TOKYO TO OSAKA: SUBDUCTION BY SLOW TRAIN*

Wes Gibbons 2020

This Holiday Geology guide offers an alternative approach to train travel between Tokyo and the Osaka/Kyoto/Nara area. The journey takes it slow by using the extensive network of local trains, giving time to enjoy the scenery and sample a taste of everyday life in Japan. Instead of hurtling from Tokyo to Osaka by Shinkansen bullet train in three hours, our route takes over a week as we meander from the suburbs of Greater Tokyo to the peaceful shrines of Kamakura and the spa-town of Atami, skirting Mount Fuji to pass Nagoya on the way to the isolated splendours of the Kii Peninsula before reconnecting with the urban masses on the approach to Osaka. For those with extra time to spend, we recommend finishing the trip off with a visit to Nara (from where Kyoto is less than an hour away). The journey is a very Japanese experience. You will see few non-Japanese people in most of the places visited, and it is difficult not to be impressed with the architecture, history, scenery and tranquillity of the many shrines passed on the way. The Kii Peninsula in particular offers a glimpse into Old Japan, especially because the route includes walking along parts of the Kumano Kudo ancient pilgrimage trail (Days 5-7).

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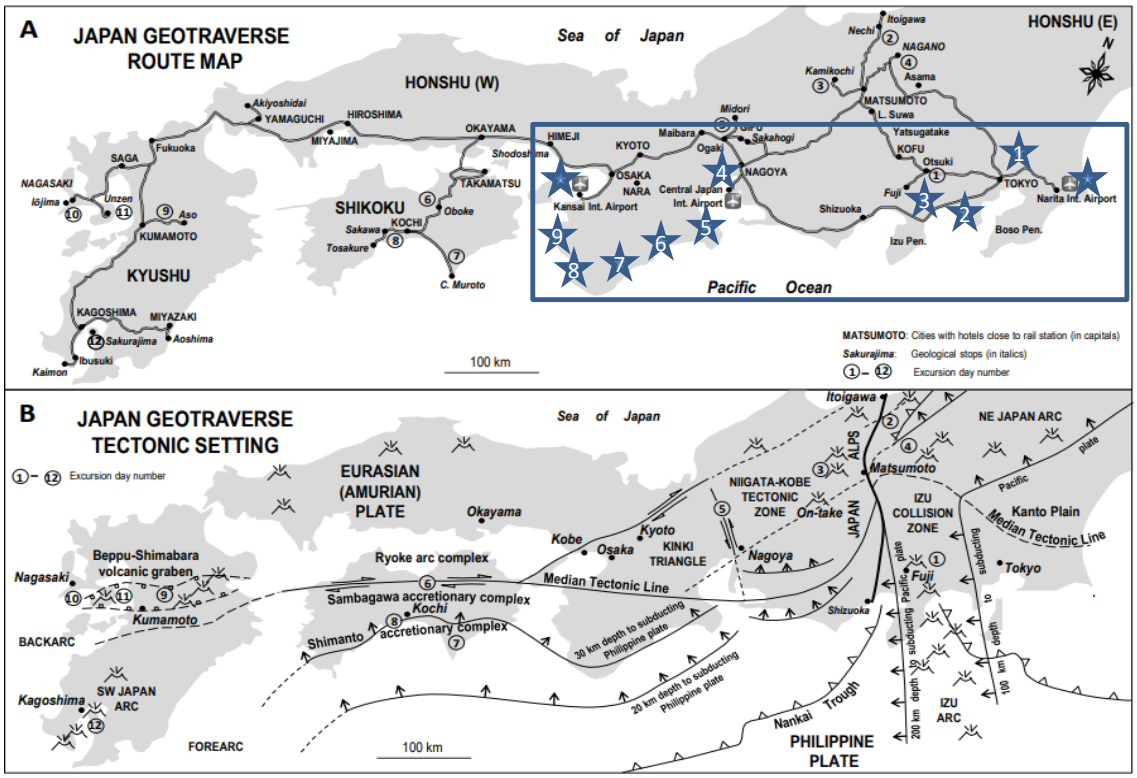
Background. The route described here offers a slow and relatively cheap rail journey from Tokyo to Osaka. This is not what most first-time visitors to Japan will have in mind because, quite understandably, they will want to experience the bullet train Shinkansen system courtesy of the Japan Rail Pass. Travelling by Shinkansen is indeed well worth doing and to see the potential of such a journey take a look at our Chapter 12 in the *Geology of Japan* book (published by the Geological Society of London) which describes a long-distance journey from Tokyo to Kagoshima in the far southwest, as outlined on the map below:



Map overview of the Geotraverse from Tokyo to Kagoshima presented in Chapter 12 of the book Geology of Japan (Gibbons, Moreno & Kojima 2016). The blue rectangle in map A, shows the ***Tokyo to Osaka: Subduction by Slow Train*** *route described below in this Holiday Geology guide, with each star representing the main stops on the way: 1=Tokyo; 2=Kamakura & Sagami Bay; 3=Atami; 4=Nagoya; 5=Matsusaka & Iseshi; 6=Owase; 7=Shingu; 8=Shirahama; 9=Wakayama. The lower map B outlines the tectonic complexity of this area, which involves the subduction of both the Pacific and Philippine Sea plates, and the collision of the Izu oceanic arc with central Honshu (note how the Median Tectonic Line arches around this collision zone).*

Logistics. The 10-day tour outlined in this guide is most easily achieved by flying into Tokyo and out from Osaka (Kansai International), travelling by train for the first 5 days using a prepaid Welcome Suica smartcard (buy from the machine in the airport train station and load it up with 10,000 Yen in cash). For the second 5 days, train travel is best made using a JR Ise-Kumano Tourist Pass (see the JR Central website: https://touristpass.jp/en/ise_kumano/?utm_source=global.jr-central.co.jp%252Fen%252F&utm_medium=referral&utm_campaign=own). Buy the pass voucher before arrival in Japan then change the voucher for the real pass in Tokyo Central Station. This pass (unlike the Suica card) allows for use of the excellent Limited Express trains running along the spectacular route around the Kii Peninsula. Total cost of rail travel (2020) for the 10-day journey will be around 24,000 Yen including airport to city travel, metro in Tokyo, commuter trains, and (in the Kii Peninsula) Limited Express trains.

Inexpensive business hotel accommodation (with breakfast) is offered by the Toyoko Inn chain. These are our preferred choice, being clean, friendly, accepting of baggage for early arrivals, and situated very close to rail stations and restaurants, but they will not be to everyone's taste (small rooms, uncompromisingly Japanese breakfast; must vacate room between 10:00 and 16:00). The Toyoko Inns at Atami, Matsusaka and Wakayama are particularly convenient for this journey, and in Tokyo there are several within walking distance of Tokyo Central rail station (in Nagoya we changed the routine by staying in the slightly more upmarket Meitetsu Inn Sakuradori). We recommend joining the Toyoko Inn membership scheme, not least because you can check-in one hour early (15:00).

Finally, with regard to time of year the driest months are typically December, January and February. We visited in late December-early January, had very little rain and lots of sun although it was cold at times, forcing emergency shopping for hats and gloves. Many people would recommend cherry-blossom (sakura) springtime, although always avoiding the overcrowded Golden Week. The hot, humid, rainy summer and autumnal typhoon seasons are probably best avoided.

Geologistics. This is active earthquake-and-volcano country and therefore prone to natural disaster. Although the geologist can feel wisely and logically comforted by the statistical unlikelihood of being there just at the wrong time, the fact that the entire route is subject to large-magnitude earthquakes, tsunamis and volcanic eruptions can add a certain *frisson* of background anxiety to those of nervous disposition. In many of the localities visited this geoanxiety can be fuelled by helpful signs providing a constant reminder of how many metres one is standing above sea level (usually not enough) and where to run in the immediate aftermath of a major tremor. The Limited Express trains in the Kii Peninsula, which in places trundle slowly around scenic coves with open access to the adjacent ocean, have their own tsunami emergency kit and instructions for Japanese- or English-speaking pandas.

It is best therefore to be aware of appropriate earthquake and tsunami drill and, just in case, where the nearest high ground is. If in doubt, do as the locals do: they are all supposedly trained to be calmly prepared in the unlikely event of an earthquake emergency. A much more common georisk than earthquake is that associated with monsoonal floods and landslides: it is for this reason (and the obvious unpleasantness of outdoor tourism in the pouring rain) that we have suggested avoiding the summer rains and typhoon season, especially as the journey visits the Kii Peninsula which is one of the wettest places in Japan. Autumn in between typhoon events, however, can produce perfect weather.

Should geohazard awareness cause some hesitation, let us emphasise the case for visiting. The tectonic setting of this area is amazing. You will be journeying around the eastern edge of the Eurasian megacontinent beneath which both the Philippine Sea and Pacific oceanic plates are being actively subducted. Furthermore, you will pass across (and tunnel through) the only place in the world where an

active oceanic arc is in the process of continental collision: the Izu Peninsula is being rammed into central Honshu island just west of Tokyo megacity and south of Mount Fuji, the highest point in Japan. No wonder the area is so tectonically and volcanically active. Extra highlights are provided by the fact that one crosses the Median Tectonic Line (MTL), the most famous paired metamorphic belt of them all, gets to see astonishing views of Mount Fuji (weather permitting), and visits the unusual forearc granites of Kumano, a remote area with splendid scenery. It would be wrong not to.

Arrival. We flew direct from Madrid to Narita Airport which is 60km east of Tokyo and well served by train, and flew back to Barcelona from Kansai International Airport (Osaka), which also has its own train station. There are several choices of train and route from Narita into Tokyo: for these and all other train information visit the excellent hyperdia website (http://www.hyperdia.com/en/).

