

**ROADSIDE GEOLOGY
OF TAIWAN:
A FIELD GUIDE**

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ABOUT THE COVER

The cover photo depicts the folded gneisses in Taroko National Park.

All photos in this book by
Stephanie Chen.

For my family.



PREFACE

This book has been written as part of the University of Toronto's Big Ideas: Exploring Global Taiwan competition. It had always been my dream to just camp out at a location for a month and know every rock and outcrop like the back of my hand, and eventually write a field guide like the ones that guided me through my own geology education.

I didn't get to stay for months. In fact, I was only able to stay for one month, but it was still an incredible experience, and truly humbling.

Taiwan's geology is very diverse and contains so many local scale variations which at many times are hard and challenging to find. It's hot and humid, mosquitoes abound, and venomous snakes lurk beneath the brush. But for those who are willing to take the challenge and experience what this little island country has to offer, you will not be disappointed.

Stephanie

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INTRODUCTION

The geology of Taiwan reveals that the Taiwan of today is composed of mostly Cenozoic material, with some traces of Mesozoic material. This is not too surprising considering its oceanic subducting environment, where the earth gets continuously recycled with tectonic activity – the older material has long since been churned away.

SETTING THE SCENE

The island of Taiwan is host to a complex convergent boundary where four different plates interact. These plates are the Yangtze subplate of the Eurasian plate to the west and north, the Okinawa Plate to the northeast, the Philippine plate to the east and south, and finally, the Sunda Plate to the southwest.

These plate interactions have created two volcanic arcs. South of Taiwan, the Philippine Sea Plate subducts under the Sunda plate to create the Luzon volcanic arc, while to the northeast, the Philippine Sea plate subducts under the Okinawa plate forming the Ryukyu Volcanic arc.

These geologic interactions are the ingredients for Taiwan's seven geologic terranes. From west to east, they are the Penghu island group, Coastal Plain, Western Foothills, Western Central Range, Eastern Central range, Eastern Longitudinal Valley, and the Eastern Coastal range. They are all conveniently arranged parallel to each other, spanning from north to south. The eastern part of the

Era	Period	Epoch
Cenozoic	Quaternary	Holocene
		Pleistocene
		Pliocene
	Tertiary	Miocene
		Oligocene
		Eocene
		Paleocene
Mesozoic	Cretaceous	"Age Of Reptiles"
	Jurassic	
	Triassic	
Mu Paleozoic	Permian	"Ages of Amphibians"
	Carboniferous	
	Devonian	"Age of Fishes"
	Silurian	
	Ordovician	"Age of Invertebrates"
	Cambrian	
Precambrian – Comprised about 87% geologic time		

Fig. 1) Simplified geochronology of the world.

island undergoes a lot of mountain building, while the western portion accumulates in fluvial sediments from the eastern activity.

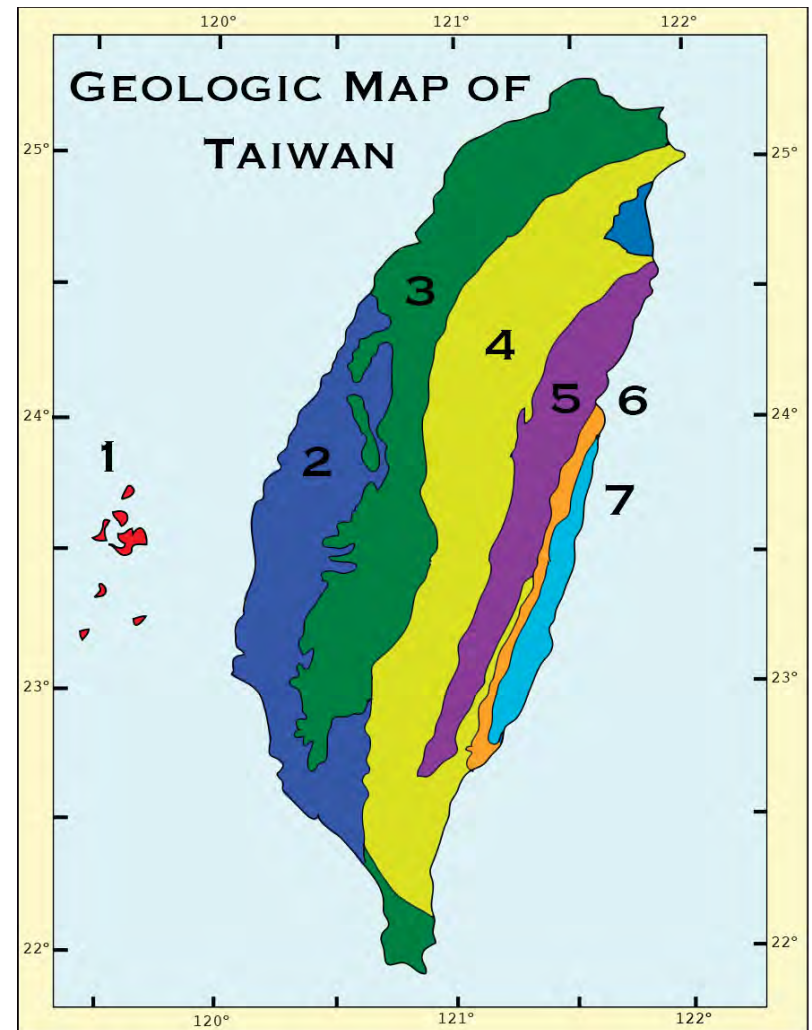


Fig. 2) Map of the geologic terranes of Taiwan. 1 – the Penghu island group. 2 – Coastal Plain. 3— Western Foothills. 4 – Western Central Range. 5 – Eastern Central Range. 6 – Eastern Longitudinal Valley. 7 – Eastern Coastal Range.

PENGHU ISLAND GROUP

Formed by Pleistocene volcanism, the Penghu Island Group in the Taiwan Strait mainly consists of flood basalts, covering over 63 islands and islets. Xenoliths found include spinel peridotites and spinel pyroxenites. The main geologic and tourist feature of the islands are the impressive columnar basalts.

The basalts are thought to have been caused by the intraplate volcanism associated with the end of Taiwan's main orogeny. The exception is the Huayu islet which is comprised mainly of quartz porphyry.

Recent studies (1994) report that the basalts might actually be of a Miocene age instead, based on foraminifera fossils found, so more data and study is needed to ascertain the origins of this terrane.

The Penghu islands have also attracted attention due to a number of macrofossils found, including extinct elephants, deer, hyenas, and even a human mandible has been discovered.

COASTAL PLAINS

The coastal plains rocks are mostly alluvial, consisting mostly of well bedded, though poorly consolidated, clastic Quaternary sediments. It is very flat with very minor topographical changes.

