Special Report of the Reading Geological Society

Field Trip to Brittany

GEOLOGY OF THE NORTH BRITTANY COAST: TREBEURDEN TO SAINT-MALO

12th – 19th September 2016

Contents

Photo on front cover: Black dolerite dyke on the beach at Pointe de la Guette (RY).

Photo inside back cover: Our leader enjoying using the RGS tankard (DR).

Introduction

This field trip was organised by Carole Gregory who laid on the coach (and driver Ted), ferry crossings and hotels for the whole week to achieve a most successful outcome enjoyed by all.

The party gathered at the coach pick-up points in Maidenhead and Reading on Monday afternoon and, with an uneventful journey, including a meal break at Taunton Dean Services, arrived on time at Plymouth Ferry port where we collected our leader. The ferry crossing from Plymouth was a night crossing with cabins arranged, which meant that we could start Tuesday with early disembarkation in Roscoff and travel to our first site. However, we received an invigorating welcome to France as we disembarked with lightning, thunder and torrential rain.

The weather had cleared by the time we left the port and remained so until the evening when we arrived at the Grand Hotel in Port Blanc, on the coast not far from Penvénan. We stayed there for three nights before moving on to the Chateau du Val near Planguenoual for two nights, then spent the last night at the Hotel Campanile in Saint-Jouan-des-Guérets, just south of Saint-Malo. Luckily for us the weather was mostly bright and sunny on all of our site visits with rain only at night or when we were in the coach.

Our leader for the week was Dr. Douglas Robinson (Doug) who is a research fellow at Bristol University, specialising in metamorphic rocks, and who led an earlier day field trip for us to the area round Wells. That trip led to the arrangement for him to lead this trip to Brittany and he provided an early brief on the geology of the North Brittany coast and, just before the trip, a detailed 33 page description of the geology of the area and of the individual sites and some specific aspects of metamorphism that we may not have come across before (“Geology of the North Brittany Coast: Trebeurden to Saint-Malo”). Carole arranged for this to be printed and distributed before the trip which gave us an opportunity to be prepared for where we were going and what we would see. It was an essential reference during the week and is referred to in this report as ‘the Guide’. Doug also provided a brief description of the terrain and a risk assessment for the activities.

Doug’s Guide refers to the sites to be visited by number and name, and the days they were to be visited on by number and date. In the event days 2 and 3 were interchanged and the order of visits to some sites also changed. Days and sites visited are listed in this report in the order visited but are referenced using the Guide’s numbering – e.g. ‘D1L2’ for Day 1, Locality 2. References to pages will refer to this report unless clearly stated to refer to the Guide. It is assumed that all readers have their own copy of Doug’s Guide so it is not included as an appendix to this report.

Photographs are provided by the reporters of each half-day unless stated otherwise. They, and any figures, are numbered sequentially, separately, in each half-day account.

After an exciting and most interesting week the Monday morning ferry departure from Saint-Malo started a long nine-hour journey to Portsmouth which gave everyone time to wind down and brought us to Reading then to Maidenhead in the early evening.

The members attending were: John Banks, Susan Barr, Alison Barraclough, Barbara Barrett, Ricki Bull, Ailsa Davies, Carole Gregory, Christine Hodgson, Christine Hooper, Hilary Jensen, Louise Knight, Roger Lloyd, Margaret Mitchell, David Price, David Riley, Edmund Shirley, David Ward, and Roger York. Thanks are due to all for making the week so enjoyable, to those who wrote-up days and half-days for this report and especially to Carole for organising it.

Summary of the Geology

The geology is much better summarised and described in Doug's Guide but, for completeness, a brief description is given here.

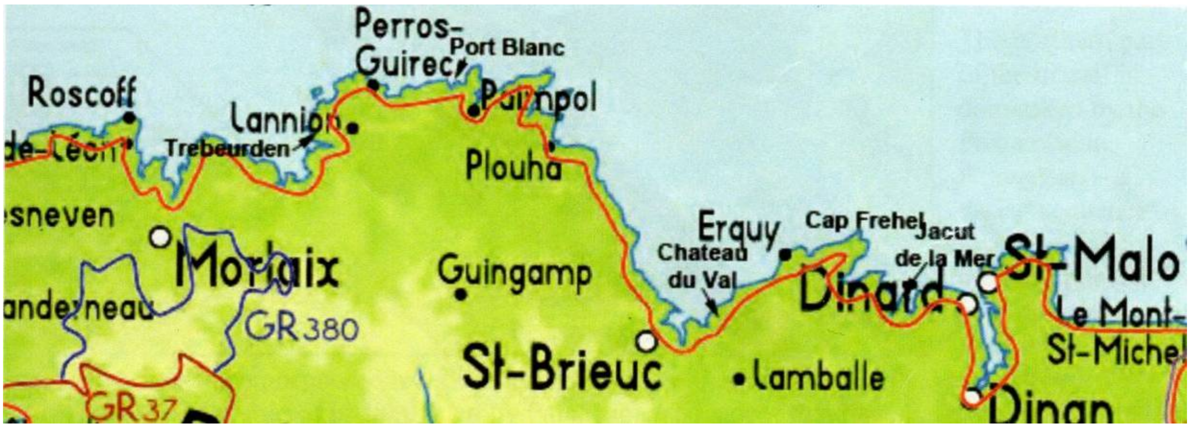

Figure 1: The north Brittany coast between Roscoff and Saint-Malo. (From the front cover of the Guide.) Taken from Graham Park 'The Making of Europe', Dunedin, 2014.

Brittany is made up of some Precambrian and old Palaeozoic rocks to the west (the Armorican Massif) with much younger Mesozoic rocks of the Paris Basin to the east. The mainly Palaeozoic Armorican Massif has four east-west trending domains separated by Variscan shear zones. Two of the Domains, Léon and North Armorican, form the northern coast of Brittany (Figure 2).

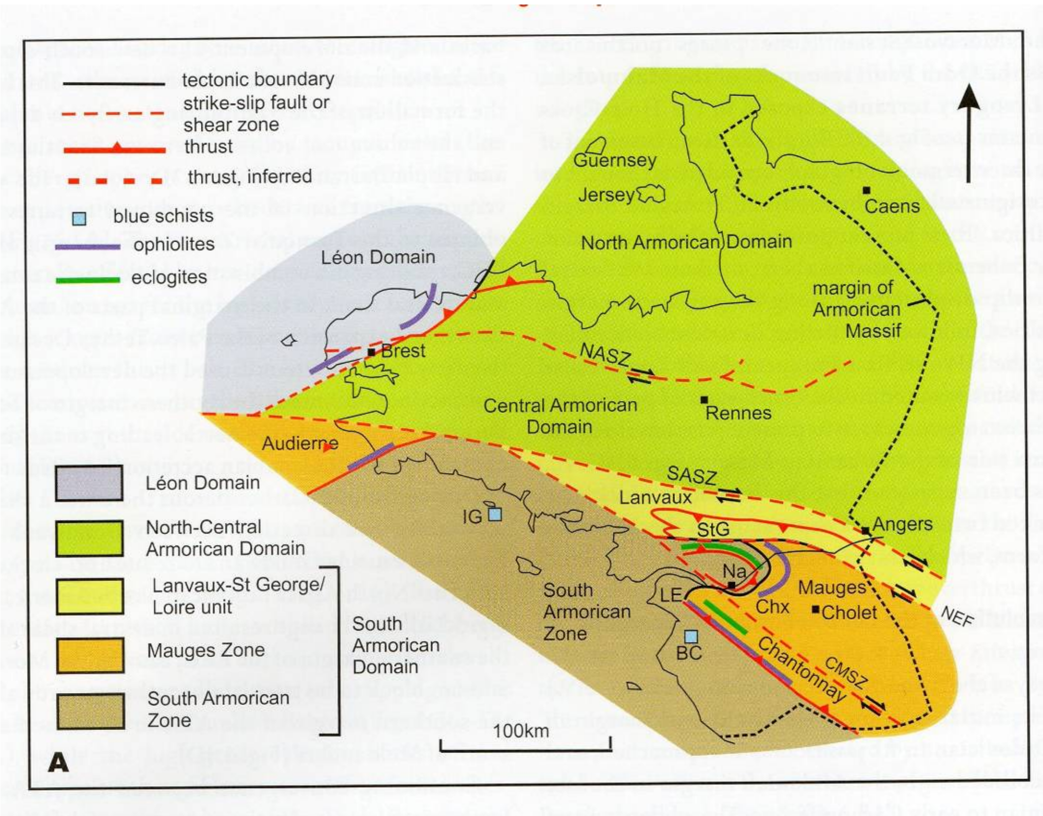

Figure 2: Taken from Graham Park 'The Making of Europe', Dunedin, 2014.

Most of the rocks belong to the Cadomian orogeny (650-550 Ma) representing interaction between the Laurentian and Gondwana continents (Figure 3). These rocks were deposited in marginal and back-arc basins between the Laurentian and Gondwana continents. By the Silurian period Avalonia, also from the Gondwana margin, had fused with Laurentia, closing the Iapetus Ocean, with the Rheic Ocean now separating Laurentia from Gondwana. The subsequent movement of Armorica is highly speculative, due to the lack of geological evidence. One suggestion is shown in Figure 4.