Upon arrival visit an ATM for cash (machines in the airport Seven Eleven branches always work for us) then head for the airport rail station to locate a Welcome Suica machine where each person can buy their IC card and load it with 10,000 Yen in cash (there are plans to introduce these machines into the airport terminal as well). We decided on using the Keisei Line Access Express train which is a compromise in cost and time between the slow, stopping local trains and the Narita Airport Express. However your choice should be influenced mainly by in which hotel you decide to stay: try to book one reasonably close to Tokyo Central Station. For example the Access Express train stops at Nigashi-Nihombashi where there is a cluster of Toyoko Inns nearby and the street running NW-SE through Ningyocho metro station (also nearby) is authentic and good for finding evening food. This, the Nihombashi area, is a convenient place to start the walk on Day 2 and we recommend it. If time allows on the arrival day visit Tokyo Central Station and trade in the Ise Kumano 5-Day Tourist Pass voucher for the real thing, and while you are at it book free reserved seats on 4 Limited Express train journeys: we chose Matsusaka-Owase return (Day 6), Matsusaka-Shingu (morning Day 7), Shingu-Wakayama (afternoon Day 7).

Day 1: In Memory of the Victims of the 1923 Great Kanto Earthquake and March 1945 Air Raid.

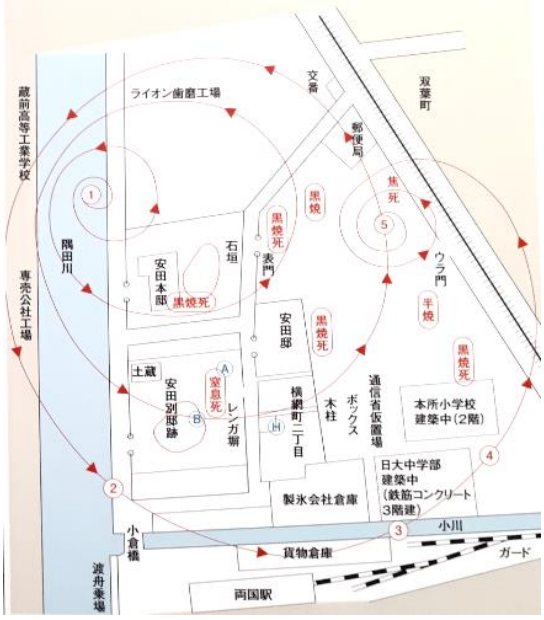
This day involves a walk through Tokyo (a city best enjoyed on foot), one of the world's most seismically active, and yet safest, megacities. Most buildings these days in Tokyo are earthquake-resistant, and much has been done to reduce the risk of dangerous fires. It was not always so. The 1923 Great Kanto earthquake led to over 100,000 deaths. Twenty two years later the continued vulnerability of this densely populated area to fire made it the chosen target for a massive napalm and phosphorus bomb attack in March 1945, when a further 100,000 people or so lost their lives as a result of what is "regarded as the single most destructive bombing raid in human history" (Wikipedia). We start our journey by visiting ground zero of this double disaster, sparing a thought for the common people who were unlucky enough to get caught up in these terrible events.

The Magnitude 7.9 Kanto earthquake began at 11:58 on September 1, 1923 when a segment of the subducting Philippine Sea Plate south of Yokohama and Tokyo ruptured across an area 130km by 70km running beneath Sagami Bay. In Tokyo after ten seconds of the initial tremor the main shock arrived and was followed by a series of powerful aftershocks. Many were killed in collapsing buildings, although a greater horror was created more slowly as uncontrolled and coalescing fires began to burn much of the city to the ground: of the estimated 69,000 people killed in Tokyo, over 90% died by fire.

Half an hour after the earthquake there were well over 100 fires burning in the city. The earthquake had ruptured the mains water system so that little could be done to stop the fires spreading, and over 90% of the

buildings were wooden. An area particularly affected by the conflagration was in NE Tokyo alongside the Sumida River, towards which thousands of people flocked seeking refuge from the encroaching fires on both sides. An impossible crush developed as people moving in opposite directions met on the wooden bridges crossing this wide river. As the fire overtook the area, the bridges caught alight and collapsed, leaving people with nowhere to go but the river, in which many drowned and boiled in the intense heat.

The greatest tragedy however was concentrated just east of the Sumida River, in an open space that had once been the army clothing depot. This area had seemed an obvious refuge and, encouraged by the local police chief, thousands of people and their flammable possessions had gathered there to shelter. By mid-afternoon however fire had encircled the zone, jumping suddenly across the river from the west and consuming bridges and riverside buildings as a terrifying flaming tornado (a “fire whirl”) that moved slowly over the clothing depot ground. People and possessions were sucked into the vortex of this superheated whirlwind which left around 38,000 dead and just a few hundred survivors. To answer personally for his misjudgement, the police chief committed suicide with a samurai sword the next day. The images below are from the memorial hall and museum in Yokomicho Park.



The Army Clothing Depot site (left) and (right) a map tracing the anticlockwise path of the fire whirl vortex at the former clothing depot.

In the immediate aftermath of the fire the bodies of the dead were burnt on the spot, creating a great pile of ashes and bones.

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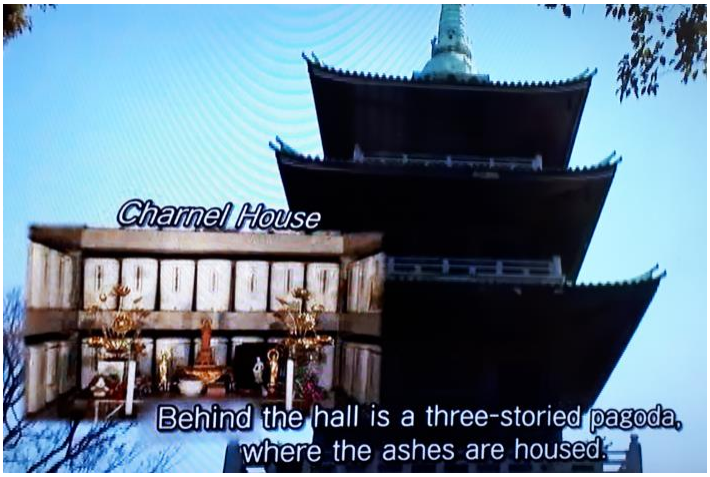
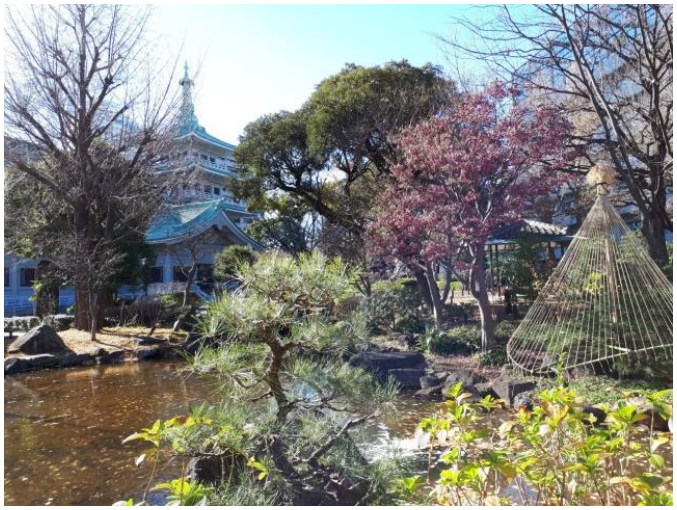
Through the Low City. The walk described here starts in the "Low City" of Edward Seidensticker (see his entertaining and idiosyncratic books *Low City, High City: Tokyo from Edo to the Earthquake* (1983) and *Tokyo Rising: The City Since the Great Earthquake* (1990)). The route firstly visits the site of the Clothing Depot Disaster, now a memorial park, then crosses the Sumida River to enter the Asakusa area and visit the famous Sensoji Temple before moving west to Ueno Park and beyond. Allow at least half a day, although a full day can easily be passed as there is much to see on route, especially with the suggestions of "extras" made in the final paragraph.

Our exploration starts at Ryogoku rail station which lies just east of the Sumida River. If staying in Nihombashi it is an easy walk NE to this station, crossing the Sumida River via the Ryogoku Bridge. From the station walk NE past the Ryogoku Kokugikan stadium (the centre of sumo wrestling in Japan) to the SW corner of the Kyu-Yasuda Teien garden park (free admission), a haven of tranquillity.

Kyu-Yasuda Teien park was once a 17th century samurai residence, now houses the Japanese sword museum (top left), and lies just SE of the Yokomicho memorial temple (spire top right). This area has been repeatedly restored after the general destruction of the Kanto earthquake and fire, the American firebombing in 1945, and the post-war industrial pollution of the lake by water entering from the adjacent Sumida River.

Exit from the NE corner of Kyu-Yasuda Teien park and cross the road junction to enter the SW corner of Yokomicho Park, the former site of the Japanese army clothing depot. Yokomicho Park is a memorial to the lives lost in the 1923 Kanto Earthquake and the 1945 bombing raid on Tokyo. A visit to the memorial hall and temple, the children's monument, museum, and gardens will leave its mark on you.





21st century children playing alongside the Yokomicho memorial hall and its adjacent gardens. Inside the hall is a graphic exhibition recording the truly horrific events of 1923 and 1945.

Leave from the NE corner of Yokomicho Park and walk N for 400m to turn left to cross the Sumida River.

Follow the walkway N alongside the W riverbank to the next bridge (Komagata) at Asakusa then cross the busy road junction and continue N to enter the crowded tourist hotspot of the Nakamise pedestrian shopping street and the gated entrance to the Sensoji Temple grounds.

People in Nakamise Street after the 1923 earthquake and fire. The Sensoji Temple buildings survived the 1923 fire but most of them were destroyed by the huge USAAF wartime firebombing raid which began just after midnight on March 10 1945. Thousands of people reportedly died from the firestorm created in the Sensoji Temple area that night. The modern temple (lower image) was rebuilt in the 1950's.

Four hundred metres E of the Sensoji shrine is the Kototoi Bridge over the Sumida River. With similarities to what happened in 1923, during the night of March 10 1945 a great many people lost their lives on the overcrowded bridge during the bombing and subsequent firestorm: https://www.atlasobscura.com/places/kototoi-bridge.