Current research in this area is mainly interested in the structural parameters of the plains, since earthquakes originating from the adjacent Western Foothills frequently disturb the plains, causing much damage to the population living there. Since the alluvium results in the amplification of seismic waves, it is one of Taiwan's more major seismic zones, hosting major earthquakes such as the 1999 Chi-Chi earthquake.

WESTERN FOOTHILLS

The rocks of the Western Foothills are mainly of the Oligocene to Neogene. Biostratigraphic dating has been done on the planktonic foraminifera and calcareous nanofossils, along with limited information from paleomagnetic studies. In addition, some of the fossil zones have been determined to be relevant in the correlation across other continents.

The rock types present are mainly sandstone, siltstone, mudstone, and shale, all with varying degrees of alteration. Some tuffaceous intercalations can be found in various parts of the Miocene rocks, determined to have been from submarine Miocene volcanism, coeval with the deposition of the alluvial matter.



Chlorite schist at Taroko National Park

CENTRAL RANGE

In the centre of Taiwan is an orogenic belt that is one of the few active arc-continent collisions on Earth. The exhumation rate is estimated at 8-10mm/yr, and the erosion rate estimated at 4-6mm/yr. Like other orogenic belts of its type, it has a ductile interior and oblique convergence.

Two major metamorphic grades can be found: the Tananao schist complex, and two slate units. The Tananao is the Mesozoic basement of Taiwan and consists of the Tailuko belt and the Yuli Belt. The Tailuko belt hosts greenschist, marble, gneiss, and granitic

intrusions. The Yuli is an accretionary prism with mafic to ultramafic lenses, as well as some of the youngest dated blueschist on the planet (Pliocene).

The two slate units are the Eocene Pilushan Formation, and the Miocene Lushan Formation. Both range from the prehnite-pumpellyite to lower greenschist facies, and they unconformably overlie the Tananao schist.

Slate complex	Lushan Formation (Miocene)	Prehnite-pumpellyite to lower greenschist facies
	Pilushan Formation (Eocene)	
Tananao Schist complex	Yuli belt	Greenschist, marble, gneiss, granitic intrusions
	Tailuko belt	Accretionary prism, mafic/ultramafic lenses, blueschist

Fig 3) Simplified stratigraphy of the Central Range.

The Hsueshan range is a significant mountain range which was created as marine sandstones and slates deposited into an inverted rift basin during the Eocene to Miocene periods. Fossils present include foraminifera, mollusks, corals, echinoids, and algae, mostly found in the shaley rocks.

Landslide research dominates the area as mass movement is so prevalent, resulting in many infrastructure difficulties weekly.

EASTERN COASTAL RANGE

As one might expect, the Eastern Coastal Range lies on the eastern coast of Taiwan. Stretching 135m long, it represents the remnants of the Luzon Island arc in the production of a forearc collisional

basin. Underlain by Miocene, Pliocene, and Pleistocene volcano-genic rocks, the main outcropping members of this terrane are an igneous complex, agglomerate, and melange.

The igneous complex comprises of two main parts: the Chimei igneous complex (CIC), and the Tuluanshan Formation. The CIC originated from a volcanic arc setting, and today is exposed at the core of the Range and in the offshore islands Lutaο and Lanhsu. It is mostly andesitic flows but also includes dikes and other igneous bodies. Also significant in this member are copper porphyries. These have been a subject of economic interest, but attempts to map them have proven inconclusive, and more data is needed to ascertain the dates and evolution of this member.

The Tulanshan Formation overlies the CIC, and is mainly andesitic agglomerate, tuff, and tuffaceous sediment. Minor basalt and dacite have been found. In 1981, nanofossils found have dated the upper part of the formation to middle-late Miocene.

Overlying the Tuluanshan is that Takangkou Formation. This is where things start to become more sedimentary. Here lies shale, sandstone, conglomerates, and at the base of the formation, andesitic pebbles and boulders, possibly from the Tuluanshan. The Takangou expresses as dark grey mudstone and siltstone in the south, thick polymictic conglomerate in the middle, and as siltstone and mudstone in the north. The rocks seem to reflect an environment of deep marine conditions. Recent studies have divided the formation into two smaller ones: the Paliwan (which originated from sediments of a proto-Asiatic continent) and the Fanshuliao (which originated from the volcanic arc, and contains an abundance of volcanic detritus).

Lastly is the melange, known as the Lichi melange. Dating to the middle-late Pliocene, the Lichi melange is a muddy matrix with an abundance of exotic blocks mixed into it. The blocks range in size from a few centimeters to a few meters, with a couple outliers that

are a kilometer wide. They are mostly oceanic rocks, ophiolite, and sandstone. So far, no exposure of the base of the melange has been found so it is not yet possible to determine the thickness of the formation, though based on one drill core, it is at least a kilometer thick. The evolution and genesis of the melange is still being debated, so more study needs to be done on this formation. Only a small amount of area has been studied in detail so far.

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NORTHERN TAIWAN

The north coast of Taiwan will put you in the Western Foot-hills terrane, with its sandstones and shales. Now, many geology students scorn sedimentary rocks for their lack of beautiful crystals and vibrant colours, but I can assure you, that is not the case here. The rocks are gorgeously and perfectly bedded, with clear and abundant crossbedding to behold. The erosion and weathering has revealed swirling patterns of bedding, and rich oranges, reds, and purples of the sediment. There is scarcely a dull outcrop of rock in this area.

N1. YU-AO ROAD CUT

漁澳路

On the way to Yehliu Geological Park, before a little fishing port named Yu-Ao, stop by the road cut on the left side of main road, i.e. Yuao Road.

This is a nice little teaser for the clear crossbedding of this terrane. Wider beds (2 to 5cm) of more porous and erodible sandstone are interbedded with more resistant, less porous shale, causing it to stick out further. These sediments are Quaternary and are derived from the orogeny to the east.

Some areas of this road also have fossiliferous limestone, appearing weathered and beige, but white and effervescent to HCl once broken open.



Crossbedding at the Yu-Ao roadcut.

N2. YU-AO FISHING PORT

漁澳漁港

Shortly after passing the Little Yu-Ao Fishing Port and about 100m past the Gui Hou Harbour Safety Inspection Office, there is a solitary red gazebo.

Marked by the red gazebo, this outcrop is incredibly gorgeous. While locals go fishing here, you can peruse the lovely different colours of the sandstones. Again, beautiful bedding features can be observed, as well as the various colours of the different sediments.

The grains are equigranular and spherical. More of this outcrop is located across the road where you can see a good cross section of this formation.



Colourful crossbedding at the fishing port.

Washed up carbonate coral fossils can be found near the water's edge. You can test it with HCl and see it effervesce.



Crossbedding from an aerial view.

Warning: The rocks near the water's edge are deceptively slick with algae. Be careful not to slip!

N3. YEHLIU GEOPARK

野柳地質公園

Being a major attraction, directions to the park are easily available, in addition to accessibility by bus, train, and shuttle. Otherwise, drive north on Yu Au road, until it turns west unto Dong Au road. Then, turn west again onto Gangdong road, where you will see signs for the park. Operating hours are 8am to 5pm daily.



