The geology of Brittany – FGS field trip to Brittany & Normandy, October 2008

Regional Geological Interpretation - the Celtic Ocean and the Cadomian Orogeny

Denis Bates, joint leader of the trip, demonstrated that Brittany is a complex area geologically, and I think it is easiest to put the rocks and localities visited into their regional context, based on interpretations from the 1990 Special Publication on this area. The Brioverian rocks of northern Brittany (ranging from 626-575Ma) were originally thought to be a normal stratigraphic sequence of lower (older) volcanic rocks underlying upper (younger) sedimentary rocks. However they are now interpreted to have formed in an orogenic zone, to the south east of a major subduction zone running down the English Channel (then the Celtic Ocean). A volcanic island arc complex offshore passed through a back-arc sequence of volcanics and sediments, shoreward to coastal terrigenous beds. These facies zones were then progressively thrust as 'terranes' upon each other and onto the edge of the Icartian Continental Plate (2000 Ma). These broad domains are shown in Fig 1 (from Rabu et al).

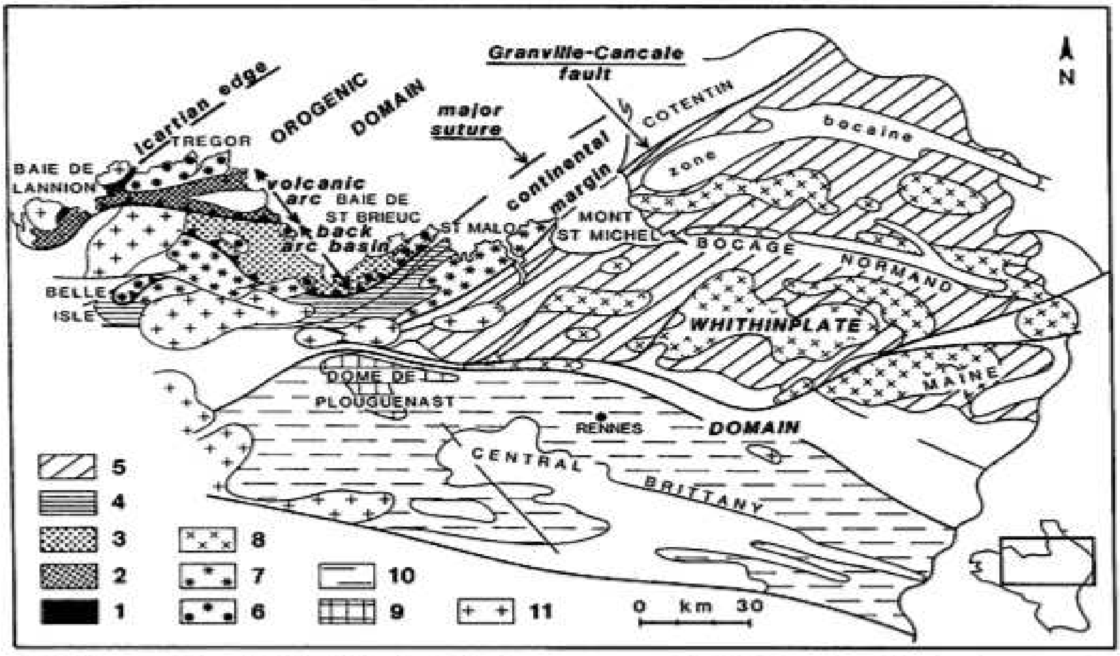

Fig. 2. Structural sketch of the Cadomian belt in the orogenic area (North Brittany) and the intraplate domain (Bocage Normand and Central Brittany). 1, Basement; 2, 3, Cadomian orogenic domain (2, island arc; 3, back arc basin); 4, 5, Cadomian continental domain (4, interbedded black chert; 5, reworked black chert); 6, Trégor granites; 7, St Malo migmatites; 8, Mancellian granitoids; 9, Dome de Plouguenast; 10, Central Brittany Brioverian; 11, Variscan granites; Unornamented, Palaeozoic cover and basin

Figure 1: Note the position of the volcanic arc and back arc zones of Baie de St Brieuc lying within the Orogenic Domain, between the subduction zone (the Icartian Edge) to the NW and the continental margin to the SE.

