countryside. Hokusai is probably a pun on Ahokusai, meaning silly or ridiculous; however, the Japanese characters literally stand for the north study room, making Katsuhika Hokusai ‘the north study in Katsushika’. Hokusai was a follower of the Nichiren denomination of Buddhism, for which the Pole Star is sacred and north is an important direction.
- 7 As with the question of the most famous Japanese artwork, without performing statistical sampling it is not possible to have a precise answer as to who is the most world-famous Japanese artist, but an Internet search with ‘Japanese painter’ returns Hokusai first, *Chambers Biographical Dictionary*⁵⁰ gives Hokusai the longest listing of any Japanese artist, and Hokusai is the only Japanese in *Life* magazine’s—admittedly rather idiosyncratic—list of the top 100 people of the last millennium (Robert Friedman (ed.), *Life millennium: the 100 most important events and people of the past 1000 years* (Diane Publishing Co, Darby, PA, 1998)).
- 8 S. Nagata, *Hokusai: genius of the Japanese ukiyo-e* (Kodansha International, Tokyo, 1995). (Translation by John Bester.)
- 9 Although this is Hokusai’s best-known work internationally,^{8,10} another view from this set, *Red Fuji*, which shows the mountain glowing red in the morning sun, is probably more famous in Japan.
- 10 L. Smith, *Hokusai. Twelve views of Mount Fuji* (British Museum Publications, London, 1981).
- 11 S. Shimoyama, H. Matsui and Y. Shimoyama, ‘Non-destructive identification of blue colorants in ukiyo-e prints by visible–near infrared reflection spectrum obtained with a portable spectrophotometer using fiber optics’ (in Japanese), *Bunseki Kagaku* **55**, 121–126 (2006).
- 12 *Oshiokuri-bune* or *oshiokuri-sen* is often shortened to *oshiokuri*, because of the word’s length. Both *sen* and *bune* are written with the same character, but *sen* is the Chinese pronunciation, *fune* Japanese; *fune* becomes *bune* when combined with modifying adjectives and nouns. These suffixes refer to boats: *oshiokuri-sen* or *oshiokuri-bune* means ‘oshiokuri boat’, and likewise *tenma-sen* means ‘tenma boat’. The latter name, however, is never shortened in the manner of *oshiokuri*.
- 13 E. Arai, *A study of the history of fishing villages in pre-modern Japan* (in Japanese) (Shinseisha, Tokyo, 1963).
- 14 I. L. Bird, *Unbeaten tracks in Japan* (1880).
- 15 F. Miura, ‘Mount Fuji, fleur de mer and oshiokuri boat’ (in Japanese), In *Miscellaneous columns on fishery* (ed. N. Kurihara), pp. 583–587 (Mana Press, Tokyo, 2006).
- 16 K. Kurumisawa, ‘A story of fish trade in Atsumi Peninsula: oshiokuri boats in the Mikawa Bay’ (in Japanese), *Minzoku Bunka* (15), March (2003).
- 17 P. F. B. von Siebold, *Nippon* (1832). (Translation by the authors.)
- 18 S. Sakakibara, *The free play in Japanese paintings* (in Japanese) (Iwanami Shinsho, Tokyo, 1998).
- 19 It has been suggested that Hokusai employed Golden Section scaling, 1:1.61, in his compositions; the similar ideas of Sango no Hi, the proportion of 3:5, and Gohachi no Hi, the proportion of 5:8, were used in Japanese architecture from the end of the fourteenth century onwards. In general in Hokusai’s ‘Thirty-six views’ series, the proportion of width to length in the design is approximately the Golden Section below the *aigasumi*, the navy-blue mist at the top of each picture. However, in *The great wave*, whose size is 25 cm×37 cm—a proportion of 1:1.48 overall—there is no *aigasumi*, and Hokusai is argued to have arranged the height of the wave to achieve Golden Section scaling for the picture below the wave crest.⁵¹
- 20 D. W. Olson, R. L. Doescher and M. S. Olson, ‘Dating van Gogh’s moonrise’, *Sky Telescope* (July), 54–55 (2003).
- 21 J. Baker and J. E. Thornes, ‘Solar position within Monet’s Houses of Parliament’, *Proc. R. Soc. A* **462**, 3775–3788 (2006).