Mushroom rocks at Yehliu Geopark.

Admission of NTD 80 and additional pay parking in effect.

When you arrive at this park, it is obvious why Taiwan has made this a protected and celebrated area of the country. The hoodoos here are stunning and amazing, and notable ones have been given names befitting their appearance. However, it can be extremely crowded here due to the large number of tour buses which drop off visitors, usually all at once, for some reason. I recommend going

very early in the morning. Across the parking lot, looking towards the mountains, you can see orange and brown sandstones crossbedded, looking like a giant marble cake.

The hoodoos here are unusual given their coastal setting. They are formed when a harder, more weather-resistant rock overlies a softer rock beneath, protecting it from the elements. Weather cracks occur in the cap rock and become bigger and bigger with time, until the rock becomes separated, forming fields of discreet hoodoos.

Yehliu hosts a number of distinct features -- interesting given how close they are together geographically. They bear evocative names such as Queen's head, Sea Candles (燭台石), Fairy Shoe (仙女鞋), Ginger Rocks, Elephant Rock, Ice Cream Rock, Kissing Rock, and Princess' Head.

The Queen's Head is so called because the face of it looks like Queen Elizabeth. It was created through wave action and crustal uplifting, leading to its tall mushroom shape. The rest of the features have evolved in similar ways. This particular one is estimated at 4,000 years old.



Hoodoo in the making. The cracks get bigger with erosion.



The “Candles” structural formation at Yehliu.



View of the refinery (background) and the metal dyed rocks of the river (foreground).

Due to the high amount of crowds here, see the following locations for other places to see similar formations: Heping Dao (pg. 14), Nanya Rock (pg. 11), Elephant's Trunk (pg. 16), and Bitou Cape (page 21).

N4. 13-LEVEL CU REFINERY/GOLDEN WATERFALL 十三層遺址/黃金瀑布

Also known as Jinguashi (金瓜石). There is ample signage to this locale, located in the Ruifang District, just off Highway 2.

No admission fee, but parking lot closes at 7pm.

This is the site of a famous, but now abandoned copper refinery. You can see long concrete pipes which used to carry material. Once, it was open to the public to peruse, but now it is off limits due to the toxicity associated.



The thirteen levels which the refinery is named after.

This locale is also known for a waterfall called the Golden Waterfall, presumably because the water has oxidized the rock to become a bright orange. There is a warning sign asking visitors not to touch the water due to arsenic content. Look towards the sea to see yellowish water from the waterfall mixing with the blue water of

the sea. The locals refer to these two water colours as yin and yang waters. The large mountain to the west is Jilung Mountain (Ji Lung Shan).



The water exiting the golden waterfalls is yellow.

Take the road up-mountain to see a view of Jilung Mountain, which is supposed to look like King Kong, with its “head” facing the water. Take the road going back down, and then take the left fork towards the town of Jiufeng for about 100m to observe the northern coast’s only volcanic rock: the dacite that makes up Jilung Shan.



View of Jilung Shan, with the “face” on the right side, facing the right.

This dacite is coarse grained and contains very euhedral biotite, along with a small percentage of quartz, which is clear and white. The rock has weathered to a reddish grey colour.

Further down this road is a scenic hike called Adagio.

N5. NANYA ROCK

南雅奇石

Driving along Provincial Highway 2 (aka Coast Highway) east-bound at the 89-kilometer mark, you will see this unique rock formation on the side of the road. There is a parking lot across the street from the rocks.

Nanya means “unusual,” and it’s no surprise why, when you see



Unusual-looking, rounded, differential weathering at Nanya.



The tall hoodoos that make Nanya a popular attraction. Thick bedded sandstone is visible in mountains behind.



Interesting weathering of the shale layer (dark), against the sandstone (light).

these very well preserved and prominent hoodoos by the sea. Like other sedimentary marvels on the north coast of Taiwan, the thick, less-resistant beds are sandstone, while the more resistant layers are shale, which are less porous.

This locale is worth visiting because you can get up close with the rocks, touch them, and observe a number of other small scale features of interest, for example: concretions can be found in some rocks, as well as conglomerate layers. It is recommended you prepare to spend some time here to explore the area and find these features.

N6. HEPING DAO (PEACE ISLAND)

和平島

Heping Island Park is on the outskirts of Keelung City. The narrow and winding roads in this city make it a bit difficult to find the entrance to this beautiful coastal park. The upgrade of the entrance



Initial view from the entrance of Heping Dao.



View from the boardwalk path, overlooking the hoodoo formations.

and parking lot has been completed in 2018.

These hoodoos are similar to the ones at YehLiu and other sections of the coastline. This place features a walking path, which takes approximately half an hour, at a perusing pace.

N7. ELEPHANT'S TRUNK/SHEN AO PROMONTORY 象鼻岩/深澳岬角

East of Keelung city, drive to the Shen Ao Fishing Harbour. There is plenty of parking space. Walk to the end of the parking lot, and squeeze past some yellow and black painted concrete balustrades, and walk the trail for about 5-10 minutes.



Close up view of the hoodoo formations at Elephant's Trunk.

The Elephant's Trunk is a lovely spot to visit. After a short jaunt across the rocky and hoodoo-marked beach, the main attraction is a cave, weathered out by the repeated wave action of the sea. You can stay at the beach, or climb a short trail up onto the top of the



Elephant's Trunk's famous sea cave beneath the promontory. View from sea level.



The promontory of Elephant's trunk.

Trunk. This place is a popular destination for a romantic seaside sunset picnic.

Here you can be up close and touch the hoodoo structures, and though they may not be as big and grandiose as those found at Yeh Liu, there are many cool things to see.

N8. LONGDONG

龍洞



View of the sea cave from the top of the Longdong trail. Notice the horizontal sandstone beds. The cave is near the centre of the photo.

Not far from the Nanya rocks, take provincial highway 2, and turn towards Longdong Bay. There is a small parking lot. Take the forest trail.

Translating directing as the Dragon's Cave, this is a popular spot for rock climbing and snorkelling. Fresh green meadows and clear blue waters greet you on this very pleasant hike. The trail takes approximately 30 minutes, as it is an ascending hike. It is not a looped trail.



Here you can see the difference between the bedding of the shale (bottom half, thin beds) and the sandstone (top half, thick massive beds).

Along the hike to the top, marked by a pagoda to rest in, you will see the alternating depositions of well bedded sandstone and shale, differentiated by the difference in jointing, and grain size. Once you reach the top of the trail, look to the north, and you'll see the entrance to a cave near the shore, which was formed through wave action. Nearby, characterizing jointing and weathering of the rock is observed by the shore.

N9. BITOU CAPE

鼻頭角

Driving northward on provincial highway 2, turn off towards Bitou Cape.