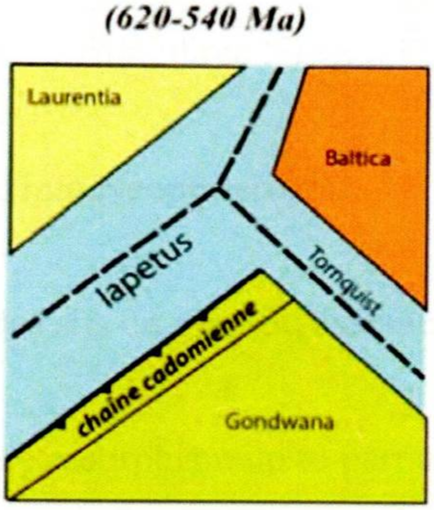

Figure 3: Taken from the Guide p3.

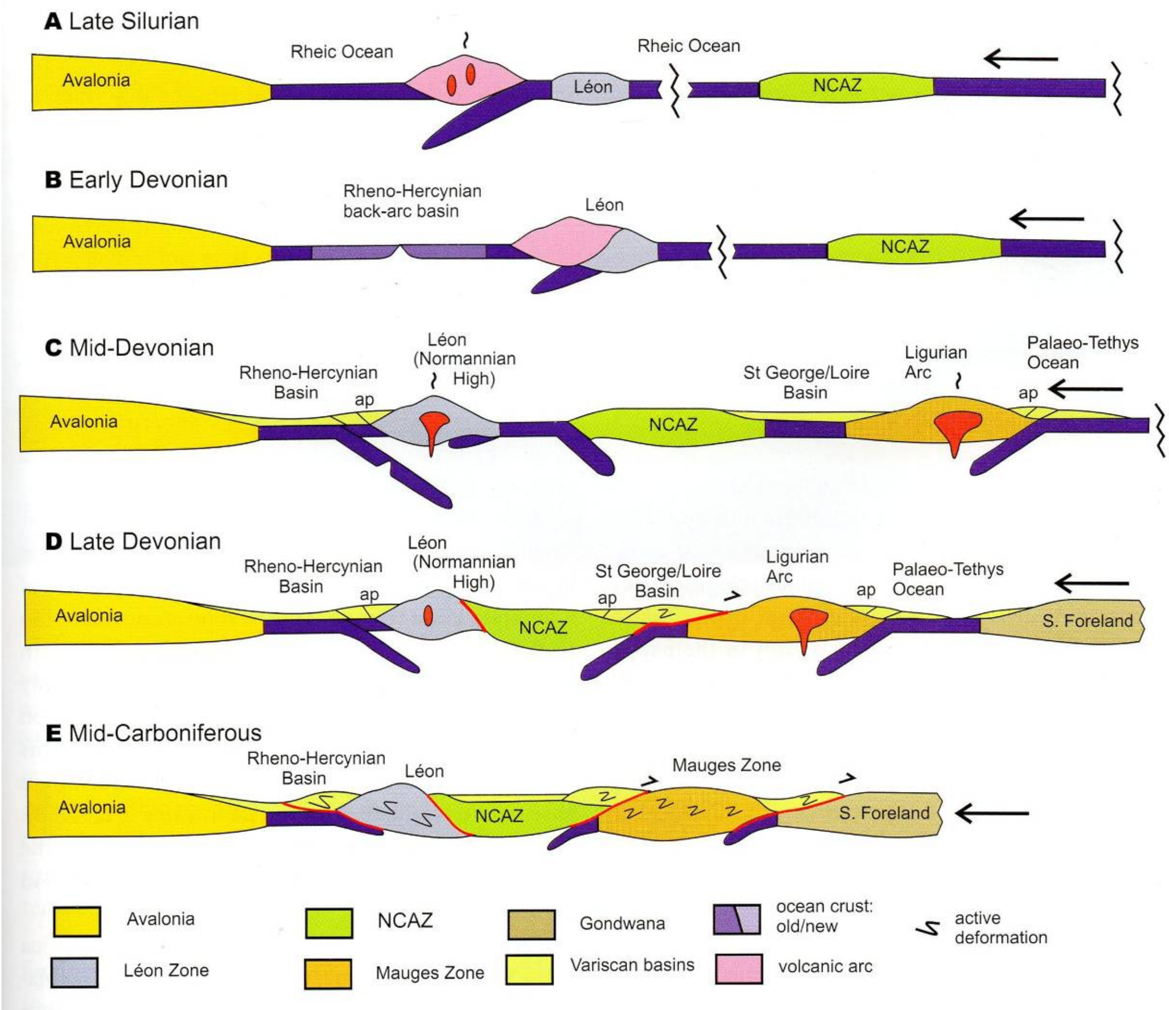

Figure 4: Movement of North Central Armorican Zone and amalgamation with Avalonia. Taken from Graham Park 'The Making of Europe', Dunedin, 2014.

The Léon Domain consists of Cadomian gneiss basement overlain by Lower Palaeozoic metasediments and arc-type volcanics. The upper part of the sequence contains basaltic rocks metamorphosed under very high pressure, indicating they have been upthrust from great depth. The northern part of the Léon Doman is represented by the Lizard ophiolite complex in southern Cornwall. In contrast to the highly deformed Léon Domain, the Cadomian basement and Lower Palaeozoic cover of the North-Central Armorican Domain has experienced only weak to moderate Variscan deformation.

There are outcrops of old continental crust (2000-1800 Ma), named Icartian basement, after the type area, Icart Bay in Guernsey.

Along the northern coast of Brittany is a belt of five Variscan (*c.* 300 Ma) granitic plutons arranged in a line trending east-northeast/ west-southwest (Figure 5), which are linked to a single batholith at depth. This belt is very similar to the slightly younger (280-270 Ma) granite batholith in Devon/Cornwall, but there is no known link. The Brittany granites might have been intruded along a shear zone; another suggestion is that they are linked to products of a hot spot.

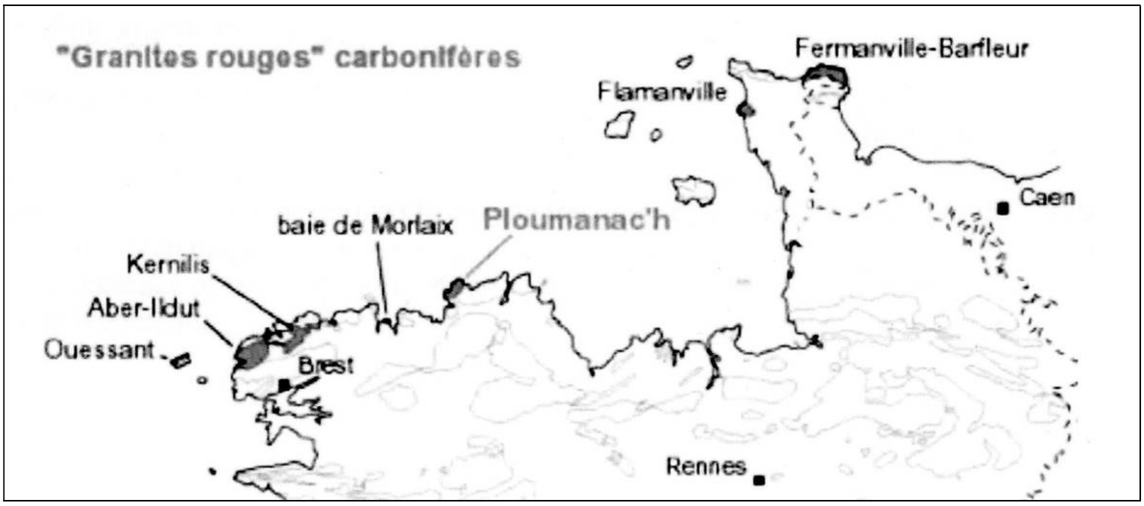

Figure 5: The belt of five Variscan granitic plutons. Taken from the Guide p9.

Tuesday 13th September – morning
(Guide: Days 1 and 3: Côte de Granit Rose - Ploumanac'h igneous complex.)

Safe and snug in the coach we set off for our first stop, about one hour's drive east, while Doug gave us an overview of the geology and more details on the sites we would visit on our first day. Over the next week we would examine the north Brittany coast between Roscoff and Saint-Malo (Figure 1, p6).

On day one of our trip we examined the granites at Ploumanac'h, which were intruded into the Léon rocks and bestow the coast's name, **Côte Granit Rose**.

D1L3. The three granites of the Toënot Peninsula [48º47'17.4" N 03º34'56.1"W**]**

We arrived in good spirits; the sun was shining, our chairwoman was flying the flag (left in Photo 1); looking forward to exciting geology.

Photo 1: First day, first stop, chair and others. NB Ricki Bull in the centre (missing from group photograph p48).

The Ploumanac'h granite complex is the result of three successive magmatic intrusive events. First a red coarse grained outer granite, then a light pink medium-fine grained granite and lastly a grey granite.

On the south side of the peninsula we could observe the relationship between the first two granites. The coarse grained granite contains xenoliths of gneiss country rock (Photo. 2).

Photo 2: Xenoliths in the first granite.

The interpretation is that the coarse granite was formed when the crust collapsed into a deep magma chamber, forcing the magma upwards. The flow fabric observed in the first granite suggests a rapid flow movement of the viscous granite magma. The second, fine-grained, granite contains numerous, some huge, angular blocks of the coarse granite (Photo 3) indicating the coarse granite was solid when the second granite was emplaced. This is interpreted as the second granite being intruded into a fractured first granite; the result is sometimes referred to as a *"magmatic megabreccia".* The granite complex was crossed by aplite veins (Photo 4).