After visiting Sensoji we recommend walking westwards, zigzagging through Asakusa towards Ueno rail station. Once at the station, keep it on your right to locate the entrance to Ueno Park where there is much to visit and explore, including the National Museum of Nature and Science. If time and energy remain, with map or mobile phone in hand, head north to visit peaceful Yanaka Cemetery then consider continuing west to enjoy a visit to Nezu shrine before returning to the city on the subway.

This journey west from Asakusa takes us from the "Low City", underlain by Holocene sediments, to higher ground (in Ueno Park and beyond) underlain by Pleistocene sediments once deposited in a broad depositional basin referred to as the "Palaeo-Tokyo Bay". The Palaeo-Tokyo Bay opened eastwards to the ocean and within it a thick sequence of mostly coastal and shallow-marine sediments were deposited (Shimosa Group) 450,000 to 80,000 years ago. The Shimosa Group outcrop typically lies at 20-50m above sea level, rising above the modern Holocene alluvial lands such as those bordering the Sumida River.

The Holocene and Pleistocene sedimentary successions that underlie Tokyo and Yokohama lie in the southern part of the Kanto Plain, the largest plain in Japan. To the south of this plain, separating the low-lying and densely urbanised Yokohama municipality from the ocean in Sagami Bay, rises a zone of forested hills forming the Miura Peninsula. This peninsula exposes Plio-Miocene forearc sediments and will be the destination of our next excursion: a daytrip south from Tokyo to Kamakura.

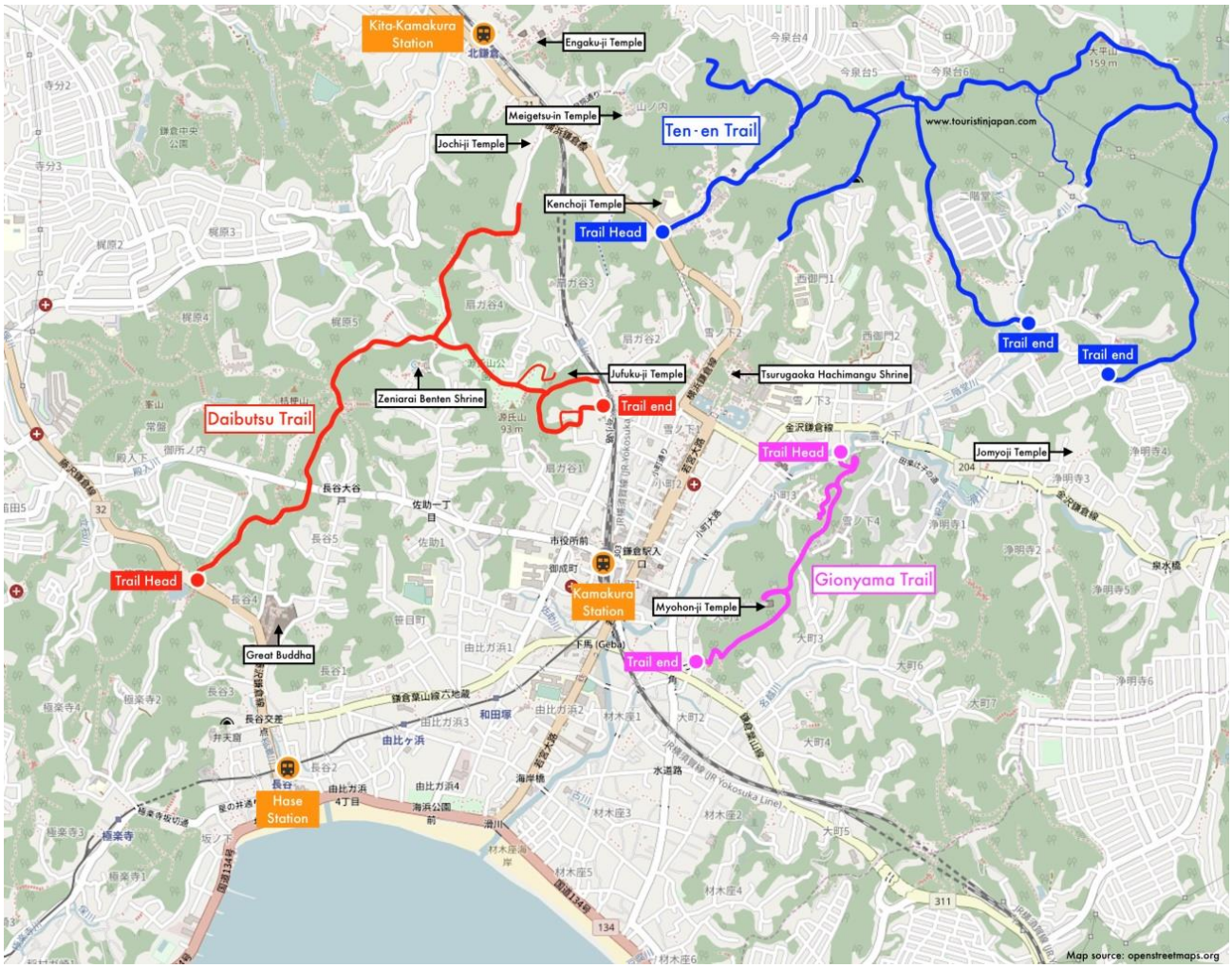
Day 2: Kamakura

Kamakura is a coastal town around an hour away by train from Tokyo. It is famous for its scenic forested hills (with walking trails) which surround and protect the town and its wide beach, and an abundance of Buddhist and Shinto temples and shrines that reflect the area's importance as an ancient political and religious centre. It makes for an excellent day out. For enthusiastic walkers there are 3 trails to consider attempting (see map below), although these are difficult after bad weather and were officially closed due to typhoon damage when we visited.

If staying in Nihombashi then take a JR Sobu Line train from Bakurocho or Shin-Nihonbashi stations to Tokyo Central Station, from where the train follows the Yokosuka Line (we did not need to change either platform or train) which initially parallels the Shinkansen route, crossing Pleistocene sediments to reach the Holocene deposits of the broad Tama River. The Yokosuka Line then turns S away from the Shinkansen line to follow the west bank of the river (with Kawasaki on the left) and curve SW to Yokohama, skirting the higher ground of Pleistocene rocks to the right (similar to the previous day's contrast between the "Low City" on Holocene and the higher ground on the Pleistocene outcrop). Between Yokohama and almost to Ofuna the train continues to run mostly along lower ground (Holocene) flanked on either side by low hills underlain by Pleistocene sediments and volcanic ash layers. Around and immediately S of Ofuna the bedrock of the surrounding higher ground comprises Plio-Pleistocene sediments of the Kazuza Group: the rocks dip northwards so that by moving S we have moved down-stratigraphy onto older rocks. The Kazuza Group comprises up to 3km of marine sediments deposited between 2.5 million and 450,000 years ago (Pliocene to Middle Pleistocene). This succession is itself underlain by the Miocene-Pliocene Miura Group, another thick (c.4km) sequence of marine forearc sediments. The boundary between the Kazuza and Miura groups is just south of Kita-Kamakura station, and the town of Kamakura itself is surrounded on three sides by hills underlain by Miura sandstones, mudstones and volcanic ash layers.

We recommend a walk from Kamakura station firstly heading N to Tsurugaoka Hachimangu, the most important shrine in the area. From here divert SE to visit the burial cave (Harakiri Yagura) of Hojo Takatoki at the Gionyama trailhead (see map below), then S to spend a while at the wonderfully peaceful Myohon-ji Temple before heading down through the town to the beach. From the W side of the beach walk N inland to cross the rail tracks and visit the splendid Hasadera shrine just W of Hase station, then finally view the famous Daibutsu ("Great Buddha") bronze statue at the Kotoku-in Temple before returning on the little electric train from Hase station back to Kamakura.

For those keen to do the Daibutsu Hiking Course, which connects Jochiji Temple in Kita-Kamakura with the Daibutsu ("Great Buddha"), get off the train from Tokyo at Kita-Kamakura (the stop before Kamakura) and walk S, crossing the rail tracks to reach the main road. In 300m, just before a level crossing and at signposts for the walking trail, turn right to face the first flight of steps. From the Daibutsu you can then do the walk described below but in reverse, even taking in the moderately challenging Gionyama Hiking Course along the route.



Kamakura Map (see text). Note the 3 walking trails in blue, red and pink, the position of Kita-Kamakura, Kamakura and Hase rail stations, the Tsurugaoka Hachimangu shrine and the Myohon-ji temple. Map source: openstreetmaps.org (https://www.touristinjapan.com/kamakura-forrest-hiking-trails/).

Stop 1: Tsurugaoka Hachimangu shrine. Reached from the station northwards by following the Komachi-Dori shopping street and passing between two ponds before the final ascent to the shrine, which was founded in the 11th century and moved to this site in the 12th century. The shrine is built on Miura Group sandy mudstones of Pliocene age.

Stop 2: Takatoki Harakiri Yagura (burial cave).Return to the ponds in the grounds of the Tsurugaoka Hachimangu shrine and turn left to a T-junction. Here turn right then immediately left into a small road that runs SE to cross the Nameri River at the Toshoji Bridge above exposures of Zushi Formation sandstones.

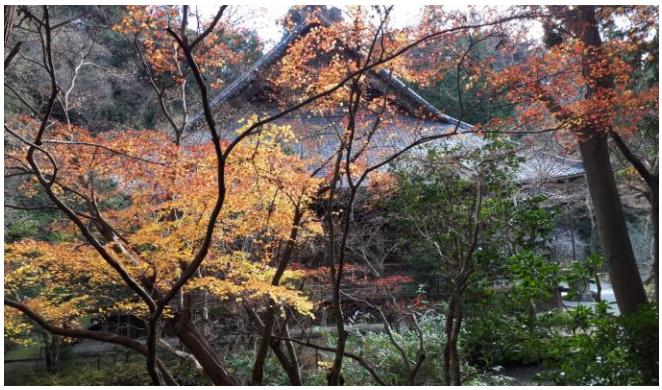
Northern trailhead of the Gionyama Hiking Course (see previous map), showing the location of the Toshoji Bridge, Takatoki Harakiri Yagura and Myohonji Temple.