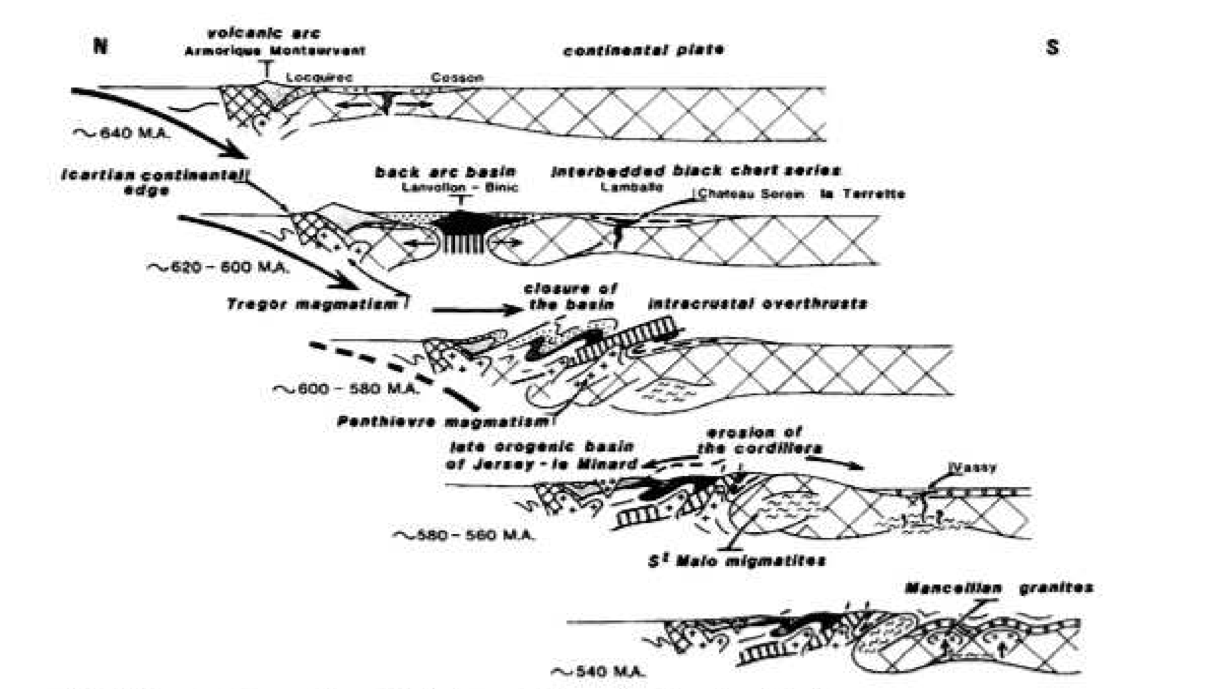

Fig. 4. Schematic interpretation of Cadomian evolution in the Armorican Massif.

Figure 2: Note how the different zones are adjacent to each other at the time of their formation (top figures) and are then gradually thrust one on top of the other, and onto the continental margin, as the mountain building progresses.

Fig 2, (also Rabu et al), attempts to show the gradual closure of this area of the Celtic Ocean during the Cadomian Orogeny – from approximately 640 to 540Ma. This sequence of events was complicated further by the oceanic plate (to the north) sliding sideways clockwise relative to the continent (to the south) along a deep vertical suture (transverse fault).

If we put the rocks we saw into this setting, then the basic volcanic rocks and ultrabasic serpentinitic rocks seen at Erquy probably represent ocean floor sequences, formed in a back arc extensional basin (see 620-600Ma in Fig 2); where the medial and proximal slope fan deposits, as at Moulin Plage, Binic and Cesson, overlying coarse pebbly debris flows (Cesson) also formed. The debris and turbidity current flows were generated by the frequent earthquakes associated with this environment. The diorite at Saint Quay represents the roots of a volcano from the island arc, seawards of this back-arc (~640Ma in Fig 2).

The continental red beds of Cap Frehel represent the undisturbed continental deposits whilst the heavily folded and contorted St Jacut migmatites represent sequences which were severely deformed during the earth movements. Note, the St Malo migmatites of St Jacut peninsular are not true basement as they are of similar age to these sequences (<650 Ma) whereas the true basement rocks are 2000 Ma (outcropping further west at Baie de Lannon).

The Jersey rocks were not visited but are part of this same basin, although interpreted to be part of a later orogenic phase (see above 580-560Ma). The Jersey Volcanic Group have been interpreted as calc-alkaline andesites and rhyolites of an island arc setting and the Jersey granites their associated magma chamber sequences, whilst the Jersey Shale Formation represents outer to medial fan turbidite deposits.

Summary of Brioverian Localities

St Jacut Peninsular - The St Malo Migmatites (Figs 3 and 4) are a series of migmatites (a mixture of foliated high grade metamorphic rocks mixed with bands of granitic igneous rocks generated by the partial melting of the metamorphic rocks to create a melt from which the granitic rocks crystallised) formed under intense heat and stress during the severe earth movements. Ptygmatic folds appear random and disconnected – they are thought to form when the rocks are very warm (hence not brittle) and non-homogeneous. The folded material represents the more viscous band and the surrounding material, being less viscous, flows around the fold. There was also good evidence of a large vertical fault; could this be a transverse fault?

At Plage de Quatre Vaux (4 valleys) there were migmatites similar to St Jacut but with thick quartz pegmatitic veins of multiple phases, which appeared to have been emplaced as a crystal mush, and now deformed, also present were possible boudinage structures.

Figure 3: Ptygmatic folds in the migmatites of St Jacut Peninsular (west).