Photo 3: Block of first granite in second granite.

Photo 4: Aplite vein in first granite.

Around the eastern tip of the peninsula [N48º47'24.0" W03º34'50.9"] we observed the contact between the second granite and the third, a light grey granite (Photo 5) termed the Ile Grande type.

Photo 5: Third granite.

Reported by David Riley

Tuesday 13th September - afternoon

D1L9. Tourney beach Site- west side: [48º49'46.2" N 03º29'45.9" W]

Following a picnic lunch on the beach we examined several features in the coarse grained outer granite. We noted lenses and ribbons of concentrations of dark coloured biotite (Photo 1). These are interpreted as reflecting magma chamber movements of a rather viscous nature at a temperature above solidus.

Photo 1: Ribbon of biotite in first granite.

Onion skin weathering was taking place at the top of some of the granite outcrops (Photo 2) and this was attributed to pressure release fissures developing during the unroofing of the granite.

Photo 2: Onion skin weathering.

D1L8. Baie de Sainte-Anne - Basic rocks [48º49'47.6" N 03º30'31.1" W**]**

We had an excellent view of the intermixing of the coarse grained outer granite and dark coloured gabbroic basic magmas (Photos 3 and 4). The contacts are well rounded indicating the basic and acid magmas were not very miscible. Within the basic rocks there are isolated pink feldspars, which are interpreted as representing crystals that were mechanically injected into the basic magma and thus known as xenocrysts (Photo 4). The finer-grained size of the gabbro compared to granite (Photo 3) has been related to a small volume of basic magma close to solidus temperature that has been chilled by a larger volume of granite magma that was partially crystallised.

Photo 3: Contact of the fine-grained gabbro with the coarse granite.

Photo 4: Feldspar xenocrysts in a basic xenolith in the granite.

Eyespots were another interesting feature (Photo 5) which arises through reaction between the original K-feldspar crystals and a surrounding basic magma. The eyespots are fine grained areas of quartz and feldspars surrounded by a rim of dark minerals, often pyroxene. These spots are interpreted as drops of acid magma injected into basic magma with the pyroxene being a reaction halo.

Photo 5: Eyespots.

D1L7. Renote Island [48º49'54.6" N 03º30'44.1" W**]**

This is another area in the outer coarse granite. Of particular interest was the erosion of horizontal joints (Photo 6), typical of the granite morphology of the Cote de Granit.

Photo 6: Erosion of the joints had also created a hole (now occupied by David).

On our way to our seaside hotel in Port Blanc we stopped at the pretty town of Perros-Guirec. After a quick visit to an old church we ended up at a nice street cafe for a well earned, expensive! beer.

Reported by David Riley

Wednesday 14th September - morning

(Guide: Days 1 and 3: Côte de Granit Rose - Ploumanac'h igneous complex.)

D1L2. Menhir of Saint-Uzec [48º47'19.5" N 03º32'40.4" W**]**

Our second day was also spent on the Ploumanac'h complex, with the first stop revisiting the intermediate second stage fine grained pinkish granite. The exposure was, however, a menhir nearly a kilometre from the shore. This stone, the Menhir of Saint-Uzec (Photo 1), is estimated to weigh in excess of 100 tonnes, and therefore could not have been moved far by its neolithic erectors in about 5000 BC. It does not show any conclusive signs of quarrying, but its outward facing side was 'Christianised' in the seventeenth century. It is surmounted by a cross, and has been extensively carved to depict a sun, moon, a hammer and other images. This imagery has been subject to various interpretations. The menhir also has some highly visible xenoliths of the first stage coarse granite detached during the intrusion of the second stage (Photo 2).

Photo 1: The Menhir of Saint-Uzec being examined by the RGS (RY).

Photo 2: Xenoliths of the first stage coarse granite (RY).

D1L1. Ile de Milliau – Contact and metamorphic aureole of Ploumanac'h pluton
[48º46'08.0" N 03º35'06.7" W**]**

A short distance from the menhir, on the southwestern margin of the granite body is the small Ile de Milliau (Photo 3). The northern half of the island consists of the pinkish first stage granite. To the south of this is the Ile de Milliau formation of alternating sandstone and mudstone layers of unknown age. The margin has been contact metamorphosed. Unfortunately the contact margin could not be visited because of the tide.

Photo 3: Ile de Milliau from the east (RY).

We were able to visit a nearby section of the contact aureole. The intrusion of granite at 800ºC brings about an exponential rise in the rate of mineral diffusion in the solid country rock. At about 500ºC new minerals have been formed particularly andalusite and cordierite in the mudstone layers. The cordierite has many twins, the crystals are hexagonal, but look round and appear black because of the many carbonaceous inclusions derived from organic material in the mudstone (Photo 4). Crystals of andalusite were visible at some horizons. This indicated a higher proportion of Al than at the horizons where greater amounts of Fe and Mg resulted in the growth of the cordierite twins.

Photo 4: Banded black mudstone and green sandstone with cordierite (RY).

Reported by John Banks

Wednesday 14th September - afternoon

D1L10. Ploumanac'h lighthouse and Semaphore station viewpoint of granite/gneiss contact [48º50'13.5" N 03º28'34.6" W]

After lunch at the viewpoint we walked east along the scenic coast. Along with the stunning sculptured shapes in the granite there was much jointing to consider; north/south trending vertical joints were of tectonic origin, sub-horizontal pressure joints and conjugate sets showing the direction of extensional and shear forces (Photo 1).

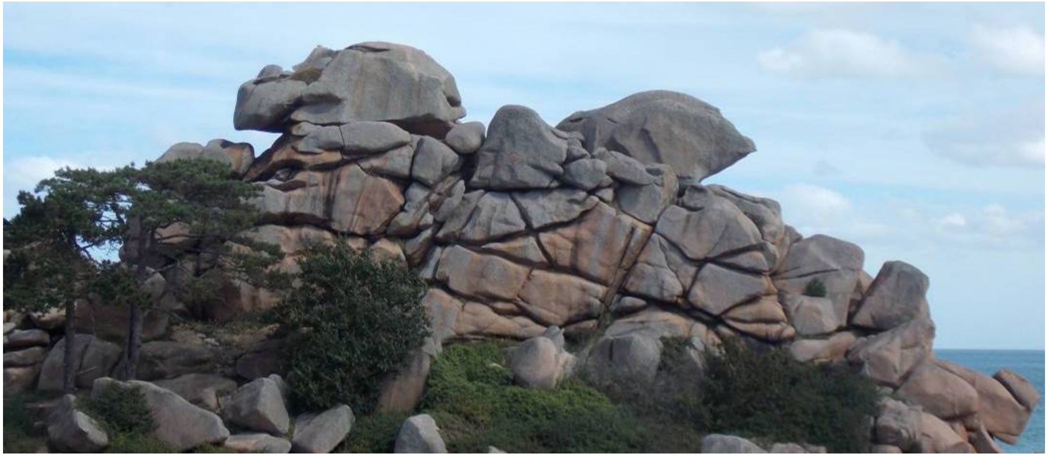

Photo 1: Fracturing in the granite.

An aplite vein was spotted. This has the same chemical composition as the granite but has much finer crystalline structure.

At Ploumanac'h (Guide p15) we looked across the bay to see the contact between the Icartian gneiss and the coarser grained granites in the west – not the easiest to spot. We wanted to see the contact between the 600 million year old granite and the 2,000 million year old Icartian gneiss - the granites having been intruded during the Cadomian orogeny. In particular there was a granite dyke showing the finer crystalline structure on the outside of the dyke where the magma had cooled quickly against the cold country rock and the coarser slower cooling of the interior of the dyke.

Pegmatites were seen in contact with the micro granite country rock. It is suggested that the pegmatites formed by a second pulse of magma intruding when the micro granites were still hot so resulting in a very slow cooling of the pegmatitic material.

Photo 2: In addition two raised beaches could be seen at this location.

D1L6. La Greve Blanche [48º49'38.8" N 03º31'31.3" W]

The party moved on to La Grève Blanche, which translates as The White Shore, (Guide p14) to look at inclusions in the coarse grained outer granite. These are termed 'enclaves'; bodies of igneous rock which have a different composition to the surrounding rock. These are not xenoliths of the surrounding country rocks.

The angular enclaves generally showed foliation so were described as gneissose (Photo 3).

Photo 3: Angular enclaves (RY).

Rounded enclaves were dark in colour being rich on biotite and amphibole and were derived from the gabbroic Sainte-Anne Bay intrusion. Being rounded it is likely that the magma was not completely solidified when it mixed with the more acid granitic magma. At one location the granite could be seen with xenoliths of basement material (Sainte-Anne's type gabbro) eroding out of the granite (Photo 4).

Photo 4: Rounded enclaves (RY).

At the end of the day some members refreshed their feet with a paddle and then it was on to the pub for a refreshing beer.

Reported by Ailsa Davies

Thursday 15th September - morning
(Guide: Day 2: Northern Baie de Saint Brieuc - Cadomian Trégor Unit.)