- 22 C. S. Zerefos, V. T. Gerogiannis, D. Balis, S. C. Zerefos and A. Kazantzidis, 'Atmospheric effects of volcanic eruptions as seen by famous artists and depicted in their paintings', *Atmos. Chem. Phys.* **7**, 4027–4042 (2007).
- 23 Katsushika Hokusai, *Fugaku Hyakkei* [*One hundred views of Mount Fuji*] (1834). (Translation by the authors.)
- 24 J. Suzuki (editor), *Fugaku Hyakkei* (Iwasaki Bijutsusha, Tokyo, 1986).
- 25 S. Koga, H. Murakami, K. Inoue, H. Sumiya and T. Imamura, 'April 1 Shimabara earthquake and Shimabara taihen' (in Japanese), *Rekishi Jishin* [*Historical Earthquakes*] **18**, 73 (2002).
- 26 Tsunami in Tokyo Bay are well known from 1703 and from 1854–55, but reports of tsunami between these dates are doubtful. The National Geophysical Data Center (NGDC) tsunami catalogue (<http://www.ngdc.noaa.gov>, consulted in March 2008), lists tsunami in the Tokyo area in 1762, 1763, 1766, 1771, 1775, 1782, and 1792, but the catalogue contains many data collected from historical records of varying degrees of reliability, and furthermore is subject to identification errors for Japanese place names. As we investigated each of these records in more detail, we found their validity to be questionable. The 1762 tsunami said to have hit Ushima seems to be a mislocation of a small village, Kita-ushima, on the island of Sado in Niigata prefecture, in the Sea of Japan, which has been confused with Ushima near Shimoda, Shizuoka; a 1763 tsunami at Minato again looks like the result of the confusion of a town in Izu in Sagami Bay and one in Hachinohe, Aomori prefecture, near the north end of the main island of Honshu. A 1766 tsunami at Choshi probably switches a town in Hachinohe with Choshi in Chiba. A 1771 tsunami listed for Ara, at 35.67° N, 139.78° E, which reads like a misprint of Awa in Chiba, is almost certainly an error referring to Ara on the island of Ishigakijima, Okinawa, at 24.3° N, 124.1° E, more than 1000 km away. A 1782 tsunami at Odawara is probably the result of confusing two events, and no such tsunami occurred.⁵² Again, the records for 1792 apparently confuse places near Nagasaki where the huge Shimabara Taihen Higo Meiwaku tsunami in fact occurred—Mie and Tomizu—with other places near Tokyo—Mie and Futtsu (Futtsu and Tomizu are written with the same Japanese characters). There remains a 1775 tsunami at Awa as the only one of these tsunami that may possibly have occurred, although we remain doubtful because the only corroborating evidence we can find is in *Ansei Kenmonroku* (1856),⁵³ a historical record of disasters, in which there is the story of an old man who in 1855 recalled a tsunami at Awa when he was very young: the sea at Awa suddenly receded and people had gone to collect the shellfish and fish lying on the sea bed when the tsunami wave crest arrived and swept them away.⁵⁴ Unfortunately there is no date given for when this happened, but it is possible that it could be 1775. Thus, after the 1703 Genroku tsunami, there are no tsunami that clearly affected either Tokyo Bay or the adjacent Pacific coast until 1854–55, except possibly one at Awa in 1775.
- 27 S. Nagata, *Chronology of Katsushika Hokusai* (in Japanese) (Sansai Shinsha, Tokyo, 1995).
- 28 J. H. E. Cartwright and H. Nakamura, 'Tsunami: a history of the term and of scientific understanding of the phenomenon in Japanese and Western culture', *Notes Rec. R. Soc.* **62**, 151–166 (2008).
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- 52 K. Ishibashi, 'Impressions on studying historical earthquakes' (in Japanese), *Rekishi Jishin* **1**, 55–58 (1985).
- 53 Y. Hattori, *Ansei Kenmonroku [The news of Ansei era]* (1856). Reprinted in T. Usami (ed.), *Taikyoku Jishinki, Ansei Kenmonroku, Jishin Yobosetsu, Bokasaku Zukai* (Kowa, Tokyo, 1979).
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