Bitou Cape features a nice short hike starting at a beach. Features of interest here include mushroom shaped rocks, honeycomb

weathering, "bean curd" weathering, as well as body and trace fossils. Bitout Cape is the easternmost cape in Northern Taiwan.



Sandstone bedding along the cliffs at Bitou Cape.

N10. TURTLE ISLAND

龜山島

Turtle Island, so named because it looks like a turtle, is only accessible with a permit and boat ride. You can choose to only take a boat ride around the island, thus avoiding the necessity of a permit to explore the island. Due to its protected status, you can only explore a prescribed trail on the actual island, which only access a small portion of the island. This area is also famous for the crabs that live near the undersea fumaroles.

The whole island is composed of andesite, having been the site of an underwater volcano which is now inactive. As you sail around the back of the island, you can see a beautiful view of the bedding and flow, and in my opinion, is worth the boat ride. Looking at it

gives you a sense of scale, as to how large the eruptions were. You can see patches of miscolored water where sulfur is emitting from undersea vents. Flying fish also abound.



View of the island as you sail around the back of it.

On the island, the geology is not particularly remarkable. Walking along the prescribed route, you can break open the rocks, which have been very weathered under the harsh sun and sea spray, and



View of the "tail" from the top of the trail.

see the euhedral amphibolites.

Climbing to the top of the trail, you can have a top down view of the turtle's "tail" which is a little cove carved out. There are venomous snakes to be aware of, and very little shade. The two old dogs that live on the island bite. However, you can visit a disused military tunnel where gunners positioned themselves, hidden within the turtle, which is pretty cool -- both culturally, and thermally.

N11. MIAOLI 苗栗出磺坑



Sandstone at roadcuts by the Miaoli museum.

Miaoli is a bit out of the way compared to the other stops, which were mostly along the north east coast of Taiwan. Miaoli is a municipality in the the northwest interior of Taiwan.

Miaoli is a town whose main economy is gas and oil. The Chuhuangkeng oil field is a sharply dipping anticline (50 to 80 degrees), composed of alternating sandstone and shale formations from the Miocene to Pliocene. It is the oldest oil and gas field in Taiwan, dating back to the Japanese occupation in 1985. Other gas fields in the area include the Chinshui gas field and the Yung-hoshan gas field.

Visit the Taiwan Oil Field Exhibition Hall (台灣油礦陳列館), which showcases the development of the petroleum industry in Taiwan, including models and rock samples from all over the island. It is located at 36 Kaikuang Village in Gownguan Township, in Miaoli, Taiwan.

Walking along the highway, you can see the different sandstone-shale formations, though in my own experience, I searched for hours looking for contacts or distinguishable features of the specific formation but I failed.

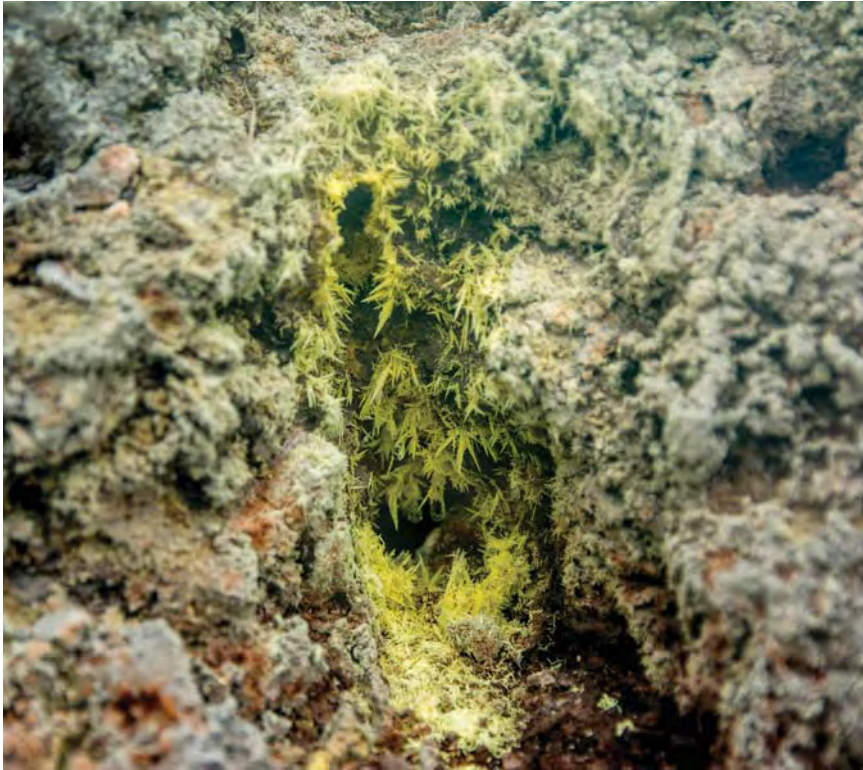
N12. YANGMINGSHAN NATIONAL PARK- XIAO YOU KENG 陽明山國家公園/ 小油坑

Located in Taipei City and is accessible by subway, and then bus. The bus will take you all the way up the mountain to the main parking lot where you can catch the park shuttle. The park is very large, and if you can, schedule multiple days to explore it fully. I only had one day and so only was able to visit one stop. Also note that the bus stops by a local university and can be quite full with students at peak hours.

This spot is a must-see if you visit the park. It is accessible by park



Up close and personal with the sulfuric vents at the top of the Xiao You Keng trail.



Close up view of the beautifully formed sulfur crystals right at the openings of the vents. Each crystal length is approximately 1cm.

shuttle as one of the many stops. It is a steep ascent and can take 1 to 2 hours to get to the top, but you can get very close to the fumaroles, which offer gorgeous sulfur accumulations. Also present are volcanic blocks of hornblende-bearing andesite, which are usually very euhedral. The size of the hornblendes vary up to a few centimeters if you have a sharp eye and luck.

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CENTRAL HWY EAST

The eastern portion of the central highway starts at Taroko National Park, and ends at the mountain village of LiShan, at the highest point in the mountains at more than 3000m elevation.

Taroko National Park is home to marbles, gneiss, sandstones, and various schists. The park's geology is known for beautifully folded rock layers, among other sights.

C1. QINGSHUI CLIFFS

清水斷崖



View of the Qingshui Cliffs from the highway.

Located along Suo Hwa Highway, between Heren and Chungte in Xiulin Township, Hualien County. Right before Chungte tunnel, there is a parking lot on the south side.

Before reaching the park, this is a nice stop to rest from the winding roads. These cliffs are composed of gneiss and marble. The tallest, Qingshui Mountain, reaches 2408m. At the bottom of the cliffs is an accumulation of sand and gravel making up the Liwu River alluvial fan. The river flows downwards from the peaks of the Qilai Mountains. This is the same river that has cut Taroko's famous gorge.