On Thursday we visited sites in the Trégor-La Hague unit situated in the northern part of the Bay of Saint Brieuc. Before reaching the first site, Doug described the unit as consisting of fine-grained acidic-granitic intrusions. The main rocks to be seen would be rhyolites and micro-granites. To the south we would see a sequence of tuffs, and ignimbrites. This is interpreted as having been a volcanic arc, situated to the southeast of the Laurentian continental edge which we had seen on the previous two days; in the afternoon we would see rocks typical of a back-arc basin, lying further southeast of the volcanic arc and northwest of the Gondwana continental margin; the rocks were deposited as volcanic intrusions at a shallow level - probably several kilometres deep, and as pyroclastic flows on the surface.

D2L1. Ploubazlanec, Pointe de l'Arcouest: The subvolcanic complex of North Trégor: transition between the North-Trégor Batholith and the Tréguier Tuff [48º49'16.9" N 03º01'22.6" W**]**

Our first stop was at the Point de l'Arcouest (Photo 1). The exposure consisted of an outcrop of micro-granites situated on the beach, thought to have been formed from a high-level magma chamber. The upper 2 km or so of the volcano cone has been eroded.

Photo 1: Micro-granite outcrop and beach at Pointe de l'Arcouest.

The surrounding beach consisted of pebbles of porphyry, mostly with a grey glassy matrix of quartz, evidence of an acidic source. The porphyry is interpreted as having been created in a two stage eruption. Firstly the magma had started to cool and crystallize, so forming the large crystals within the magma chamber; a subsequent eruption before full crystallization then caused rapid cooling and resulted in the fine-grained matrix which forms the remainder of the porphyry.

However, no evidence has been found in the area of other common volcanic arc deposits such as blueschists, ophiolites or eclogites, and there is no evidence of folding which would have been a consequence of continental collisions.

A single example of an ignimbrite (Photo2) was also found near the outcrop examined. This clearly shows small thin lenses of a dark material within the greenish matrix, which are the remains of collapsed magma bubbles.

Photo 2: Ignimbite weathered surface (RY).

D2L2. Porz Even: Tréguier tuff – volcanic expression of the Trégor batholith
[48º47'22.8" N 03º02'09.1" W**]**

Our second stop was at Porz Even. As we walked along the beach we passed boulders of pillow lavas which are being used as sea defences. (Photo 3).

Photo 3: A fine example of pillow lava seen near the outcrop.

Photo 4: Rhyolitic ignimbrite.

The outcrop demonstrates the eruptive phase of the rocks which we had seen in the previous stop, and consists of rhyolitic ignimbrites. Typically these weather light grey. There was no evidence of any texture or fine fabric within the rock except for some discontinuous banding. [Photo 4)

Reported by Edmund Shirley

Thursday 15th September - afternoon

D2L4. Port Beni: Pleubian microgranite and Icartian basement [48º50'57.6" N 03º10'14.5" W**]**

Lunch was taken at Port Beni beach. Here a geological notice gave a brief introduction to the rocks that could be seen in the area. We would see both ortho- and para-gneisses, Pleubian microgranite and dolerite dykes.

Doug explained that the main country rock at Port Beni was the Pleubian (the town of Pleubian is nearby) microgranite, a plutonic component of the Tregor unit, (seen in the morning). This rock had been dated at 615 Ma. Within this rock could be found large blocks of the Icartian basement gneiss rocks, much older at *c*. 2000 Ma. These basement rocks were a complex of batholith, volcaniclastic rocks, ignimbrites and lavas ranging from intermediate to acid composition. We would see a variety of metamorphic rocks including augen-granitic gneisses and dolerite dykes of Cadomian age (about 650–550 Ma) which intersect both the Pleubian micro-granite and the Icartian basement gneisses. Doug said there were 3 sets of dykes in these rocks, two of which were of the same age and were contemporaneous with the micro-granite, i.e. 600-650 Ma. A bigger set of dykes was of Hercynian age (Hercynian or Variscan orogenic phases having an age of approximately 380-280 Ma). Photo 1 shows the first dyke we encountered, running through the micro granite. Light coloured and glassy, this dolerite dyke ran east-west and was about 2 to 3 metres wide on the shoreline. A few metres further on we checked out the chilled margin of a second dyke with a beautiful contact against the Icartian ortho-gneiss (Photo 2).

Photo 1: Dolerite dyke.

Photo 2: Contact of dolerite dyke with ortho-gneiss.

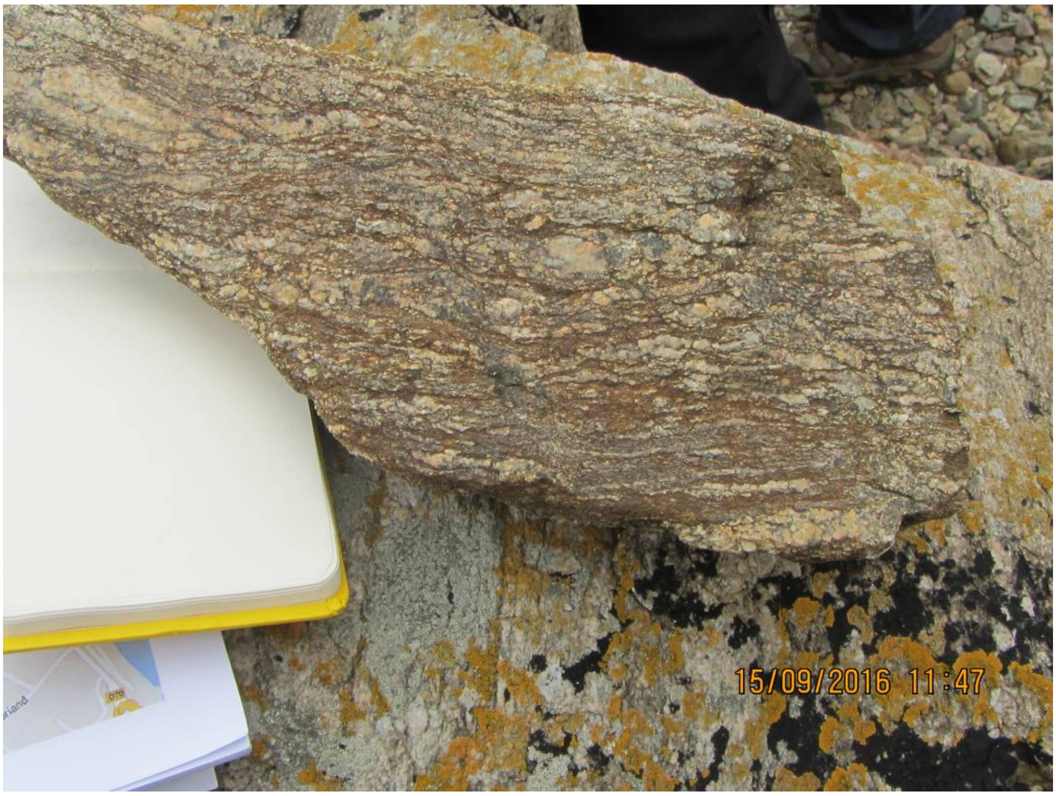

Photo 3: Second dyke - close-up of chilled margin

The basement rocks were all metamorphosed and Doug explained the process. These ortho-gneisses were very massive, with a clear metamorphic fabric, almost like sedimentary bedding (to use Doug's description) (Photo 3). The sample was differentiated into lighter and darker bands which was typical of a gneissose fabric. This massive rock represented an ortho-gneiss (Photo 4). Originally the rock was an orthoclase feldspar large-crystal granite which has been deformed and boudinaged to the point where the boudins appeared rounded. These rounded original feldspars were given the name augen gneiss, augen being the German word for eyes (Photo 5).

Photo 4: Ortho-gneiss (RY).

Photo 5: Augen gneiss (RY).

The original protolith, consisting of granites and coarse grained rocks, was metamorphosed and the age of the metamorphic deformation could be dated using rubidium/strontium isotopes. So the metamorphic age was put at 2 Ga. It is possible to look through the metamorphism age to get the age of the granite rocks using very specialised radiometric dating techniques using zircon. However, this has not been done on these basement rocks. It was thought that 2 Ga was the age when the edge of the original Laurentian crust was deformed.

Para-gneisses are nowhere near as massive as the ortho-gneisses. They show rapid alternation between quite soft material containing some crystals and lighter coloured layers that are dominated by quartz. These are the para-gneisses. They represent quarzitic horizons, interbedded with volcaniclastic material. The brown, greeny colour is a typical feature pointing to a protolith being volcaniclastic with lots of iron and magnesium and very soft chlorite. Some of the material is normal volcanic basaltic sediment. So we can think of a marine environment into which volcanic debris was falling. Both the para-gneisses and the ortho-gneisses may be found close together.

These basement rocks were a complex of batholith, volcaniclastic rocks, ignimbrites and lavas ranging from intermediate to acid. The volcanics were thought to be generated by continental collision between the Laurentian and Gondwana continents with the generation of an associated island arc complex. The boundary was not intrusive but was tectonic. The layered fabric developed in these rocks, was due to the great pressure and temperature generated during the collision. The layering was in response to movement at right angles to the direction of imposed pressure. Doug speculated that the deformation occurred at a depth around 10 km. The flow of rocks at an elevated temperature would be of a plastic nature and, while not a liquid flow, would deform and produce the gneissose banding evident in the rocks.

D2L5. Chapel of Saint-Gonery [48°07′28″ N 2°49′07″ W]

We left Port Beni to visit Castel Meur. En route we stopped to see the remarkable old chapel at Saint-Gonery. This was notable for the tower which had been built out of the normal vertical alignment and the painted ceilings done by itinerant artists (Photo 5).