View of the Nameru River from Toshoji Bridge. "The name comes from the way it flows, kind of "licking" ("nameru" in Japanese) the stones at its bottom" (Wikipedia). Here the river can be seen licking gently dipping bedrock exposures of sandstones belonging to the Miura Group. The sediments of the Miura Group are up to 4,100 metres thick and were deposited 3-16 million years old (middle Miocene to early Pliocene times) in a marine forearc basin.

One hundred metres N of the Toshoji Bridge on the left is an information board marking the site of the 13th century Toshoji Temple which belonged to the once-powerful Hōjō clan in Kamakura. The temple was destroyed by what was left of the Hōjō clan (reportedly over 800 people) which committed mass suicide in response to the successful invasion of Nitta Yoshisada's troops in July 1333. A little further on along the lane, at the foot of these hills, is the isolated burial cave Takatoki Harakiri Yagura.

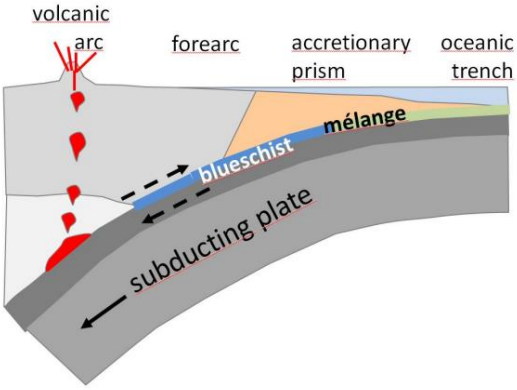
Takatoki Harakiri Yagura. Yagura are artificial burial caves common in the soft sandy Pliocene-Miocene rocks of the Kamakura area. Isolated caves, like Takatoki Harakiri Yagura, are referred to as Harakiri Yagura. Hōjō Takatoki was the last ruler of the Kamakura shogunate, the feudal military government of Japan during the Kamakura period from 1185 to 1333. The cave exposes Miura Group sandstones deposited by marine turbidity currents.

Stop 3: Myohonji Temple. This temple can supposedly be reached via the steep Gionyama Hiking Couse (but we were unable to verify this as the trail was closed) or by the easier option of returning across the Toshoji Bridge and turning left to follow the narrow main road. In 600m this road crosses the Nameri River and there is access (left) to the Myohonji Temple.



Left: December colours in the valley forests surrounding the Myohonji Temple, founded in the 13th century and still preserving a deep sense of peace. Right: Statue of the monk Nichiren who established the Nichiren sect of Buddhism to which Myohonji Temple is dedicated.

Stop 4: Yuigahama Beach. Returning to the gate to the Myohonji Temple grounds (by the Hikigayatsu Kindergarten) turn left to enter a narrow lane and in 300m turn right to cross the railway and river then turn left to reach the coastline.



Yuigahama Beach looking southeast across Sagami Bay towards the Miura Peninsula, in the forearc of the subducting Philippine Sea tectonic plate. The beach here rose 2m as a result of the 1923 subduction zone earthquake. In medieval times the beach "became a battlefield in 1180 at the time of the battle against Hatakeyama Shigetada, and again in 1333 for the fight between Nitta Yoshisada and the defense forces of the Hōjō. Lastly, it became a battleground in 1416 during Uesugi Zenshū's rebellion. Human bones of the era are still occasionally found during excavations. It is on this beach that Nichiren, the founder of the Buddhist Nichiren sect, was put on a boat to be taken to Katase and executed" (Wikipedia).

The epicentre of the Great Kanto Earthquake lay offshore beneath Sagami Bay, the shoreline of which was hit by widespread damage and loss of life. Reports of what happened in Kamakura describe the sea suddenly receding after the tremor, followed by the arrival of a 6m-high tsunami which swept into the town and killed around 300 people. The combination of tremor, tsunami and fire produced a human death toll in Kamakura of over 2000.

Stop 5: Hasadera Temple. Walk across the beach to its western side then turn N towards Hase rail station. After crossing the railway line turn left to visit Hasadera temple, built well above tsunami height on the western hillside overlooking the town and beach. Highlights of the visit to the temple complex include a huge wooden statue of an 11-headed Kannon, extensive views over the town, and a cave system exposing Miura Group sediments:

Miura Group Cenozoic sandstones and mudstones exposed inside the Hasadera Temple caves.

View across Kamakura, the Miura Peninsula and Sagami Bay from the Hasadera Temple hillside. The S coast of SW Japan from the island of Kyushu eastwards lies in the forearc of the N-NW subducting Philippine Sea Plate. East of Shizuoka the subduction is interrupted by the collision of the Izu-Bonin arc. Further E, here under Sagami Bay, Philippine Sea plate subduction resumes towards the NE, producing a complex geology involving the double subduction of two plates in opposing directions (see map B at the beginning of this report). The 1923 earthquake was a fault movement beneath Sagami Bay predicted by the seismologist Akitsune Imamura who at the time was not believed and, until September 1923, fell into disgrace for frightening the public.

Stop 6: Daibutsu statue. After visiting Hasadera continue N away from the railway to visit the famous Daibutsu (Great Buddha) statue in the grounds of Kotoku-in Temple. After this, return to Kamakura via the Hase electric railway and catch the next train back to Tokyo.

The Daibutsu statue was cast in 1252. The 1923 Great Kanto "earthquake devastated Tokyo, the port city of Yokohama, and the surrounding prefectures of Chiba, Kanagawa, and Shizuoka, and caused widespread damage throughout the Kantō region. The earthquake's force was so great that in Kamakura, over 60km (37 mi) from the epicenter, it moved the Great Buddha statue, which weighs about 121 tonnes, almost 60 centimetres" (Wikipedia). Between the pedestal and the statue a stainless steel plate has been inserted to lessen the shock in future earthquakes. An original pavilion housing the statue was destroyed by a tsunami in 1498. The tremor responsible for this tsunami, which must have been enormous to reach so far inland, is known as the Meiō Nankaidō earthquake and was the result of another rupture of the Philippine Sea plate, this time centred W of the Izu Peninsula.

TOKYO TO OSAKA

Day 3: Atami.

Today we leave Tokyo megacity and head southwest from Tokyo Central Station to Atami on a local train journey that follows the JR Tokaido Line and takes 1.5-2 hours. The first part of the journey follows the same route as the previous day as far as Ofuna. Beyond Ofuna the line heads west, crossing the Sagami and Sakawa rivers to reach Odawara, an zone much affected by earthquake activity: "destructive seismic faultings occurred five times during the last 400 years, in 1633, 1703, 1782, 1853, and 1923, with a recurrence interval of about 70 years" (see 1985 and 2004 papers by Katsuhiko Ishibashi: https://earth-planets-space.springeropen.com/track/pdf/10.1186/BF03353091). We are now approaching the Izu Peninsula and crossing a mighty and complicated tectonic plate boundary, moving from the Okhotsk (North American) plate on to the Philippine Sea plate which here is characterised by the Izu-Bonin volcanic arc colliding northwards with Central Honshu. Immediately to the W of the Izu Peninsula is the Amurian (Eurasian) Plate, making this area a collisional triple point junction (see Map B).

Odawara lies just east of Hakone stratovolcano, the most recent major caldera-forming eruption from which occurred around 50,000 years ago, although many smaller events have been recorded since (the most recent alert was in 2019). The Tokaido train line beyond Odawara, skirting the SE flank of Hakone Volcano, was extended as far as Nebukawa and Manazuru in December 1922. This proved to be unfortunate timing as during the Kanto earthquake the following September two passenger trains were destroyed here. One of these trains, southbound but waiting in Nebukawa station, was overwhelmed by an earthquake-generated landslide of andesitic lava and pushed into the sea, killing most of those on board, along with many living in the village below. The other train, travelling north towards Tokyo, was just south of the station on a bridge crossing the Nebukawa River and hit by the tsunami that followed the earthquake.

Memorial to 1923 train disaster in Nebukawa station (source: Junko Nagata © Japanbyweb.com)

Arriving in Atami you will need to top-up your Welcome Suica Card using the machines alongside the station entrance to pay for tomorrow's journey to Nagoya (in 2020 for us the top-up needed was an extra 2,000 Yen).

The hot spring (onsen) resort of Atami is built on steeply sloping hills of Pleistocene basalts and andesites belonging to the Izu-Bonin Arc. The volcanic nature of the terrain is obvious from the moment you step out of the rail station in front of which there is a footbath heated by geothermal waters.

The area around the rail station is the best place to find food and drink. After hotel check-in we recommend a walk to the Oyu geyser: follow the main road SW from the station and turn right just before crossing the Ito River to find the geyser on the left.

Oyu geyser. Reported to have once been one of the biggest in the world and capable of shaking the ground when erupting, the Oyu geyser finally gave up the ghost following the 1923 Great Kanto Earthquake and is these days encouraged to erupt artificially. The small stone monument to the right is the tombstone of Toby, a dog owned by Rutherford Alcock, the first British envoy to Japan and remembered for being the first non-Japanese person to climb Mount Fuji. The dog went too close to the geyser, was scalded and died. The tombstone reads: "Poor Toby".

The rest of the day can be spent exploring Atami, starting with the Kinomiya Jinja shinto shrine and its sacred camphor tree named O-kusu (left), then climbing to the Atami Baien plum tree garden before returning to descend to the beach via the Ito River walkway. From the beach there are views across to Atami castle, out to sea rises the island of Hatsushima, and from the E side of the beach there are steep steps leading back to the station area.

Atami port and beach, with views to the castle (right) and Hatsushima (left). The 1923 earthquake produced a tsunami which in Atami reached a height of 7 metres and ran inland for 200m. The island of Hatsushima was uplifted by 1.8m.