TAROKO NATIONAL PARK

The road to from Taipei to the Park is very windy, and even windier within the park, so be sure to pack medication if you are susceptible to car sickness. Sometimes the roads turn into one lane, and rockfalls are common. Stopping in one spot for extended periods of time is inadvisable, and park staff recommend wearing a helmet. Free helmet rentals are available at various points throughout the park.

The rocks here are not very competent, hence the frequent landslides and rockfalls, so hammering the rock wall is inadvisable. Hammer open rocks that have already fallen to the rock instead.



Behind the entrance gate are the marbles.

C2. TAROKO ENTRANCE GATE

太魯閣入口

Located where the Jinwen Bridge (錦文橋) crosses the Liwu River (立霧溪), there is large space to park, as well as convenience stores within view. These will be the last shops before you enter the park, so stock up on supplies here.

The Liwu River carves the gorge that Taroko is centered upon. This resting point before entering Taroko Park is a good place to observe all the alluvial deposits by the riverbank, as well as the dipping marble layers of the Chuchu formation at the roadcut by the gate.



Beautiful folded gneiss along the Shakadang trail.

C3. SHAKADANG TRAIL

砂卡噹步道

This trail is one of the first trails you will come across as you enter the park. It is about 1 hour hike one way, and you must trace the route back to get back to the start (it is not a looped trail). This trail is worth taking to see beautifully folded gneiss and limestone and chert layers.

Notice the sizes of the rocks that have travelled down the river, as you hike along it.

At the end of the trail, there is a small rest stop where aborigines set up a food stall, as well as souvenir shops where locals have polished a very pink plagioclase to make jewelry. They claim these pink rocks are only found once typhoons have knocked the rocks from the high mountains down to the river.

Rocks with pink minerals for sale at the end of the trail. The locals call this the “rose flower”.





Changchun shrine next to a large landslide (right side of photo).



Gneissic folding by the riverbank. Approximately 100m across, in this photo.

C4. CHANGCHUN SHRINE 長春祠

After Shakadang Trail, turn back and return to the entrance gate, and take the south fork this time.

You will encounter a temple to the left. It is a good place to stop to enjoy a cultural visit to the temple as well as observe the adjacent narrow landslide. The shrine's English name is the Eternal Spring Shrine. Years ago, this landslide took out the temple, but it has now been rebuilt. If you wish, you can visit the shrine and climb up, though the climb looks quite steep and intimidating.

To see interesting geology, looking down across the riverbank, beautifully folded banded gneiss can be observed. Unfortunately, access to the river is prohibited, as the park authorities do not want any pollution in the river.

C5. SWALLOWTAIL GORGE (YEN TZE KOU)

燕子口

Continuing through the park, along the provincial highway no. 8, you will pass many bridges, and finally Xipan dam. Soon after the dam, you will come upon the Gorge. You can drive through it, as the trail actually just follows the highway, should you wish. If



Caves and coves carved out at Swallowtail gorge.

you do choose to walk, you will have to walk back to get your car afterwards.

While there are many trails in the park, Swallowtail Gorge is the best one to observe more beautiful geology. The trail follows a marble gorge forged by the river, and exposes the inclined folds in the grey and white marble sandstone. Potholes and caves have been carved out as well.

While walking through the tunnels, look up, and you can see where



The grey and white marbles of the Swallowtail gorge.

the rock has cleaved and broken at the contact between the white and grey marbles.

Midway through the trail is a rest stop with a café selling food, drink, and souvenirs. A viewing platform has been built so you can look down the gorge.

Warning: rocks frequently break off the roofs of the tunnels, so don't stay in one place too long. A helmet is recommended.



Contact at Baisha Chiao between the sandstone (orange) and gneiss (grey).

C6. BAISHACHIAO

This is the site of a bridge that is being built to cut through the mountain, thus avoiding the large (50m across) landslide further down the current road. Since it is not yet finished, it may not appear on any maps yet.



Contact between white schist (top layer) and marble (bottom layer) of the Chuchu formation.

Look down by the riverbank to see the contact between the sandstone (weathered orange) and gneiss.

This contact reappears a few times in the next kilometer because the tectonic activity has “crumpled” the structure.

C7. CHUCHU FORMATION

Pass through the Jiuqu Bridge (九曲洞), which consists of 9 small tunnels. Stop at around 100m from the third tunnel.

The ChuChu Formation is composed of marble sandstone, which are sometimes interbedded with thin beds of white mica schist. This is a good locale to find these schist layers. If you look across the river, you can see the layers of the more reflective rock.



The green chlorite schist at the roadcut by Cimu Bridge.



Landslide to the east of Tai Shan Tunnel.

C8. CIMU BRIDGE (CIMU CHIAO)

慈母橋

Continuing on provincial highway 8, Cimu Bridge, translating to Motherly Devotion Bridge, is a red bridge, with a little pavillion on the side.

West of Cimu Bridge, you can find the chlorite schist of the Kuyuan formation. It interbeds thick limestone layers. The chlorite schist is made obvious by the pale green colour, and very low competency.

This low competency makes the road cut very unstable so it is not recommended to stay here for extended periods.



Chlorite schist contrasting with the white serucite schist.



Vista view of the gorgeous He Huan Shan mountain range.

C9. TAI SHAN TUNNEL

泰山隧道

There is a trail to the right of the Tien Shao Tunnel, located at mile 166 of Highway 8. Park in the parking lot before the tunnel. The boardwalk trail leads to down to the river, so be sure to check that the water levels are safe if you intend to go all the way down to the river.

Along the trail, you can observe the chlorite schist interbedded by quartz-sericite schist. The chlorite schist is significantly softer than

the quartz sericite schist. The chlorite schist can be rubbed away by just your fingers. This has resulted in many landslides, including a very large one adjacent to the tunnel at the time of writing. After you pass a small cave and rope bridge, you can climb down the steps (they are a bit steep and precarious) to the river bank where you can observe close up folded marbles that were inaccessible earlier in the park.

*Watch for high river levels, and slippery trail due to water dripping.

C10. HE HUAN SHAN

合歡山

Driving along the highway to the heart of the mountains some more, you will be greeted by breathtaking valley views, as well as a cooling of the air as you climb in altitude. The valley is river formed, and rocks here are inclined schists. Again, lots of evidence of landslide activity can be seen here. Drive for about an hour after the Tai Shan Tunnel, passing through the cloud forest, and you will start to climb into the He Huan Shan mountain range, marked by a change in foliage from tall trees transitioning to tall grasses and shrubs.

If you wish, there is a stair trail that leads up the mountain. There is also a ski resort/café at the top where lots of tourists stop for photos. It can be very windy up here.

The geology to observe here are the inclined schists, which are dark grey and white in colour. I personally did not have a lot of time to explore this area but it is so beautiful that I would recommend allotting at least an hour to hike and explore.

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SOUTHEAST COAST

This southeast area encompasses the route down to Taitung, and as well as further inwards towards the centre of the island. Here, you can look for the East Taiwan Ophiolite, the famous Lichi melange badlands, beautiful schists, and more.