Photo 5: Saint-Gonery spire.

D2L7. Cathedral town of Tréguier [48°47′16″ N 3°13′51″ W]

We also had time to sit down and to look around the cathedral town of Treguier. We admired the use of the local granites used to build the cathedral.

D2L6. Castel Meur [48º51'58.9" N 03º13'51.2" W]

At Castel Meur we aimed to see some spectacular dykes. We had to walk along the coast to get to the location and on the way we were rewarded with a view of a small house built between two huge outcrops of the Pleubian micro-granite (Photo 6).

Photo 6: The house wedged between Pleubian granite outcrops.

Perhaps 400 m further on we could see a number of dykes all trending east-west (Photo 7).

Photo 7: Dyke swarm; 5 dark coloured dykes.

We reached a saddle on the higher ground where we could see another dyke about 10 m wide (Photo 8) dipping down below sea level to emerge 50 m away again trending east-west. This dyke was well jointed and eroded. These dykes could have been of Hercynian age.

Photo 8: Dyke 10 m wide.

Doug gave a summary explanation of the classification of igneous rocks. He said that they can be classified as acid, intermediate or basic according to the percentage of silica contained. Variations in the amount of silica could be explained by differentiation within the magma chamber. One sample chip that he passed around was dark with amphibole making the rock a hornblende. We admired the dark elongate prisms of amphibole. Doug declared this sample to be a diorite and pointed out that amphibole is a component of the basic end while biotite is a component of the acid end.

We then retired to our hotel for a well earned meal.

Reported by Roger Lloyd

Friday 16th September - morning
(Guide: Day 4: Central Baie de Saint Brieuc.)

D4L1. Brehec [48º43'37.3" N 02º56'52.8" W**]**

Port de Brehec is about 15 km southeast of Paimpol. This stop was to allow us to examine the Lower Ordovician Red Bed sediments exposed in the Bay. Doug explained that these rocks were eroded from the Cadomian sequence, following the collapse phase at the end of the Cadomian orogeny.

Brehec has a long sandy beach, backed by cliffs, with the Port at the north end – but we walked to the southernmost cliffs initially.

The cliffs (Photo 1) are about 10 m high and dip gently to the southwest and consist of alternations of red mudstones and yellowish sandstones, each layer being between 5 and 15 cm thick. Large bedding planes (Photo 2) carried two sets of fractures aligned approximately north-south and east-west and had very pale green surface deposits which also entered the fractures and are believed to be manganese mineralisation.

Photo 1: The cliffs at Port de Brehec.

Fallen blocks on the beach (Photo 3) showed sedimentary features, including distinct cross bedding, desiccation cracks and ripple marks, but slightly less convincing rain spots and burrows.

The surface between some sandstone and mudstone members had flakes of mudstone about 2 cm long by 2 mm thick caught up in the sandstone, indicating a localised high energy erosion event just as the sandstone was deposited.

Photo 2: Bedding plane showing north-south and east-west fractures.

Photo 3: Various sedimentary features.

Also found, both loose on the beach and enclosed in the sandstones, were ironstone nodules, remarkably like marcasite nodules in the chalk. These were 3-4 cm diameter and composed of weathered iron oxide minerals.

The party now returned to the north end of the beach, examining the cliffs as they progressed. 200 m short of the north end, a large crevice in the cliffs was examined and found to be a fault within the red beds. Here the sediments dipped at 50º to the south and had very similar characteristics to the rocks at the south end of the bay.

100 m short of the north end of the bay, outcrops on the beach were examined – these consisted of poorly sorted conglomerates (Photo 4).

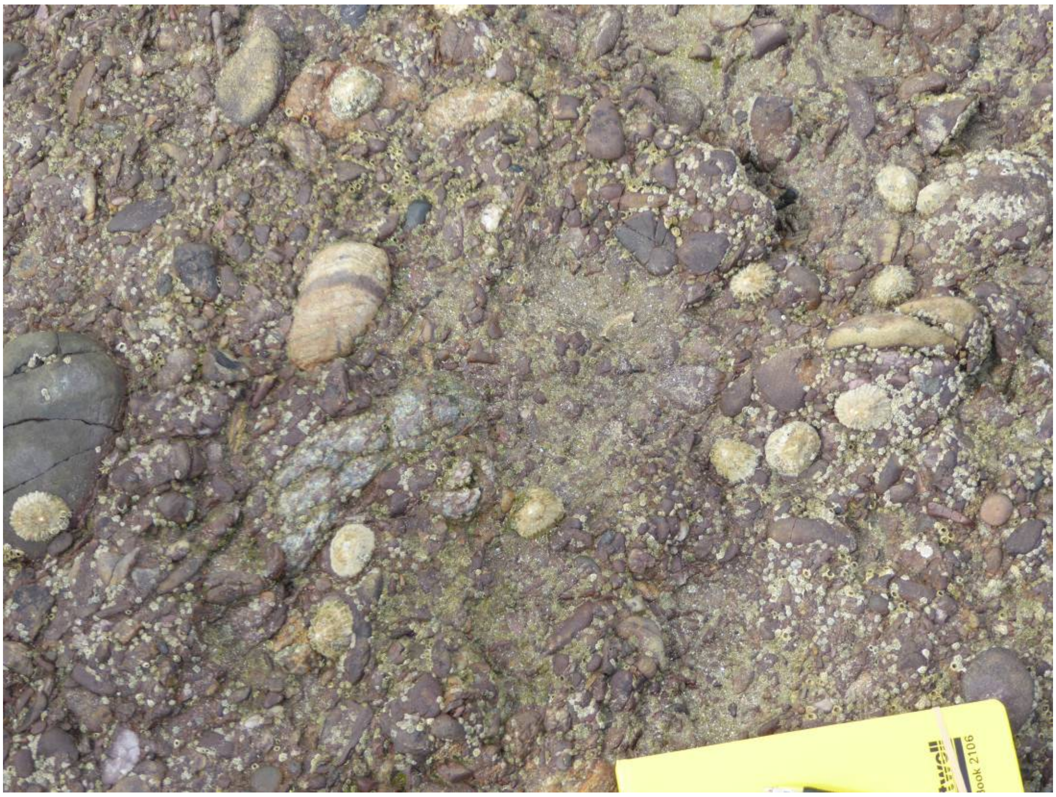

Photo 4: Conglomerate.

Clasts ranged in size from 2 cm up to 30 cm and in roundness from almost spherical to angular. Rocks identified in this conglomerate included sandstones, mudstones, basalts, gneisses and quartz.

Some debate followed regarding the structure of this deposit – was it a wadi deposit? – if so, some expected it to be much more angular. Or was it a beach deposit, perhaps indicated by the large number of rounded pebbles. Examples of both were cited by the members, but no definitive conclusion was reached.

After this very pleasant morning in the sun, the group returned to the coach for lunch and to travel on to the next site.

Reported by David Ward

Friday 16th September - afternoon

D4L2. Languex (Grève des Courses) Metaconglomerates, the Poudingue de Cesson
[48º30'58.3" N 02º42'19.5" W**]**

We arrived at the sandy beach and walked south to the cliffs and rock exposures. To seaward there was a huge tidal flat stretching into the Baie de Saint Brieuc, now designated a bird and wildlife reserve. We were warned that the tide can come in very fast but it was then far out although there was a lot of standing water. At the back of the tidal flat are cliffs originally of Brioverian (750-580 Ma) sandstones, mudstones and conglomerates but which are now very deformed (600 Ma).

Two conglomerate facies occur here, within 100 m of each other, one polygenic, the other monogenic. They are separated by mudstones and sandstones which have also been deformed.

The Poudingue de Cesson is the local name for the polygenic conglomerate (based on the English term puddingstone). The clasts in the conglomerate have been sheared, thinned and stretched (Photo 1). The original beds have been reduced to half their thickness. They have been interpreted as a basal conglomerate of the volcano-sedimentary succession of the Saint Brieuc Unit.

Photo 1: Poudingue de Cesson.

Further south a Brioverian volcaniclastic sequence was seen which had been intruded by a dyke which has been put under so much strain that large boudins had been formed. Doug also pointed out an SC shear zone similar to that described on page 29 of the Guide (Photo 2). This shows very fine bedding with an isoclinal fold above the yellow pen. The mudstones and sandstones had been worked into an intensely folded isocline which has then been stretched and boudinage formed. Another large scale isoclinal fold was seen nearby (Photo 3).

Photo 2: SC shear with an isoclinal fold.

Photo 3: Larger scale isoclinal fold.

The undeformed, monogenic conglomerate was seen (Photo 4) a little further to the south. The composition and dating evidence (667-656 Ma) suggest that the clasts were sourced from the Hillion granodiorite which outcrops to the east on the other side of the bay.

Photo 4: The undeformed, monogenic conglomerate.

D4L3. Planguenoual (Jospinet beach) [48º33'04.1" N 02º36'20.7" W**]**

This beach was just along the road from the Chateau du Val and was notable for a very wide and long slip. Quite why rapidly became apparent when a small fleet of tractors and trailers and some amphibious craft came along the beach and up the slip to some industrial units. They were used in farming the mussels which were grown on ropes from poles standing out on the beach (Photo 5).

Photo 5: The mussel farms at Jospinet beach.