Day 4: Atami to Nagoya. Although the journey from Atami to Nagoya can be made in less than 2 hours by bullet train (at a cost of over 8,000 Yen), the journey is more scenic taking local trains changing in Shizuoka, Hamamatsu, and Toyohashi, a route which takes over 4 hours and costs under 5,000 Yen. Note that if paying using a Welcome Suica Card it may be necessary to show this on arrival in Nagoya if the automatic machine does not allow you to leave the station (in December 2019 the Suica could legally be used for the journey but the ticket machines in Nagoya had not been upgraded). If time allows consider continuing past Nagoya to spend the night in the Toyoko Inn at Matsusaka; otherwise overnight in Nagoya (as we did), get a morning train using your new 5-day pass, and leave bags in Matsusaka before moving on to Iseshi.

The highlight of the journey today is the view of Mount Fuji which, in good weather, can be enjoyed slowly with the mountain profile gradually changing as the train to Shizuoka moves from the SE to the SW side of this huge volcano. However, as an aperitif, one can start by enjoying tunnelling through the volcanic rocks of the Izu Peninsula.

Local JR train bound for Shizuoka about to leave Atami station and enter the first of the tunnels cutting through the volcanic arc rocks of the northern Izu Peninsula. Beyond this initial short tunnel the train passes Kinomaya station to enter the 7.8km Tanna Tunnel, notorious for its geohazards and resulting loss of life during construction (67 workers died). Excavation of this tunnel included overcoming the ingress of hot volcanic waters and the constant threat of earthquakes and rainstorms in this tectonically highly active area. During construction there was a major collapse in April 1920 (17 out of 42 men trapped were dug out alive), followed by damage during the 1923 Kanto earthquake. On November 26 1930 at 04:02 local time the tunnel was hit by a magnitude 7.3 earthquake centred on the northern Izu Peninsula and caused by the movement of the left-lateral Tanna Fault which slices through the tunnel. This fault displaced rocks 2.4m vertically and 2.7m horizontally, blocking a pilot rail tunnel under construction.

Emerging from the Tanna Tunnel the Tokaido rail line passes Numazu (known for its 9.3m-high tsunami prevention gate) and follows the urbanised northern side of Suruga Bay. On a clear day the view from the train is dominated by Mount Fuji which 25km to the N rises to a height of 3,776m, the highest point in Japan.

Mount Fuji is a basalt-dominated volcano associated with the westward subduction of the Pacific plate although it has an eruption rate much higher than other volcanoes along the same (Izu-Bonin) arc. It lies in an area where 3 plates meet, a "triple junction" of the Philippine Sea, Eurasian (or Amurian), and North American (or Okhotsk) plates, under which the Pacific plate is subducting at around 85mm/yr. The Philippine Sea plate is subducting northwards beneath the Eurasian (or Amurian) and North American (or Okhotsk) plates at rates of about 25mm/year (Suruga Bay) and 15 mm/year (Sagami Bay) respectively. Beneath Mount Fuji however the Philippine Sea plate includes the Izu-Bonin arc which is less dense, therefore harder to subduct, and so produces plate collision. One result of this collision is that Mount Fuji is not circular but elongated in a NW-SE direction as a result of the stress field generated by the northwestward-directed compression of the Philippine Sea plate, which produces extension that favours eruption from fissures aligned in a NE-SW direction.

Mount Fuji peaks just 100km W of Tokyo city centre, as well as lying close to dense populations to both N and S. It is a conical composite stratovolcano built upon an older andesitic volcano of Middle Pleistocene age, and started erupting around 80,000 years ago. The eruptions from Mt. Fuji over the last 2,000 years or so have all emanated from the flanks rather than the summit, suggesting that the heavily urbanised areas surrounding the volcano may be especially at threat not just from ash but also from lava flows.

TOKYO TO OSAKA

The most recent major volcanic event (the Hoei eruption) occurred in December 1707 when an explosive Plinian ash plume rising from the SE side of the volcano drifted over Edo (former Tokyo) and caused darkness at midday. The Hoei eruption started explosively with the emission of felsic materials but later became basaltic. It has been modelled that beneath Fuji there is a deep (c.20km) basaltic magma chamber and a shallower (8-9km) felsic magma chamber. Volcanic ash blew eastwards during the 1707 event, depositing layers over 100mm thick 100km away (reaching 160mm in Kamakura, for example).

The Hoei volcanic eruption came 49 days after a huge earthquake had ruptured the Philippine Sea plate boundary west of the Izu Peninsula, and a likely link between earthquake and eruption has been widely discussed. Four days after the Great Tohoku 2011 earthquake in NE Japan there was a magnitude 6.2 (East Shizuoka) earthquake at shallow depth beneath Mount Fuji on its southern side. Although no volcanic eruption ensued then, the fact remains that the volcano has been dormant for over 300 years, which is unusually long given its history. Furthermore the volcano today is not showing much degassing activity, suggesting that gas pressure is building up inside the volcanic plumbing system, making an explosive eruption more likely.

TOKYO TO OSAKA

Any future eruption from the volcano is likely to be preceded by weeks or, more probably, several months, of seismic unrest. Volcanic eruptions are thus more predictable than earthquakes, and Mount Fuji is no Yellowstone because it lacks a huge caldera-forming magma chamber. Nevertheless it has been estimated that a repetition of a Hoei-type event today would cost Japan over $20 billion (Japanese GDP in 2018 was $5 billion). For more details see https://www.sciencedirect.com/science/article/pii/S0012825218302046#bb2000.

Moving west from Shizuoka towards Nagoya we have by now having moved from the Izu arc on to the Eurasian (Amurian) tectonic plate, with the Philippine Sea plate subducting below at depths of 20-30km. Like Tokyo and the Izu Peninsula, this entire zone has been designated by the Japanese Government at being high risk of a major "Tokai" earthquake over the next 30 years.

Day 5: Iseshi. We used the Toyoko Inn at Matsusaka (where there are plenty of restaurants) as a base from which to explore Iseshi and the Shima Peninsula coast to the SE (Day 6) and the Owase area to the SW (Day 7), making the most of the Limited Express trains included in the Ise Kumano 5-day Tourist Pass.

It is a short train ride from Matsusaka to Iseshi which is the site of the Ise Grand Shrine, one of the oldest and most venerated Shinto shrines in Japan, and set in scenic wooded surroundings. "The buildings of the two main shrines of Naiku (Inner Shrine) and Geku (Outer Shrine) are examples of the pre-Buddhist architectural style called shinmei-zukuri, characterized by extreme simplicity…. Both the main sanctuaries and the Uji Bridge in front of Naiku are rebuilt every 20 years during the shikinen sengu ceremony that was established over 1,300 years ago. This ritual plays an important role in preserving and conveying the roots of Japanese culture to the next generation" (Suzuki & Takaji 2017, Acta Geoturistica: freely available online).

The Ise Grand Shrine area is of additional interest because of its geology. In this area lies the major tectonic boundary known as the Median Tectonic Line (MTL). The MTL can be traced across Japan for over 1,000km and has a fault displacement history that goes back to around mid-Cretaceous times 100 million years ago. The MTL is best known for separating two quite different geological terranes: the high temperature Ryoke and low temperature Sanbagawa metamorphic belts. The striking contrast in metamorphic history between these two belts led Miyashiro (1961, 1973) to propose the idea of "paired metamorphic belts". The low temperature side of the paired metamorphic belt (in this case Sanbagawa) is the result of the subduction of

cold oceanic lithosphere into the mantle, whereas the high temperature side represents the rise of hot melted rock (magma) and fluids beneath the arc. Thus with the concept of paired metamorphic belts came the realisation that metamorphic and structural geology in the field and under the microscope could be interpreted in terms of plate tectonic processes. It was a revolution in geological thinking, and the MTL is the type locality.

The MTL runs alongside the Geku shrine to the N of which are rocks of the Ryoke Belt whereas to the S are rocks of the Sanbagawa Belt. Inland exposure is poor, as is typical for Japan, and there are thick Quaternary sediments beneath the low ground N of Iseshi. However, in the forests behind the main Geku shrine complex, near the Tsuchinomiya shrine, there are poor exposures of Sanbagawa schists. The best and easiest places to admire the various Sanbagawa rock types at Geku however are in the polished steps leading to the various shrines.

Green-blue mafic metamorphic rocks from the Sanbagawa Belt used in the steps to the Geku shrine complex.

A typical visit to the Ise Grand Shrine involves an easy walk through the town from the station to Geku (the outer shrine), where free green tea can be enjoyed before catching the bus (51 or 55: included in Tourist Pass) to visit the Naiku (Inner Shrine). When we were there it was New Year's Day and the massive morning crowds made waiting for the buses pointless so we walked back to the station and took a train to Futamino-ura to visit the Futami Okitama Shrine. Later in the day, when the crowds had thinned out, we returned to Iseshi and took a 51/55 bus from the station to the Naiku, visiting the forested shrine complex in the early evening light, which turned out to be a bonus.

The secretive thatched buildings of the Ise Grand Shrine are built from cypress wood and the architectural style dates back to the earliest recorded historical period in Japan (around 4th century AD).

The coastal Futami Okitama Shrine is an easy walk N from Futamino-ura station to the coast then E to the shrine where you are rewarded with excellent exposures of Sanbagawa metamorphic rocks accompanied by many stone frogs. The frogs are considered to be messengers of the Great God Sarutahiko Okami and being surrounded by them will supposedly help to make your wishes come true.

Sanbagawa greenschist tablet accompanied by frogs.

Exposures of Sanbagawa rocks alongside the coastal path to the Futami Okitama shrine. The rocks here, close to the Median Tectonic Line, are highly deformed so that any original sedimentary or igneous textures have been overprinted by a pervasive metamorphic foliation (dipping gently from left to right). The green/grey-blue colour banding here reflects differences in mineralogy and owes its origin to chemical differences in the original rocks being deformed.