Formations we will see include the Takangkou, Lushan, and Pilishan formations, as well as the Tananao schist.

SE1. FANSHULIAO BRIDGE

蕃薯寮橋

Travelling south from Hualien, located at 28km mark on highway 11. It is marked by a small red bridge, as well as a name plaque. There is space for about 3 cars to park, and a boardwalk viewing platform of the gorge.

The Fanshuliao river cut a narrow gorge, which legend says the aboriginals who lived here believed whoever could vault across would be made the chief. The bamboo poles left by the braves who died trying became a thick bamboo forest of today.

At the roadcut right before the north end of the bridge, you will find the Takangkou formation. This formation is mostly shale, sandstone, and conglomerate, but also has significant amounts of andesite volcanic detritus. This roadcut features these volcanic ag-



The roadcut by the Fanshuliao bridge.

glomerates, which also includes pieces of gabbro and serpentinized peridotites, most likely from the remnants of the East Tawian ophiolite. Interestingly, some of these pieces are also magnetic, possibly containing magnetite due to hydrothermal alteration of the original silicate minerals (see pg. 52 for more information about the ophiolite).

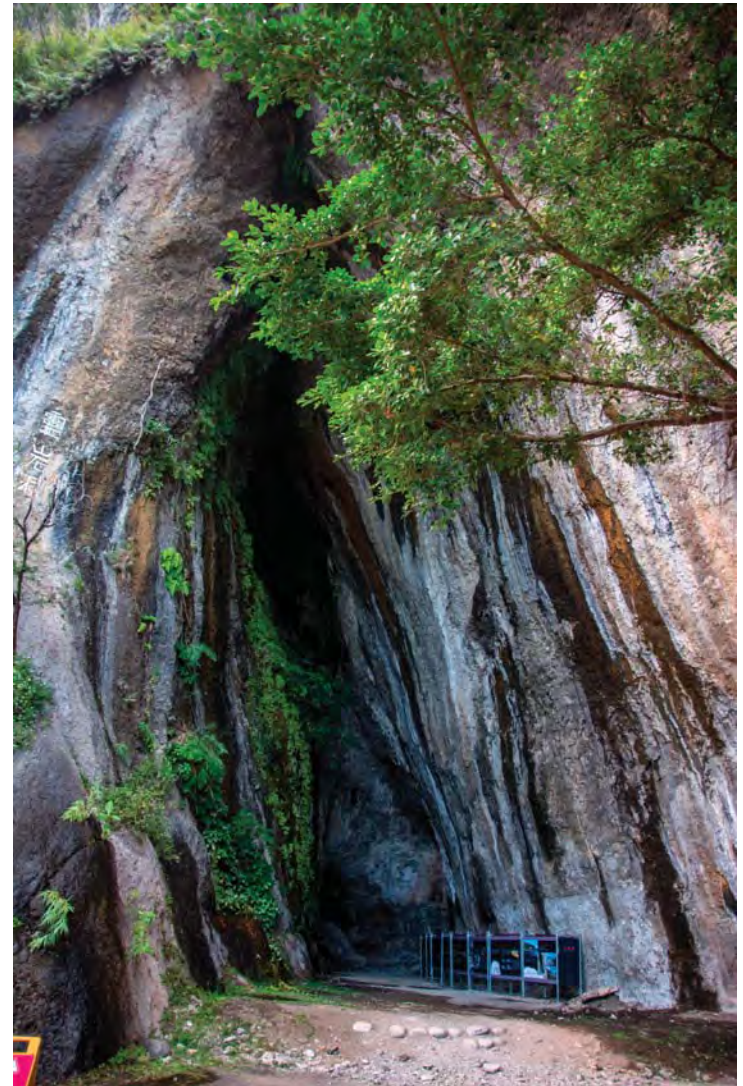
Gabbro with hornblende and plagioclase found at the Fanshuliao roadcut. The purple mineral is probably rodingite.



SE2. BAXIAN CAVE

八仙洞

Turning south from provincial high way 9, onto provincial highway 11, many signs will be apparent leading to Ba Xian Cave, or Ba Xian



The entrance to Baxiandong's most famous cave, site of the first Taiwan's earliest prehistoric finds.

Dong. There is free and abundant parking. Trains also go straight to the site (Baxiandong stop).

BaXian Cave is an archaeological site and tourist attraction. It is the site where many prehistoric items belonging to the Changbin culture have been found, suggesting that people once sheltered in these caves. There is a looped trail that takes you to all the caves., which should take an hour or two.

The main geology seems to be sandstone. These caves were probably formed through repeated wave action. Tectonic uplift has elevated some of the caves to be 100m high above sea level now.

SE3. EAST TAIWAN OPHIOLITE

An ophiolite refers to the sequence of rocks that amalgamate when an oceanic plate has been thrust onto the edge of a continental plate. The East Taiwan Ophiolite is made of a sequence of mafic and ultramafic rocks at the bottom, then red shales from the deep sea, and finally topped with pillow basalts. The age is still debated.

This ophiolite has long since been inactive and only portions of its remnants are exposed on land now, mostly on the eastern coast. These remnants include sections of pillow basalts, glassy basalt, gabbro, plagiogranite, and serpentinized peridotite.

The peridotites have been found to contain mostly serpentine with minor



Peridotite found at SE3A.

amounts of orthopyroxene pseudomorphs, and trace elements of spinel. Closer examination of the serpentine reveals a poikilitic texture. Red colouration indicates oxidization due to the olivine undergoing serpentinization.

The gabbros are coarse-grained and contain euhedral to subhedral hornblende and plagioclase, and accessory amounts of ilmenite and magnetite.



Gabbro found at SE3B.

SE3A. SOUTH OF BRIDGE 9.

Take provincial highway 197 to the Chishang township in Taitung County, and head south towards Guanshan township. Eventually you will come across a small bridge, marked with the number 9. Pull over on the south end of the bridge.

At the roadcut, you will find the massive mafic and ultramafic material, characterised by coarse, green grains and plagioclase crystals. This will contrast with stop SE3B.



Roadcut at SE3b. Notice the igneous material (grey) intermixed with the sediment (brown).

SE3B. 1 KM LATER

Continue south along highway 197 for about 1 km. You will know to stop when the roadcuts look very sandy, like in the photo on above.

Here you will see the plutonic sequence in its brecciated form. The matrix is pelagic sediment.

SE4. WANRONG VILLAGE

萬榮村

WanRong village is one of eight indigenous villages in Wanrong Township, Hualien County on the east coast. Finding this locale can be a bit difficult. Even finding the town can be tricky, as the

romanization is different in different maps. The small, aboriginal town is pronounced “wan-rong” but older maps will confusingly name it as Wan Jung, Ran Jung, or some other variation. In addition, this is not a popular tourist spot, and the locals here do not speak English, and will not know what you are looking for if you say you are looking for rocks. Behind the city hall, to the west is a winding mountain path which serves as a service road. Take it.