We walked south-west along the beach to exposures of the Port Morvan Gneiss (750Ma). This is high grade metamorphic rock resulting from the burial of shale down to between 20 and 25 km. As the depth increases, temperature and pressure increase, the minerals lose the hydroxyl components and recrystalise, the shale changes to slate then to phyllite, schist, and gneiss. (With greater depth it could change to granulite and eventually to migmatite.)

The Port Morvan Gneiss (*c*. 750 Ma) is exposed on the shore where it is separated from the Hillion granodiorite (645-625 Ma) by an east-west fault. The granodiorite is to the south with the gneiss to the north. Further north towards the sea is another fault beyond which lie very weathered basaltic rocks (very probably basalt sills) (Photo 6).

Photo 6: The Port Morvan Gneiss to the left with the Hillion granodiorite to the right.

D4L4. Port Morvan [48º34' N 02º35' W**]**

At Port Morvan the Port Morvan Gneiss could be seen to have originally been well bedded sedimentary rock. The gneiss is dated at 750 Ma and forms the Pentevrian basement. The lighter coloured layers had been sandstones and the darker, greener layers had been volcaniclastic deposits (Photo 7).

The gneiss was very fine grained showing that the crystals had been under a lot of strain, recrystalising into smaller and smaller crystals under the shearing stresses. Because the volcaniclastic rocks were more plastic than the sandstones, the latter often showed pinch-and-swell or even full boudinage (Photo 8).

The rear wall of the exposure showed gneiss above and a basalt layer below. Vertically bedded gneiss was exposed on the beach in front of the face. It is believed that a fault along this face caused this exposure of the basalt sill intruded into the gneiss.

Photo 7: Lighter (sandstone) and darker (volcanic) banded Port Morvan Gneiss.

Photo 8: Boudinage.

Reported by Roger York

Saturday 17th September - morning
(Guide: Day 5: Eastern Side Saint Brieuc Unit - Erquy-Cap Fréhel.)

D5L1. Cap Fréhel Lighthouse [48º41' N 02º19' W**]**

Caution was needed due to the 70 m high and in places sheer cliffs.

Doug explained that the main rock type was the Fréhel feldspathic sandstone, a medium grained clast supported sandstone containing quartz and white feldspar. The feldspar originated from the Fort Fréhel diorite (see next site) lying unconformably below and indicates a short transport distance as feldspar is unstable. This was supported by later investigations of the rock which contained subangular clasts, also evidence of relatively short transportation. The resulting rock is an arkose sandstone, a sandstone which contains at least 25% feldspar. The red/pink colour of the beds suggests a subaerial depositional environment, and was laid down in an east to west trending rift basin, possibly as an alluvial fan or fluvial sequence.

There were also traces of burrows (Photo 1) and possible shell fragments.

Photo 1: The red arkosic Fréhel feldspathic sandstone with possible trace fossils (RY).

The base of the beds consist of the Erquy conglomerate (not visible), which is composed of subangular clasts with imbrications and rocks including vein quartz and volcanics as well as sedimentary sandstones and mudstones.

Close examination of the beds indicated that the clasts were well sorted with planar bedding with small scale channel cross bedding at an angle of approximately 40°. The cross bedding was richer in feldspar (about 35% content) and contained medium clasts which varied from sub-rounded to angular. The main beds dipped at 12-15° west, and were well-bedded, interbedded in places with a finer grained well sorted sandstone.

Some beds included tension gashes infilled with quartz. The main set of tension gashes trended north to south supporting the concept of east to west rifting.

D5L2. La Roche Goyon or Fort La Latte [48º40' N 02º17' W**]**

The entrance to the Fort is across a bridge as a fault has been eroded and widened by wave action. The rock exposed just inside the outer gatehouse is the Saint Brieuc diorite – the Pentevrian basement rocks. Crystals of biotite up to 5 mm and of plagioclase up to 4 mm can be seen. These are also inclusions of a fine porphyry which are squashed and aligned. It may be that these inclusions are of the same rock but a different facies (Photo 2).

Photo 2: Saint Brieuc diorite with inclusions.

Reported by Alison Barraclough

Saturday 17th September - afternoon

To recap on the geology of the area, the two sites visited in the afternoon were in the Saint Brieuc unit, a thick volcanic and sedimentary sequence (*c.* 600 Ma) which overlies a granitic basement, and is intruded by gabbro-diorite plutons (*c.* 580 Ma). The structural affinities are shown in Figure 1. These are complex and it is therefore difficult to devise a plate tectonic setting. This unit lies between the Tregor-La Hague unit to the north west and the Saint Malo unit to the south east. The Icartian crystalline basement lies further to the northwest where subduction occurred in the Cadomian orogeny and it could be postulated that the Tregor-La Hague unit represents a volcanic arc, with the Saint Malo unit to the south east being the continental margin. The Saint Brieuc unit is therefore most likely a back-arc basin. Figure 2 shows a hypothetical and stylised representation of the plate tectonic setting.

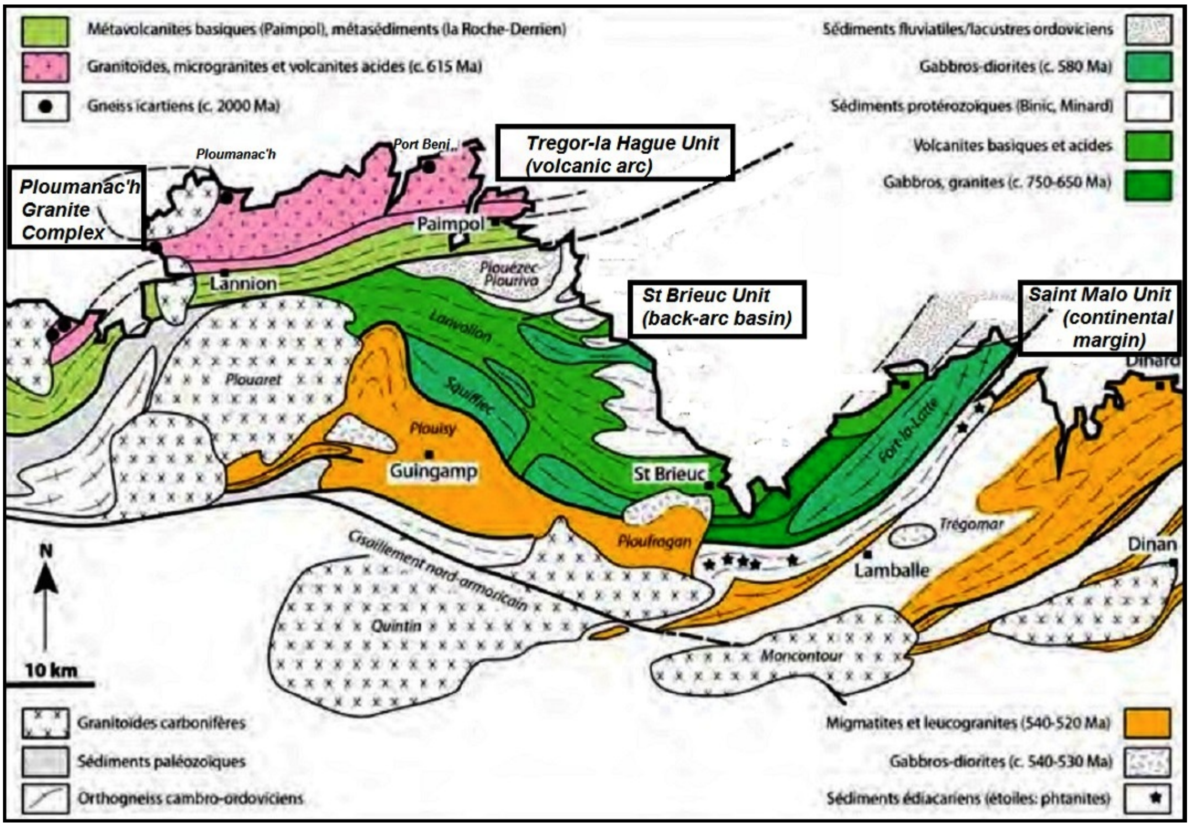

Figure 1: Structural affinities of northern Brittany. Amended from the Guide p7.

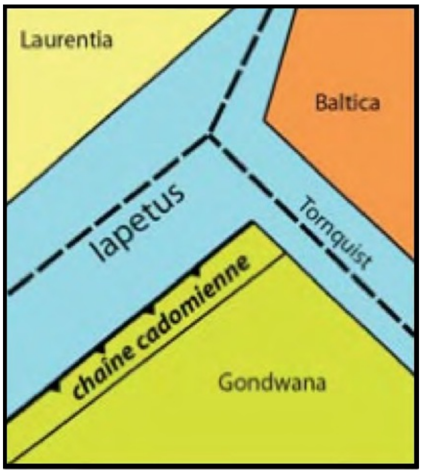

Figure 2: Taken from the Guide p3.

D5L3. Plage de la Fosse and Pointe de la Guette [48º40' N 02º21' W**]**

The exposures in the cliff backing the beautiful sandy beach were the same as we had seen earlier in the day at Cap Fréhel and were part of the Upper Cambrian/Ordovician red bed sequence, the Fréhel sandstone unit. This unit is 350 m thick and is the upper part of the sedimentary sequence known as the Erquy-Fréhel Group. This accumulated in a depositional basin within in east-west graben structure. The underlying conglomerates are likely to be alluvial fan deposits with detritus shed from the scarp of the graben, whereas the Fréhel sandstones are indicative of braided river draining the basin axis as shown in Figure 3.