The highlights of the Futami Okitama shrine are these two small isolated sea stacks known as Meota Iwa. The two rock pillars are tied together by large shimenawa (ropes traditionally used in the Shinto faith), signifying the bond between a married couple. The larger (male) rock comprises mafic greenschist, whereas the smaller (female) rocks appear to be metasedimentary. The successful bonding between these two metamorphic rock exposures assures good luck in finding a partner and subsequent marital harmony, affording the shrine great popularity.

The Sanbagawa rocks represent oceanic igneous and sedimentary lithologies that have been deformed and metamorphosed as they were buried by plate subduction. They typically contain minerals that grew under conditions of relatively high pressure but low temperature (HP/LT). They therefore belong to the "cold" side of the paired metamorphic belt where oceanic plate subduction controlled a long history of deformation and metamorphism in mid- to Late Cretaceous times (c. 100-60 million years ago).

Day 6: Owase and the Magose-toge Pass.

The 10:18 Limited Express train (2020) from Matsusaka arrives in Owase at 11:41, giving around 4 hours to enjoy a climb up the Kumano Kodo pilgrimage path to the ridge summit of the Magose-toge Pass before taking the return train in mid-afternoon. The scenic train journey leaves Matsusaka initially to run S to cross the Kushida River at Taki then turns W then S on the Kisei Line to cross the MTL and enter the Sanbagawa Belt. The rocks S of the MTL on the Kii Peninsula were formed as oceanic materials accreted to the overlying plate during subduction. A simple overview of these accretionary complexes reveals the most deeply subducted and metamorphosed rocks closest to the MTL. As one moves S so the rocks become less metamorphosed, i.e. they have been less deeply buried by subduction. South of the Sanbagawa Belt outcrop (after leaving the Miya River valley S of Misedani) the train line firstly crosses a major structural boundary known as the Butsuzo Tectonic Line and enters the outcrop of the Jurassic Chichibu accretionary complex. Then, following the Ouchiyama river valley beyond Ise-Kashiwazaki station, it enters the Cretaceous outcrop of one of the most famous accretionary complexes in the world: the Shimanto Belt.

Reaching the S coast at Kii-Nagashima the train continues crossing Cretaceous Shimanto metasediments as far as Aiga, beyond which the line diverts west to follow the Choshi River below a steep forested ridge to the S. This ridge marks a prominent outcrop of Miocene granite intruding the Cretaceous Shimanto rocks. After a few kilometres the train turns S to tunnel through the ridge and reach Owase station.

Walk due E from the station, following a narrow road to a T junction where you turn left to cross a river and from this bridge cross the road and head N, choosing the road on the left which follows the valley to a large cemetery. Climbing above the tarmac of the town, the Kumano Kodo trail reveals its original medieval stone-paved character as it ascends N towards the Magose-toge Pass. Make a short signposted diversion to Kudo Falls (left) where there are exposures of Shimanto metasediments. The granite that forms huge blocks clogging the narrow stream valley here can be seen *in situ* high above by returning to the Kumano Kodo trail and following it to a track on the left that leads to a lookout from where are great views over Owase (the granite outcrops are underfoot behind the lookout).

Viewpoint looking S over Owase. If the predictions of a future large "Tokai" earthquake generated by subduction faulting in the Nankai Trough are realized, then towns such as Owase are likely to be hit by a tsunami very soon after the main tremor. Owase has a history of repeated tsunami events (1707, 1854, 1944) and so has been the subject of several studies concerning hazard impact. It has been calculated, for example, that the northern part of the town would be especially badly hit by tsunami water, which would overwhelm the coastal strip and channel its flow northwards into the valleys draining the steep granite ridge to the north.

Continuing the steep climb to the pass you will pass outcrops of Shimanto Supergroup metasediment along the way.

Trailside exposures (left) of Shimanto Supergroup siliceous oceanic metasediments contrast with the pale granite paving stones in the Kumano Kodo trail itself.

At the summit turn right onto the path leading towards Mount Tengurasan. A short distance along this path you will discover large outcrops of the granite. Note the large feldspar crystals that give this rock a porphyritic texture: it has been described as the “Kumano Granite Porphyry” and is of Miocene age, intruding the Cretaceous Shimanto accretionary rocks.

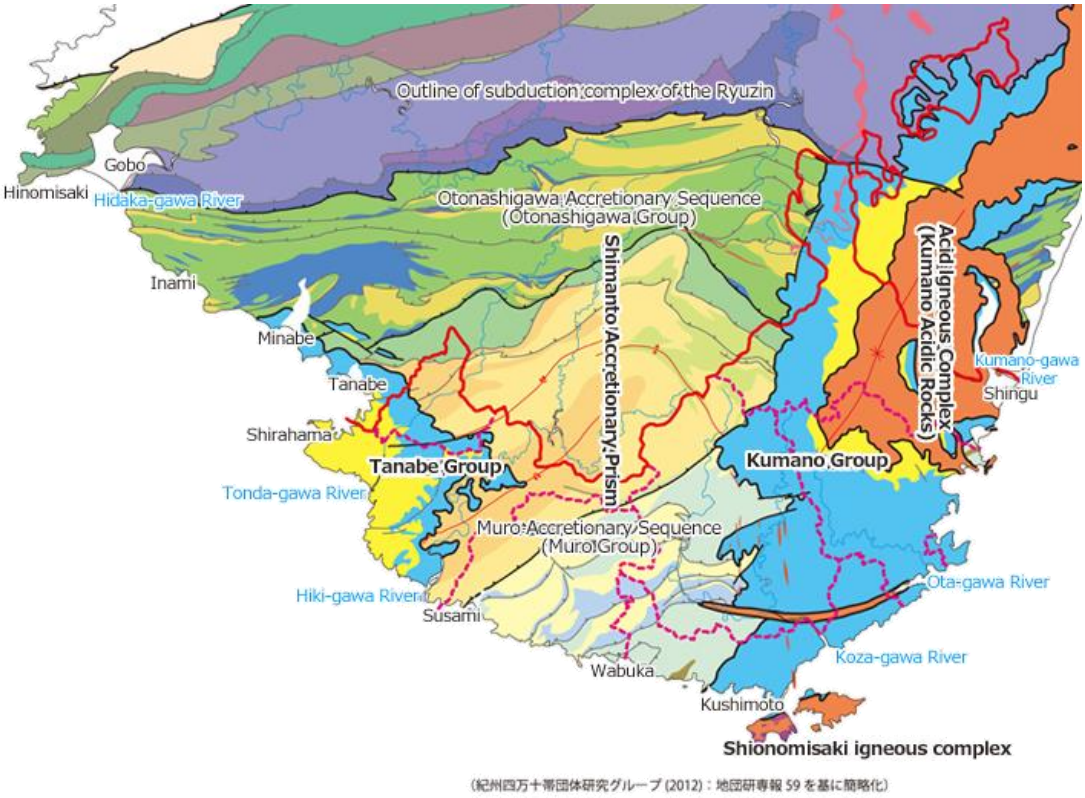
Exposures of Kumano Granite Porphyry on the ridgetop above the Magose-toge Pass show a distinctive sloping weathering pattern resulting from north-dipping fractures (“joints”) that probably mimic the shape of the igneous intrusion. Mapping of this granite outcrop by Kawakami and Hoshi (2007) has led to the interpretation that in the north it forms a steep dyke-like structure whereas to the south it flattens out to become a thick sill-like (or ponded laccolithic) body. We suggest that the joint pattern here is reflecting this change from a sub-vertical to N-dipping to sub-horizontal orientation.

Return by the same route (it is possible to continue N on the Kumano Kodo path to Aiwa station, but the train logistics are more complicated: the Limited Express, for example, does not stop in Aiwa).

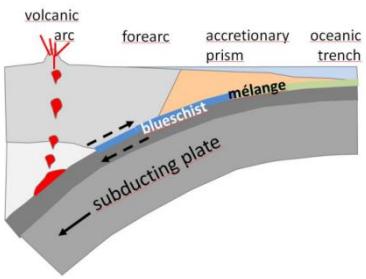
Day 7: Around the Kii Peninsula: Matsusaka-Shingu-Wakayama.

This day trip follows the train line clockwise around the Kii Peninsula stopping for 3 hours in Shingu. Leaving Matsusaka on the 09:16 Limited Express train (in 2020) return to Owase and continue on through granite country to Kumano beyond which the route briefly re-enters the Shimanto Supergroup outcrop beneath the flat coastal plain. Just before Shingu we enter another large area of Miocene granite.

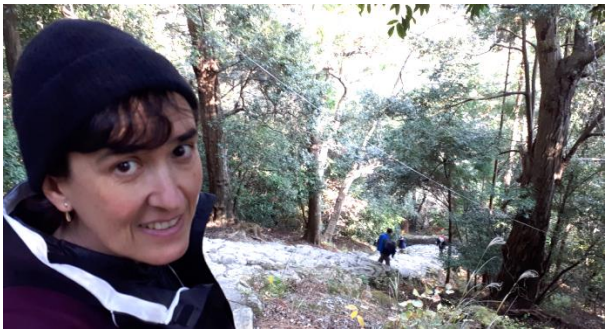
Leaving bags in the station lockers, and after picking up a map from the tourist office, we recommend a clockwise walk through the town, visiting the Kamikura Jinja shrine, the Kumano Hayatama Taisha shrine, the ruins of Shingu Castle, and finally the Asuka Jinja shrine before returning to the station for the afternoon train (15:06 in 2020) to Wakayama.



Geology of central and southwest Kii Peninsula. Image from Nanki Kumano Geopark page: https://nankikumanogeo.jp/eng/geo_theme/earth/. *The geological map shows part of the large outcrop of Miocene (14.5-15.5 million years old) granitic and rhyolitic rocks that crop out in the eastern part of the Kii Peninsula (in orange) and the position of Shingu. This igneous group includes the granites seen around Owase the previous day and has been called the Outer Zone Granitic Rocks (OZGs) because it is found in the outer part of the subduction system unusually close to the trench:*



The OZGs on the Kii Peninsula lie in the forearc/accretionary prism area away from the arc and anomalously close to the oceanic trench. This peculiar location is thought to be a result of something unusually hot having been subducted beneath SW Japan around 15 million years ago (An arc? A spreading ridge?). There has been much discussion about the tectonic setting responsible for these strange "forearc granites": see the paper by Shinjoe et al. published in the Geological Magazine in 2019.