This first stop is eye catching due to the rocks painted by the inhabitants of this area. The rocks here are a beautiful chlorite schist, observed by its green-grey colour, schisty texture, and high reflectance of the chlorite mica. Some foliations can be observed indicating further tectonic stresses.



Aboriginal paintings on the schists, featuring orthorhombic habit, along the Wanrong service road.

The weathered-out red xenocrysts that are present are in fact not garnet, but perhaps epidote according to professors of geology at the National Taiwan University.



Chlorite schist with epidote xenocrysts. The large xenocryst on the bottom right is approximately 1 cm long, showing a clear oxidation ring.

SE5. TAIMALI 太麻里

Taimali Township is about an hour's drive south of Taitung. Located on the pacific coast, this charming little town is populated by mostly aboriginals such as Paiwan and Amis. It had been called "the village of sunrise" because there the sun rises from the eastern sea.



A winding road on the hill in the back of the village is used by the tourists heading to a famous resort. Approximately an hour's drive uphill, there are interesting rocks exposed on the road side beneath a house.

They are phyllites and dark grey, compact sandstones interbedded, with the beds approximately 40-50 cm thick, all inclined gently. These are of the Lushan formation, as are all the rocks found in Taimali. The Lushan consists of slates, argillites, phyllites, and the dark grey sandstones.



Phyllite (left) interbedded with sandstone (right) at Taimali.

SE6. LICHI BADLANDS 利吉惡地

Also written as "Liji Badlands." Located in the Beinan Township of Taitung County, the badlands are a major attraction in Taitung and so directions are readily and frequently marked on road signs. Follow the signs on county road 197.

Wrapped around the southern portion of the Coastal Range, these impressive badlands are actually a melange: a mix of mud and various other lithologies to create a large breccia. The sharp and characteristic ridging is from the weathering of the mud matrix. The melange is approximately 1-3km wide and extends as far as 70 km northward of the accreted arc in the Coastal Range.

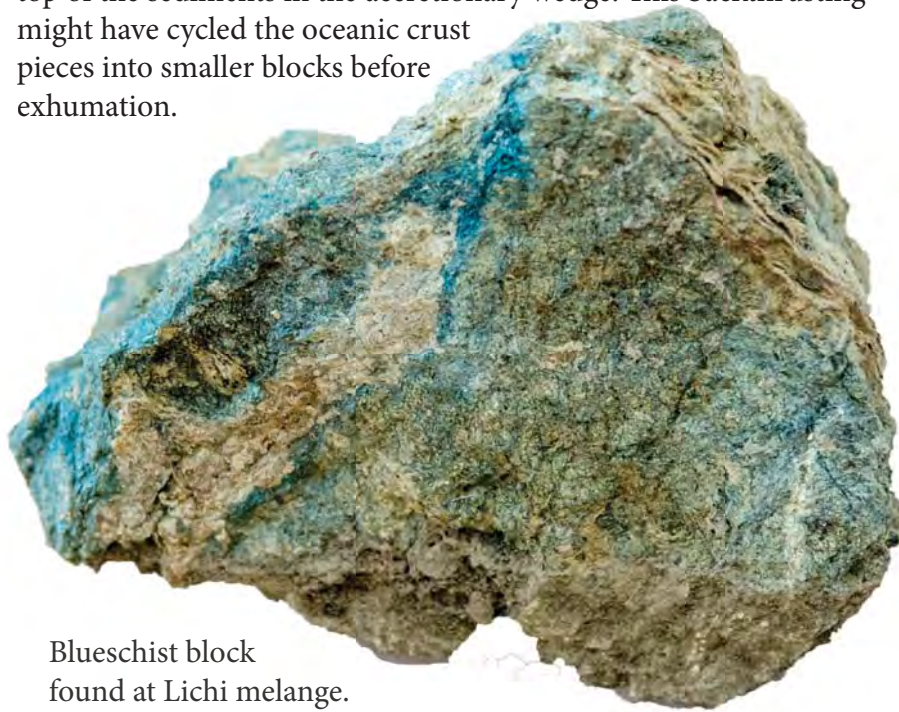
Most of the blocks are exotic – they are submarine. They come from a number of sources and thus are a number of varieties: (1) the



Looking up at one of the mud walls at the Lichi Badlands.

ophiolite suite, which includes peridotite, gabbro, basalt, and pillow lavas; (2) Takangou Formation (Miocene) turbidites and sandstones; and (3) volcanics, which includes andesites and tuffs. Disrupted areas are intercalated with early-Pliocene forearc sediments.

This melange is considered to be one of the world's most studied and least complicated setting from which to develop arc-continent collision models. In this case, the Chinese Passive Margin is colliding with the Luzon Island Arc. The evolution of the Lichi melange is still being debated. Originally, it is thought to be an olistostrome. Then, a tectonic collision model was proposed. But neither of these models explained why most of the slumping and shearing seems to have occurred in the retrowedge of the subduction, instead of the prowedge near the trench. The latest model proposed is the retrowedge evolution model, which proposes that backthrusting sheared and mixed the oceanic basement before being uplifted on top of the sediments in the accretionary wedge. This backthrusting might have cycled the oceanic crust pieces into smaller blocks before exhumation.



Blueschist block found at Lichi melange.

SE8. SANXIANTAI

三仙台

Sanxiantai is located on the coast of Chenggong Township, Taitung County. Driving southbound from Hualien to Taitung along the coastal Highway 11. There is free parking and no admission, and is always open. Gift shops and snack stalls are open during the daytime. Follow the short trail around the beach to reach the bridge.



Corals decoratively lining the walkways at Sanxiantai. These ones are approximately 20 cm long.

Sanxiantai is a popular tourist destination due to the beautiful 8-arch bridge that spans a small expanse of water. It is part of the East Coast National Scenic Area. The name translates to “Three Saint’s Island” due to the 3 large rocks on the island. There is a trail going around the island, taking about 2 hours at an average pace.



The famous eight-arch bridge at Sanxiantai. The three boulders which give this locale its name is on the left.

Lining the walk, as well as all along the beach, are fossilized corals, which look like tabulate corals, similar to the ones found on the north coast.

Walking around the island, you can see sea caves, and other sedimentary features. Erosion has cut the landbridge leading to the island, and in 1987, the bridge was built.



Volcanic agglomerate at Sanxiantai.

Note that since Sanxiantai is a nature reserve, collecting of rocks or plants are not permitted.

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SOUTHWEST COAST

The southwest portion of Taiwan in this guide is mainly Kaohsiung (高雄), pronounced *gao-shong*, and southward. Kaohsiung is geologically interesting due to the mud volcanoes and mud formations that have resulted. Due to the easily weathered nature of the mud and the dynamic system of the active mud volcanoes, no structure is permanent, and thus, the images in this guide will invariably be lost to time.