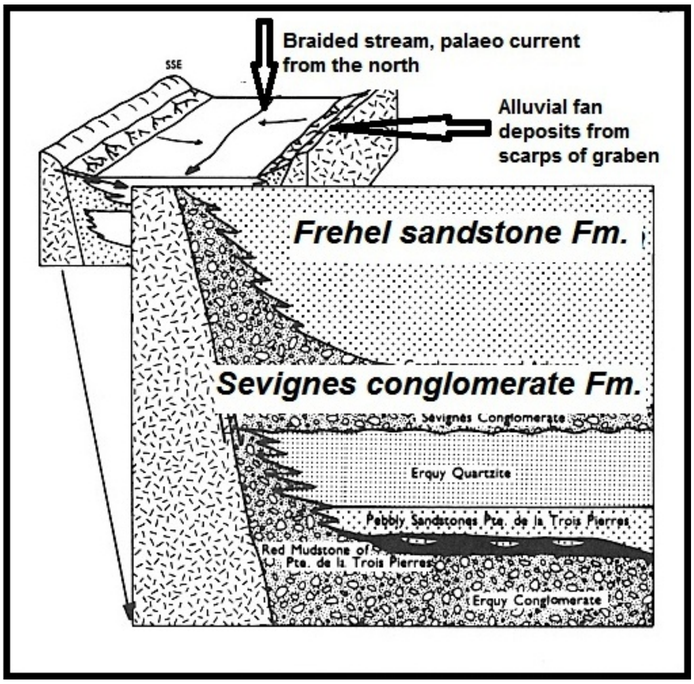

Figure 3: Amended from the Guide p25.

Close examination of the sandstones revealed sedimentary structures typical of this depositional environment. Photo 1 shows interbedded layers of course granular gritstone and fine feldspathic sandstone with trough bedding and a variety of colours from pale pink through to red. The palaeocurrent direction is from the north. They are rich in quartz, the source of this being the Fort la Latte quartz diorites of Pentevrian age. These are exposed nearby at Pointe de la Guette but, because of the tides, were not visible at the time we were there. The whole unit was dipping to the north at 30º and faulted.

Photo 1: Sedimentary structures in Fréhel sandstones.

Intruding into the Fort la Latte quartz diorite and the overlying Erquy-Fréhel Group are numerous dolerite dykes of Carboniferous age relating to the Variscan orogeny. This is linked to the Ploumanac'h granite intrusions. Dolerite is defined as a medium-grained equivalent of a basalt - a basic rock dominated by plagioclase feldspar and pyroxene, with olivine. Photo 2 shows the contrast between the dark grey dolerite and the older red bed sequence. The dyke is about 25 – 40 m thick and one of many intruding into the Fréhel peninsular in a north-northwest – south-southeast direction. Tension gashes could be seen in the dolerite trending in the same direction.

Photo 2: Dolerite dyke.

D5L5. Pointe de la Heussaye – Erquy Volcanic Formation [48º37'47.4" N 02º28'30.4" W**]**

The Pointe de la Heussaye (or Pointe de la Houssaye on Google maps) is a small peninsular in the south side of Erquy Bay. Figure 4 is a simplified geological map of this area. The Erquy volcanic formation is over 500 m thick and well exposed on the intertidal reefs and in the low cliffs around the headland. It consists of volcaniclastic sediments (pale brown on Figure 4), basaltic intrusions (green on Figure 4) and lava flows (pale blue on Figure 4) and the box on the top right of the diagram shows the vertical section postulating the relationship between them. The box bottom right is the current position after orogenic and erosional processes showing the sequence is nearly vertical and younging to the north.

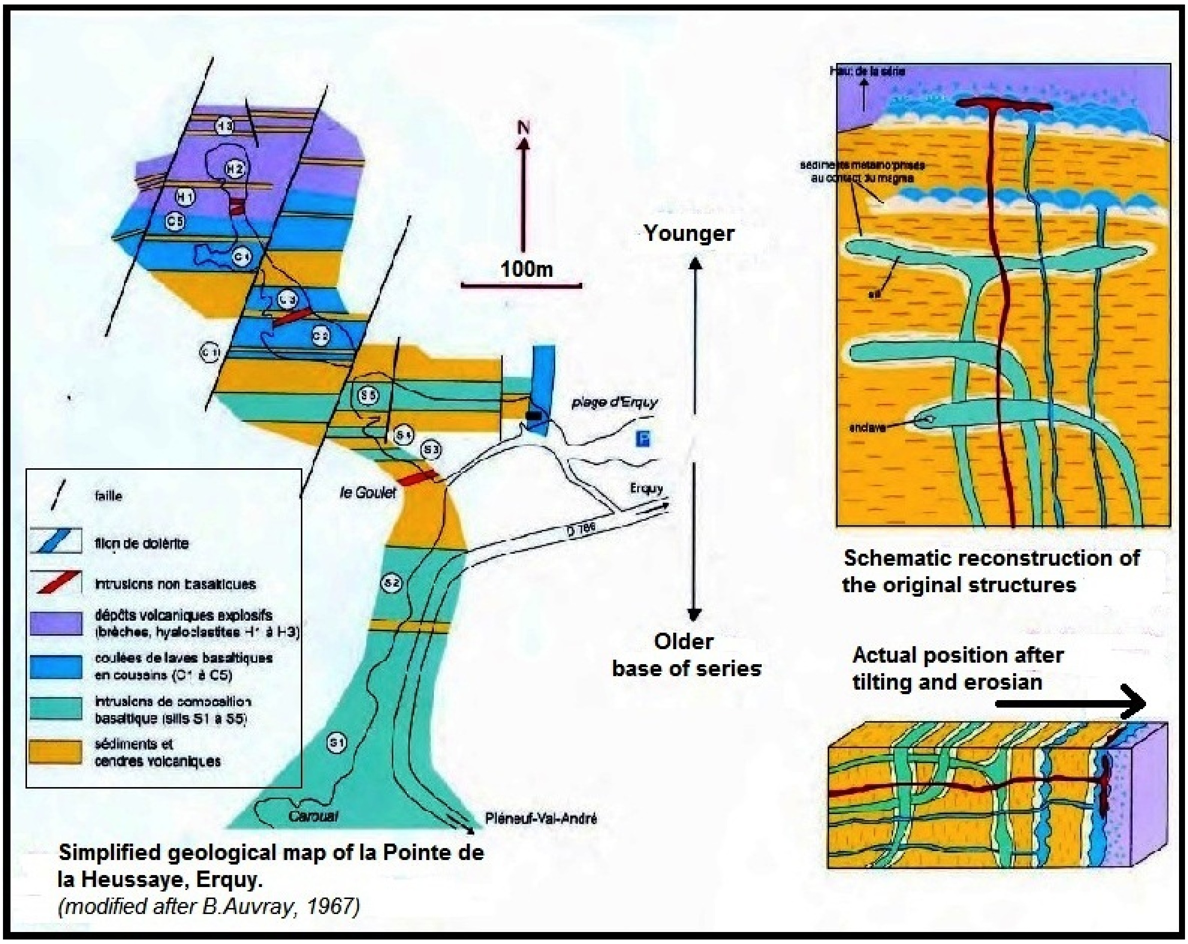

Figure 4: Amended from the Guide p27.

The lava flows in the sequence were submarine and consequently are splendidly pillowed. This was the main feature we had come to see. Photo 3 shows an annotated view of the headland showing the pillowed lava flows as part of vertically bedded sequence of the Erquy Volcanic Formation.

Closer examination of the pillows showed them to be 1.3 m - 1.5 m across and with well defined outer "rinds". The lack of vesicles and the devitrified glassy rind is an indication non-explosive extrusion in water at depth. Between the pillows we noted the presence of hyaloclastite which forms when lava is extruded into water with rapid chilling causing fragmentation around the pillows. These deposits contain angular fragments of flakes and chips of lava from sizes of a millimetre to a few centimetres and can be clearly seen in Photo 4 surrounding the pillows. The fragmentation is most likely caused by thermal shock as the result of rapid cooling. The space between some pillows was filled with a more brecciated material, known as inter-pillow hyaloclastite breccia. Today, these pillow lavas would be typical of submarine flows in the Sea of Japan, at depths of 600 m. The postulated hypothesis that the Saint Brieuc unit is the result of its tectonic setting within a back-arc basin gains credence with the examination of these pillow lavas.

Pillowed lava flows and volcaniclastic sediments are interbedded and at the base of a lava flow it is possible to see structures such as load casts formed from the loading of the pillows into the soft sediments. Basalt sills had intruded into the sediments and subsequent erosion caused these to be well-developed features on the beach and rock platform.

Photo 3: Pillow lavas in Erquy Volcanic Formation.