To arrive at our first exposure of the Kumano granites we need to expend considerable energy climbing to the Kamikura shrine. The steep climb up irregular granite steps to Kamikura shrine needs to be taken carefully.

Kamikura Jinja is built on porphyritic granite bedrock and behind the shrine loom huge rounded masses of the same Miocene granite. Great rock "tors" such as these "very gradually become isolated by chemical weathering along horizontal and vertical cracks ("joints") and their rounded shapes are sculpted by physical exfoliation. Removal of soft weathering products such as clays along the joints, especially during the wet season, slowly makes the remaining rock mass increasingly unstable and liable to topple into lower ground. It is just a question of erosion and time" (From ***Kruger Geology on Safari****: http://barcelonatimetraveller.com/wp-content/uploads/2019/03/Kruger-Big-5-Holiday-Geology.pdf). And perhaps aided by a major earthquake…..*

After visiting the Kamikura Jinja follow the backstreets of the town northwards to the Kumano Hayatama Taisha shrine, then walk S to climb the ruins of Shingu castle, entering by climbing the steps on the W side and working clockwise through the grounds to exit on the E side.

View from Shingu Castle up the Kumano River into the granite hills to the NW. Granitic rocks of Miocene age are found in the SW Japan forearc from Kyushu to the Kii Peninsula, across a distance of 800km. The igneous event responsible for these forearc granites (and related rhyolites) was mostly confined within a relatively short time bracket (2 million years). The granites were intruded simultaneously from Kyushu to the Kii Peninsula just after Japan had rotated clockwise to its present position, opening the Japan Sea behind it and thus separating the archipelago from the Asiatic mainland. In the eastern Kii Peninsula the granites intruded both Shimanto belt accretionary rocks (as seen on the previous day) and, further west, Kumano Group forearc basin sediments which were deposited in Early to Middle Miocene times.

TOKYO TO OSAKA

Left: Kumano porphyritic granite exposed in the walls of Shingu Castle. The grey granite contains large crystals of pale feldspar which give it a porphyritic texture. Right: View SW from Shingu Castle showing the typical Kii Peninsula coastal landscape of low-lying, densely populated towns bordered by steep forested hills forming a young, immature landscape sculpted by high tectonic activity and rapid erosion under heavy rainfall.

The coast-hugging Kuroshio train journey around the Kii Peninsula to Wakayama takes 3 hours and is one of Japan's classic train rides. Leaving Shingu the train initially passes through Kumano granite country but for most of the journey down to the southern tip of the peninsula the underlying rocks are Kumano Group forearc sediments. At Kushimoto the line turns northwest, passing the isthmus to Shionomisaki where an outcrop of Miocene igneous rocks S of the Kumano Group sediments includes a mix of gabbro, dolerite and rhyolite. West from Kushimoto, after Tanami, the train leaves the Kumano Group and once again enters the outcrop of older Shimanto Supergroup accretionary rocks (in this case Eocene to Lower Miocene in age). West of Susami the line crosses the Hiki River and enters the outcrop of another sequence of Miocene forearc sediments called the Tanabe Group (see the Nanki Kumano Geopark geology map above). Passing Shirahama (the location for tomorrow's excursion) and W of Minabe, the route moves back on to the accretionary rocks which, beyond Gobo, are now of Cretaceous age similar to those seen around Owase the previous day. For the Shimanto Supergroup enthusiast, the boundary between the Cretaceous rocks to the N of Gobo and the Eocene-Lower Miocene rocks to the S is called the Aki Tectonic Line. Further north the rocks become more highly deformed as we move back to the Sanbagawa Belt at Wakayama where the Toyoko Inn is as usual conveniently close to the rail station.

Day 8: Shirahama.

Today we return southward down the line to spend time cycling around Shirahama, a popular tourist spa town within the Nanki Kumano Geopark on the southwestern coast of the Kii Peninsula. There are regular Limited Express trains making this journey, and the cycle hire at Shirahama rail station is free for holders of the Ise Kumano Tourist Pass.

Left: Topographic map of the Shirahama Peninsula with numbered geological localities: see the Nanki Kumano Geopark information board outside Shirahama train station. Our recommended bicycle route runs NW from the station, around the peninsula (below the "You Are Here" rectangle), then follows the shoreline anti-clockwise to the bay between locations 1 and 2. Right: Plate tectonic evolution of the area. Note (1) initial onset of subduction and growth of Shimanto Supergroup "Nankai" accretionary prism above the subducting plate; (2) development of Kumano Group forearc sedimentary basin on top of Shimanto rocks; (3) Intrusion of Miocene Outer Zone Granitic Rocks (OZGs) into both Shimanto and Kumano sequences; (4) Present day tectonic setting, with the Philippine Sea Plate subducting beneath the Nankai Trough at around 50mm/year and an angle of 15° under the Eurasian plate. Around Shirahama are exposures of the Lower Miocene Tanabe Group forearc sediments (see Nanki Kumano Geopark geology map above).

Follow the road NW from Shirahama station for 500m then, where the road bears left, turn right to pass under a road bridge and reach the coast close to the Nanki Shirahama Toretore fish market. Follow this quiet coast road for over 1km to a junction with Highway 33. Turn right and, cycling along the pavement (the road is too busy) follow W then NW then N on Highway 34. This highway curves around the N coast of the peninsula before turning S to reach a bay north of the town centre. Leave your bikes here and descend to the beach to enjoy cliffline exposures of Tanabe Group sediments.

Tanabe Group sediments are well exposed in the cliffs around Shirahama. In the image above Shirahama Formation cross bedded pebbly sandstones are overlain by a thick conglomeratic unit (see close-up in inset). The Tanabe Group is Miocene in age and was deposited in a forearc basin unconformably on older Shimanto Supergroup accretionary rocks.

Continue along the coastal road for a few 100 metres to a right bend with excellent exposures of Shirahama Formation sandstones and mudstones in a low cliff face on the left (landward) side of the road:

The upper part of the Shirahama Formation succession exposed in these roadside cliffs is dominated by pale sandstones with thin dark mudstone layers, whereas in the lower part grey mudstone layers are more common. This records a transition in time from lower energy (mudstone) into higher energy (sandstone: submarine channels?) sedimentation within the Miocene forearc basin.

Some of the sediment layers show curving beds indicative of soft-sediment deformation due to slumping (e.g. the fold below and to the left of the white pen). Such phenomena may have been caused by earthquakes and/or destabilisation of the sedimentary layers due to rapid sedimentation. Many of the thinner pale sandstones show ripples, sometimes draped by dark mud which preserves the sedimentary structure in delicate detail.

The general lack of abundant trace fossils such as animal burrows in this succession is consistent with an environment characterised by rapid sedimentation in a tectonically active and climatically energetic marine basin.

Out to sea from the same locality is Takashima, more commonly referred to as Engetsu (Island of the Full Moon) because of its near-circular arch eroded into the Miocene Shirahama Formation siliciclastic sequence.

Continue following the coastal road into town, passing exposures of Tanabe Group sediments eroded into honeycomb or "tafoni" textures, to reach the Mifune and Tsukumoto footbaths and the venerably old Saki-no-yu onsen, all well-known hot spring localities overlooking the sea. For those with time and energy, the coast road further east climbs on to the sandstone-dominated Tanabe Group outcrop to pass coastal exposures at Senjojiki and Sandanbeki.

Back at the rail station we recommend catching a Limited Express train that begins at Shirahama as this makes finding a non-reserved seat much easier.

Day 9: Wakayama.

Our final day using the Ise Kumano Tourist Pass is the most relaxing: hopping on and off the Wakayama Electric Railway between Wakayama and Kishi. The delightful trains running along this line are worth the journey alone, but to this one can add the famous Three Saigoku Shines, exposures of Sanbagawa schists, and, the grand climax, Nitama the Stationmistress cat will greet you at Nishi Station.

The first station stop is Nichizengu. Walk 100m N from the station to locate the grounds of the Hinokuma-Kunikakasu shrine complex. Here we are 3km S of the Kino River: most of Wakayama is built on low-lying recent sediments on either side of this river. The southern side of the city however exposes metamorphic Sanbagawa Belt rocks, most of which are quartz-muscovite metapelites but in some areas (such as Saikasaki coastal park SW of the city) include metamorphosed mafic rocks such as metabasaltic greenschists similar to those we have seen at the Futami Okitama shrine on Day 5.

Moving on down the line to Kamayama station, walk a short distance S to the Wada River, turn left to cross the first bridge (right) and follow the narrow lane 300m S to the Shizukahi shrine, conveniently situated above tsunami height on a narrow E-W ridge which rises abruptly from the alluvial plain. This ridge forms an outlier of Sanbagawa pelitic schists, one of several emerging from the alluvium in this area and to the S & E.

Lane leading S from the Wada River towards the Shizukahi shrine outlier of Sanbagawa metamorphic rocks (steep hill rising top-right).

The path up to the Shizukahi shrine conveniently doubles as a tsunami escape route.

Descend back to the lane then continue S to take the first road on the right at the end of which cross the main road and continue a short distance to a major crossroads across from which is the Kamayama shrine complex. Here emerges another, much smaller, outlier of Sanbagawa schist, although the shrine was closed when we visited.

After Kamayama shrine we head back N towards Kamayama station, deviating NW to visit the Sakatahachiman shrine and Ryohoji temple. From Kamayama cross the main road northwards then turn left and right to follow a small tributary channel that runs N towards the Wada River. Following this stream take the road first left which runs W then curves NW around exposures of Sanbagawa pelitic schist. 100m further on we reach steps (left) which climb another Sanbagawa schist outlier to the Sakatahachiman shrine. The Sanbagawa bedrock is exposed underfoot in front of the shrine.