During my travels here, I lodged in Kaohsiung, and hired a car to reach these destinations. These four sites are quite out of the way, and are difficult to reach via public transit. At the time of travel, it was incredibly hot, so be sure to bring plenty of water.

MUD VOLCANOES:

Mud volcanoes are created when tectonic compaction forces water through porous sedimentary rocks, often in convergent margins where fluids can travel along faults. The fluids have often been influenced by the fluids expelled during clay dehydration, halite dissolution, or from meteoric waters (ie. rain) near the surface. The sediments in these Taiwanese mud volcanoes are usually a composition of clay minerals such as illite and chlorite, with small amounts of kaolinite. The gases emitted from these mud volcanoes are often >95% methane, with small amounts of propane, ethane, and carbon dioxide.

The two mud volcanoes discussed below are both of the Chi-San Fault group, which is one of Taiwan's most active faults. The fault is a thrust fault in Pliocene-Pleistocene mudstone.

SW1. WU SHAN DING MUD VOLCANO

烏山頂泥火山

From Kaosiung, drive north up provincial highway 22 for about an hour, and once in Yanchao district, turn right onto Wu Shan Gang road. It is a small, winding forest road. Drive for about 45 minutes to an hour, following the wooden signs for the mud volcano.

Admission is free, but you need to sign in with your name, address, and number of your ID (passport or driver's license or the like) at the entrance booth. The guard at the booth probably won't speak English so just be ready to show your ID. It is recommended you



The tallest mud volcano at Wu Shan Ding, visible right as you enter the park. Approximately 3m tall, you can see the fresher flows emitting out the side.



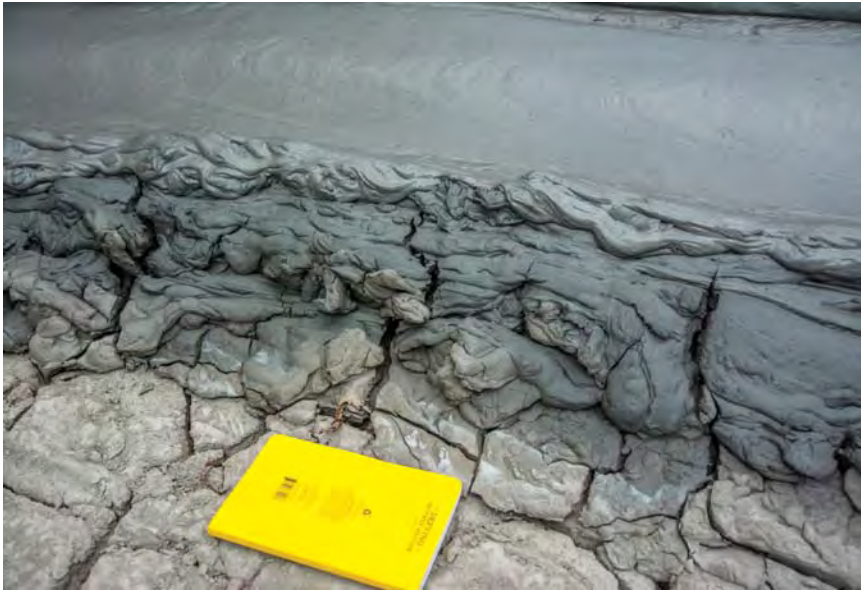
Close up view of the surface of the recent flows. You can see the individual layers of mud representing different depositional episodes.

come by car as this location is not easily accessible by public transport.

The Wu Shan Ding area is the site of the largest and most well preserved mud volcanoes.

The first thing you will see is the vast and large mud cracks that cover the area. A big mud cone volcano is right in front of the entrance as well. It is about 3m tall! Keep walking inward, and you'll see what looks like a line of volcanoes, almost like it was subject to hotspot migration in igneous volcanoes. Of course, that is not what has happened. I suspect the first volcano became stoppered up by hardened mud, and the liquefied mud had no other option but to escape from the next weakest spot, sprouting a new cone there.

Observe the different mud volcanoes and mud flows, and see if you can tell the relative ages of the flows. The older material will have



More flow structures at Wu Shan Ding. Here is a good contrast between fresh mud flows (dark grey) and the old.

weathered more causing more pronounced and sharp ridges in the mud. In fresh flows, you can see the effect of the mud's viscosity on the shape of the flow.

In the smaller volcanoes in the forest, you can even hear and see the methane bubbling out of the mud.

Note: Do not step on the darker mud, which is the fresh mud. It is not only dangerous, but damages the structure.

SW2. XIN YANG NU HU BEE FARM

新養女湖養蜂場

Continue driving through the forest and follow the signs (in Chinese) for the bee farm. It is about a 10 minute drive away, through a twisting and turning road. The bee farm is marked by a large archway with the name on it.



Methane on fire at the mud pool at Xin Yang Nu Hu Bee Farm.

This is the site of a large mud pool. Methane is emitted here much more aggressively than observed at Wu Shan Ding. The owner of the area, which is also a bee farm, selling honey and lemonade, will light the methane on fire for you to see. It is a very impressive spectacle.

For the full mud volcano experience, you may as well visit both SW2 and SW1 since they are nearby, though if you really only have time for one, visit SW1 (Wu Shan Ding) as there are more mud volcanoes to examine.

SW3. MOON WORLD

月世界

Moon World is a popular tourist destination, and as such is easily accessible by MRT or railway, and if you are driving, there are ample road signs pointing to it. Driving on provincial highway 28, turn onto Yequiu road in Tianliao district, then follow the signs.

Moon World is a park of boardwalks that goes through a big mud-



Taking a closer look at the mud landscape at Moon World. Notice the lack of blocks, and relative smoothness of the mud.

dy badland. The structure looks very similar to the LiChi melange, but importantly, these were formed by accumulation of mud, not the uplifting of a submarine floor. Hence, there are no exotic blocks in the mud. This makes the ridges look smoother, and sometimes narrower. While the LiChi melange will have no noticeable bedding, here at Moon World, you can look for areas which look like inclined bedding which indicates the paths of old flows. Moon World was so named because the landscape looks like that of the moon.

Walking along the boardwalk trail loop will take about an hour at a moderate pace. There is a section that includes quite a number of stairs to climb, after which you can look down at the main park area.

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CONCLUSION

Taiwan can be a pretty challenging terrain to explore, and if there's anything to take away from this book, it is that there is so much geology to discover.

Don't be afraid to stray off the path and follow your curiosity wherever it takes you. The air is hot and the terrain is rugged but one of the magical things about being a geologist is being able to look past these things and see the beauty right beneath our feet.

It is an oft-repeated saying that humans are always so focused on looking ahead, they never stop to look up at the stars. They should also take some time to look down at the rocks, and appreciate the incredible processes that are happening mostly unseen and unthought of.

There will never be a time when we've discovered everything there is to discover. Be brave and ambitious and chart your own course.

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