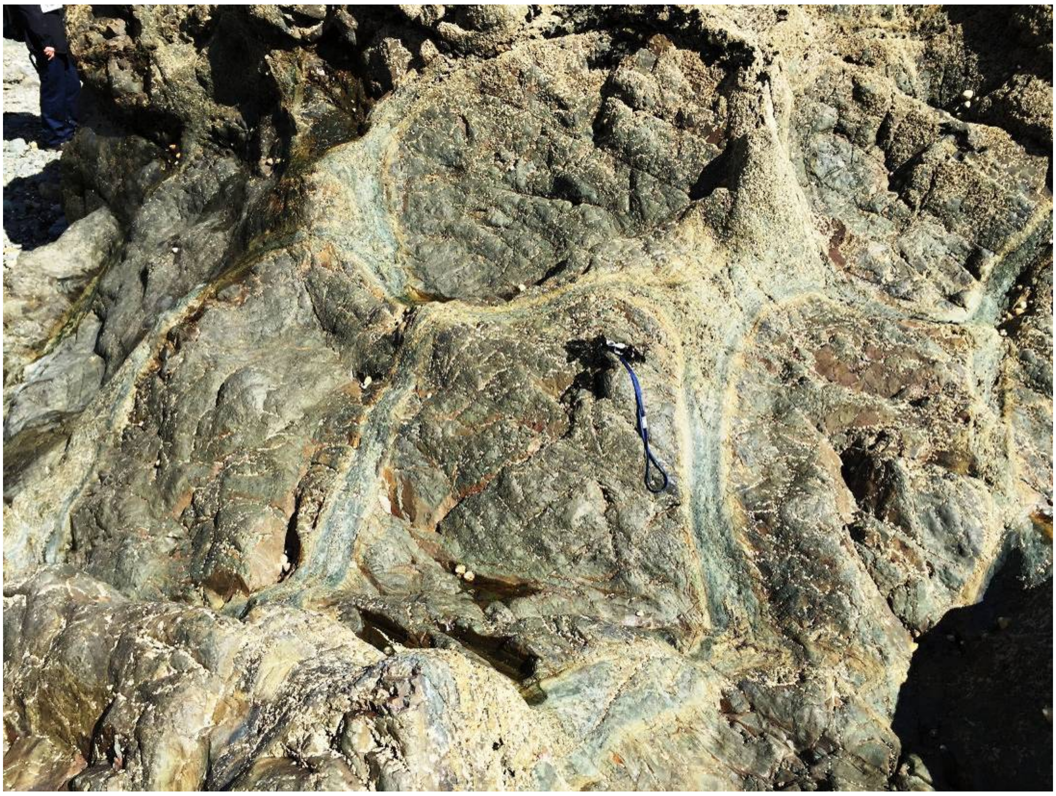

Photo 4: Hyaloclastite surrounding pillow lavas.

Reported by Hilary Jensen

Sunday 18th September - morning

(Guide: Day 6: Saint Malo Migmatite Belt and Contact with Saint Brieuc Bay.)

D6L1. Pointe de Saint-Cast and Pointe de la Garde: strike-slip shear zone along the northern boundary of the Saint Malo migmatites [48º37'27.9" N 02º14'21.2" W**]**

The day started in the bay with an informative discussion on the Cadomian sub division 3, (see map and text in the Guide p4). (We visited Pointe de la Garde but not Pointe de Saint-Cast.) We were at the margin of the Gondwana continent, in a major sheer zone, with rocks dating to the pre–Cambrian, 580 Ma. These had undergone metamorphism, and the migmatite belts were formed under this. Two sets of rock are in this Saint Brieuc Unit, first the grey fine grained gneisses, intruded by aplite dykes and second the deformed migmatites. The area is indicative of very high grade deformation. Comparisons were made with other mylonite belts, where again the rocks have been so compressed that they produce ribbon like structures, becoming ever more crystallised. Direction was northeast /southwest which led to questions about the overall tectonic systems which had previously been put forward.

At Saint-Cast the whole peninsula is contained within the two points of the two major strike-slip sheer zones; the fabric is strongly sheared with very finely banded migmatites, demonstrating that extreme deformation (Photo 1). Movement was lateral within a ductile flow.

Photo 1: Finely banded migmatite gneisses of Pointe de la Garde (RY).

D6L2(a). Jacut de la Mer – South end of Plage du Rougeret [48º37' N 02º11' W**]**

At this location there were good outcrops where we had examples of the different types of migmatites (see map on page 33 of the Guide), and where there is an elongated dome–like structure at the continental edge, with the deepest section of this moving from a solid state towards very heterogeneous rocks, with a low viscosity and a very low density, thus forming the dome by a yet further enhancement of the overall deformation.

The strongly banded magmatites were composed of three types and these were seen and identified for use in the field – metatexite, which still has a strong identity of the original rock type (Photo 2); inhomogenous diatexite where there has been much more movement with a separation of the solid state (Photo 3); and finally the third, inhomogenous diatexite, the liquidised form, with only the biotite remaining (Photo 4).

The diagram on page 30 of the Guide informed our thinking on the very high temperatures involved in the process, with an identifiable pathway along the 30ºC/km gradient, and which was a possible melting point for some rocks/minerals (but it was pointed out that not all rocks will melt at that depth). There was gradation from the metatexite to the diatexite. It was noted that one of the very first minerals to melt is sillimanite.

The actual composition of the migmatite was also explained and identified in the location – see photographs and text pages 30 and 31 of the Guide — and we had many good examples of both the lighter granitoid rocks with biotite intrusions on the beach, as well as the very much darker banded features of the schists and the gneisses.

Altogether a most informative morning which added some very different aspects to our overall picture of the geology of these units and which was developed even further in the Rance estuary locations later on that day.

Photo 2: Metatexite migmatite at Plage du Rougeret, Jacut de la Mer (RY).

Photo 3: Inhomogenous diatexite migmatite at Plage du Rougeret, Jacut de la Mer (RY).

Photo 4: Inhomogenous diatexite migmatite at Plage du Rougeret, Jacut de la Mer (RY).

Reported by Margaret Mitchell

Sunday 18th September - afternoon

D6L2(b). Jacut de la Mer – Plage du Ruet [48º35' N 02º12' W**]**

Lunch was the first event of the afternoon, taken on the rocks at the Plage du Ruet where we found homogeneous diatexite, a coarse grained granitoid rock in which everything but biotite has been melted and aligned (biotite has a lower viscosity and buoyancy than the other materials). A good example of biotite selvage – restite (Guide p31) was found (Photo 1). Deposits of tourmaline, a small deposit of epidote, and a large expanse of an aplite seam with larger crystals growing at the junctions with the granitoid rock, were also found in this area (Photo 2).

Photo 1: Biotite restite.

Photo 2: Tourmaline and epidote.

The figures on page 33 of the Guide demonstrate the melting that had occurred in the envelope of the dome, so allowing us to understand the uneven rises and falls as the peaks were caused where the most buoyant of the materials created greater rise in individual sections of the whole.

D6L3(a). Rance Estuary –Plage de Garel [48º35' N 02º00' W**]**

This was a site that Doug had not visited before but, because of its location on the border between the gneiss and mica schist areas (as per the figures on p.33 of the Guide), he anticipated that it would be an interesting site. After treading our way carefully over often slippery stones we found both gneiss and a muscovite-rich mica schist. There were also some granite intrusions into the schists (Photo 3).

Photo 3: Aplite intrusion forming surface.

Rocks were dipping to the north and as one went north along the beach more gneiss was to be seen, following what one would expect from the chart (Guide p30). Some ptygmatic veins were found which appeared to be tectonic but in fact the quartz had intruded in a curved manner according to differences in viscosity (Photo 4). Again, to the northern end of the area, a small area of garnet was found (Photo 5).

Photo 4: Ptygmatic vein.

Photo 5: Garnet.

D6L3(b). Rance Estuary – Pointe de Cancaval [48º36' N 02º01' W**]**

On the northern side of this point lies the migmatite band, the gneiss lies to the south. Here the migmatite is inhomogeneous, with no signs of melting but signs of incipient melt – i.e. in transition. We were unable to get down to the rocks on the point, the path lay quite a bit above it on a headland with a knotted rope down a steep slope to allow access at one point on the path, a step too far for our intrepid geologists. However, towards the point along the path were outcrops of rocks where the lower part was gneiss while the upper part showed signs of this transition. At the very end of the point, there appeared to be some evidence of a metatexite boundary (Photo 6).

Photo 6: Metatexite boundary, Pointe de Cancaval.

D6L4. Usine Marémotrice de la Rance (Rance Tidal Power Station) [48°37′05″N 02°01′24″W**] and an official end to the trip**

The Rance tidal power station is the second largest in the world. Information Boards were honest about the effects on currents and water flow resulting from the barrage as well as the silting of the estuary which, though a natural problem with all river estuaries, may be exacerbated by the barrage. A few of us managed to find the visitor centre, hidden underground, and learned, among other things, about the cathode protection for the blades of each turbine which prevent erosion by seawater. A view of the hall between the turbines was also impressive.

At the end of this stop the gratitude of the members was expressed by David Ward, who also made the presentation of a tankard to Doug. Doug thanked the group for their hospitality and pleased David by saying that “It has been like a holiday!”. A card and thanks were also given to Carol for all her hard work organising the trip and for sorting out all the little and not so little hiccups that happen on a group trip.

See over for the Group Photograph (Photo 7).

Photo 7: Carole Gregory, Roger York, Christine Hodgson, David Riley, Alison Barraclough, Ted (driver), Margaret Mitchell, John Banks, Louise Knight, David Price, Doug Robinson, Susan Barr, Barbara Barrett, David Ward, Hilary Jensen, Edmund Shirley, Roger Lloyd and Ailsa Davies. Christine Hooper is not shown. Ricki Bull, who took this photograph, may be seen in Photo 1 on page 9 of this report.

Reported by Ricki Bull