Sanbagawa bedrock exposed in the floor of the Sakatahachiman shrine. These rocks display an intense metamorphic foliation which has destroyed all trace of any original sedimentary or igneous textures.

The rock basement in this area (of Cretaceous and older ages), rises to form a series of outlier hills above the densely populated alluvial and coastal low ground, as demonstrated in this view N from the Sakatahachiman shrine towards the Kino River.

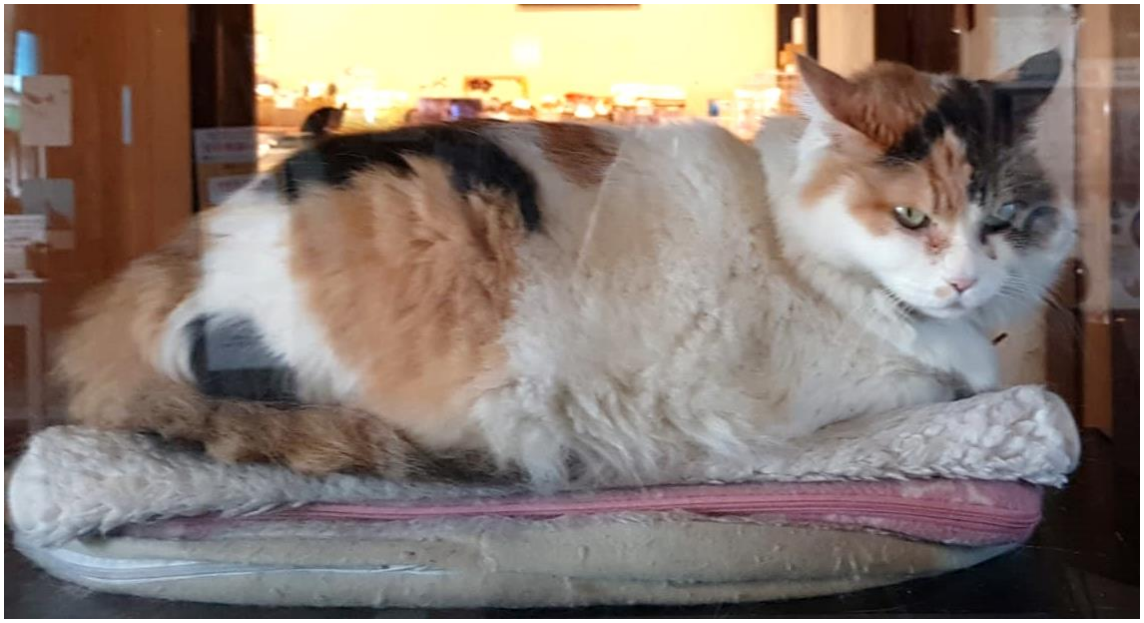
Returning to the foot of the shrine entrance, take the road opposite which leads to the Ryohoji temple and its extensive graveyard, before retracing the route back to the tributary channel and joining the road leading back N to Kamayama station.

The third station stop of the day is at Idakiso, a station run by Yontama the Cat Stationmistress. A short distance to the S of the rail station rise hills of Sanbagawa schist on the lower slopes of which is built the splendid Idakiso shrine, dedicated to Itakeru-no-mikoto, a God of Wood. In the hills to the south are prominent belts of mafic greenschist, examples of which are utilised as blocks and slabs within the walls of the buildings here:

Blocks of green and blue mafic schist used in steps and walls are common within the Idakiso shrine complex.

Granite stone lantern (ishi-dōrō) in front of a wall built from Sanbagawa mafic schists at Idakiso. Granite is a popular stone used in Japanese temples and graveyards, and most locally produced stone comes from quarries in Ryoke Belt rocks exposed around the Inland Sea (especially in northern Shikoku).

The train east of Idakiso crosses a watershed through hills of Sanbagawa schist to emerge on the alluvial plain of the Kishi river, which drains N into the Kino River. Accompanied by the tune of *Strawberry Fields Forever* (the berries are produced locally), the train draws into Kishi station, famous for its bark roof and feline Stationmistress Nitama.



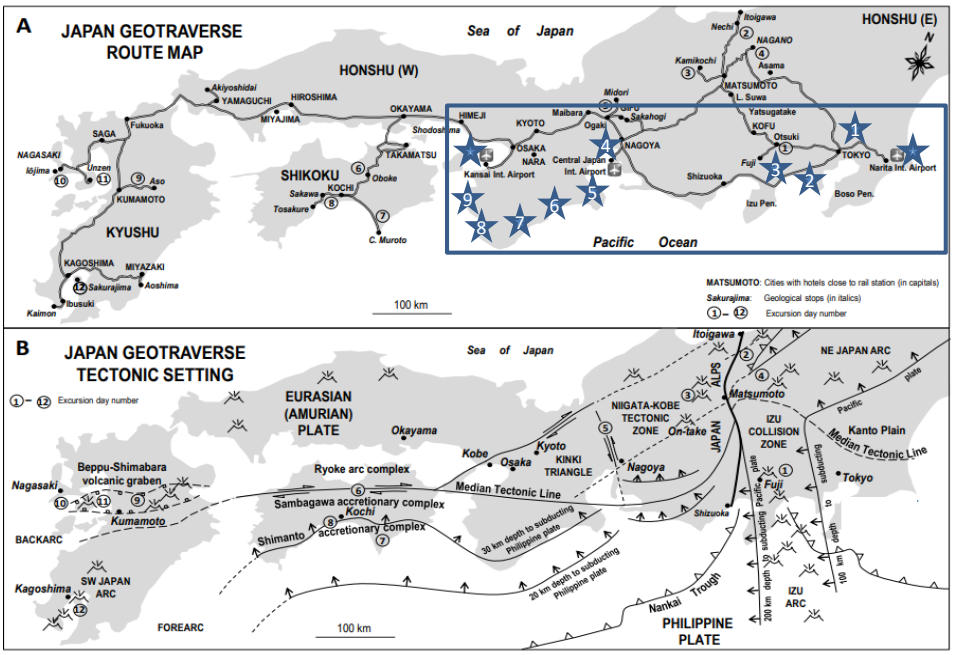
Nitama (Tama number two) the Stationmistress at Kishi, controlling the station from her electric blanket.

End of the line for the Tama densha, whose fortunes were reversed by adopting a cat as stationmistress.

Our final journey was back to Wakayama to collect bags and move on to Kansai International Airport to overnight in the Hotel Nikko before flying back the 10,300km to Barcelona.

We found our experience of slow travel through Japan informative and enlightening. The sense of personal security and the friendliness of the people make the visit unstressful, and (with the help of Hyperdia) we had no problem navigating the train system and finding our way around.

Finally, for us of course enjoying the geology and scenery provides the icing on the cake. Starting from the Kanto Plain, with its recent history of devastating earthquake and fire above the double subduction zones of the Pacific and Philippine Sea plates, the route moves west through the Izu Collision Zone. Passing Mount Fuji and crossing the MTL to arrive in Nagoya, the route follows around the coastline of the Kii Peninsula to visit the Sanbagawa Belt at Iseshi, the Shimanto accretionary metasediments, the Miocene Outer Zone Granitic Rocks and Tanabe forearc sequence, before returning N to cross back into the Sanbagawa Belt at Wakayama. An enriching lesson in subduction processes.



Wes Gibbons 2020

http://barcelonatimetraveller.com/

Background to Holiday Geology Guides

The author and geologist Wes Gibbons has always had an interest in writing short geoguides aimed at inquisitive tourists, offering them the opportunity to learn about the landscapes and rocks of scenically attractive places. His argument is that there is so much more to know about rocks and Earth history than the superficial descriptions offered by tourist guidebooks, which rarely even scratch the surface of Deep Time.

His first attempt in this direction produced *The Rocks of Sark* (1975), published jointly with John Renouf of Manche Technical Supplies in Jersey, a venture that taught a youthful Wes to always be the one responsible for the final proof reading. In 1976 Wes moved from Sark to begin a PhD supervised by Greg Power (Portsmouth University) and Tony Reedman (British Geological Survey). Living in a former Post Office in the village of Greatham on the Hampshire-West Sussex border, Wes decided to pass his spare time preparing a guide to the geology of the Weald in southeast England. He sold the idea to the publishers Allen and Unwin who commissioned other authors to develop a mini-series: *The Weald* (1981), *Snowdonia* (1981), *Lake District* (1982), and *Peak District* (1982).

His next field-based guidebook surfaced in 1985, fruit of several years research work in Corsica (*Corsican Geology: a field guidebook* by Gibbons and Horák). Two years later Wes launched the Holiday Geology series, using a simple, inexpensive format later described as "a single A3 laminated sheet …. folded into three and (with).. six portrait panels … filled with a lively mix of colour photos, maps, sections and text" (review by Nigel Woodcock in Geological Magazine, 2000). The first two Holiday Geology guides were *Scenery and Geology around Beer and Seaton* (1987) and *Rocks and Fossils around Lyme Regis* (1988). The Holiday Geology concept attracted the attention of the British Geological Survey who went on to expand the series to over 20 titles.

Following his retirement in 2004 to live in Barcelona with Teresa Moreno, Wes maintained his interest in publishing field guides by writing the text to *Field Excursion from Central Chile to the Atacama Desert* (Gibbons and Moreno 2007), *The Geology of Barcelona: an Urban Excursion Guide* (Gibbons and Moreno 2012), and *Field Geotraverse, Geoparks and Geomuseums* (in central and southwest Japan: Gibbons, Moreno and Kojima 2016). His most recent publishing project, the most ambitious so far aimed at a general readership, has produced the book *Barcelona Time Traveller: Twelve Tales* (2016, Spanish translation 2017: Bimón Press Barcelona) and the resurgence of the Holiday Geology concept, although this time in virtual format linked to the *Barcelona Time Traveller* webpage.