Figure 4: St Jacut East – more St Malo migmatites

Saint Quay lies at the northern end of the western side of the Baie de St Brieuc and the sequences here include a dioritic igneous intrusion of Cadomian age, 559 Ma, with many good examples of xenoliths, and later cross-cutting granitic veins and patches (Fig 5)

Moulin Plage – steeply-dipping thick sandstones are, as Graham demonstrated, locally overturned to S. In Fig 6, these thick sandstones young from left to right. The left hand bottom corner of the picture comprises the laminated top of one turbidite, this has been cut into by the following thick proximal turbidite which occupies most of the photograph. Rip-up clasts of dark shale are just visible along the lowest part of this turbidite which is some 1.5-2 m thick. They were laid down as medial and proximal turbidites (dense flows of sand, silt and mud which flow downhill under gravity in turbulent conditions and the turbidite deposits form fans such as at the bottom of a submarine canyon. Sediment may gather on the shoreline and then flow as a mass when the earth is shaken by an earthquake, as at Aceh, Indonesia on Boxing Day, 2004, or when it becomes unstable under its own weight as at Aberfan, 1966).

Figure 5: The grey diorite intrusion at Saint Quay shows pink granitic areas and pale pink cross-cutting veins (do the pink granitic areas represent chemical alteration of the diorite, i.e. the addition of K^+ (potassium ions) to change the feldspars to orthoclase?).

Figure 6: Boudinaged quartz vein at Moulin Plage cutting through sub-vertical sandstones

Thick turbidites are normally associated with submarine fan systems, which develop along tectonically unstable coasts, often associated with subduction trench systems, such as along the modern day coast of California. Here tongues of igneous rocks similar to those seen at Saint Quay were present. Also boudinaged quartz veins were apparent (boudinage structures were common throughout the area). Boudins are formed by extension in a non-homogenous series of rocks. The rigid tabular rock (here a quartz vein within sandstones, but often a bed of sandstone within shales), is stretched and deformed within less competent rocks. The competent bed is sheared to form sausage-shaped ‘boudins’ (French for sausages).

At Binic there were similar subvertical, but relatively undeformed, sands of proximal turbidites again with shales, often contorted, forming lenses and possibly slumped, but without the tongues of igneous rocks.

Cesson – here, thick pebble layers (Fig 7) were originally interpreted as a basal conglomerate of shallow marine origin. However, if you look more closely, the pebbles lie in a mud matrix and the mud supports the pebbles, they do not support themselves, so have not been winnowed. I prefer to interpret this as a debris flow, which would complement a proximal turbidite origin for the overlying sandstones and shales. These shales and sandstones are frequently heavily deformed and sheared (Fig 8), with the degree of deformation increasing southwards, culminating in a thick subvertical mylonite zone. Mylonite is formed by recrystallisation as a result of deformation, at temperatures of 250°-350°C, typically during dynamic metamorphism, the foliation lies roughly parallel to the fault or shear zone.

Figure 7: Boudinaged pebbles at Cesson.

Figure 8: Severely sheared sequence, Cesson.

At Cap Frehel, on the eastern edge of Baie de St Brieuc, a sub-horizontal sequence of red beds (Fig 9), some cross bedded (Fig 10), others rippled, occur, indicating deposition under shallow water and the iron rich character suggesting an arid continental origin;

Figure 9: Note the flat-lying undisturbed nature of these red beds, which contrasts with the subvertical sheared nature of the turbidites seen at Cesson.

Figure 10: Close up of the red beds showing their cross bedded nature

At Erquy on the northern edge of Erquy bay, coarsely-bedded sandstones similar to those seen at Cap Frehel are present with locally well developed overgrowths forming good quartz crystals. Along the southern edge of the bay, a sequence of sediments and volcanics outcrop, which are now subvertical. The volcanic sequence exposed along the southern side of Erquy Bay comprises a sequence of relatively homogeneous bedded basalts, but other interesting features are:

- Ultrabasic serpentinitic rocks are also present (Fig 11), here apparently bedded and fractured; these probably represent oceanic crustal sediments or possibly subvertical dykes now appearing horizontal,
- Sometimes repeated volcanic activity has broken up earlier solidified lava to create clasts (Fig 12),
- Elsewhere pillow lavas are present; limonitic weathering is common, here outlining the pillows.

Figure 11: Ultrabasic serpentinitic rocks at Erquy

Figure 12: Volcanic clastsin lava at Erquy

Jersey Brioverian Sequences

I compared the Brittany Brioverian rocks with those in Jersey where the geology is also dominated by rocks of Brioverian age. The Jersey Shale Formation (~2500 m thick) is a sequence of fine-grained turbidite sandstones of a medial to distal fan setting (flow is dominantly to the north, away from Brittany), with lesser amounts of siltstone and shale, and occasional mud-rich conglomerates (Fig 13). Overlying these is the Jersey Volcanic Group (~2250 m), a sequence of volcanic rocks (dominantly andesites and rhyolites of an island arc setting) and a ploygenetic conglomerate (the Rozel Conglomerate – Fig 14) of a shallow water or continental origin (the clasts support themselves with no appreciable mud). The Jersey Shale shows multiple phases of deformation, but only low-grade metamorphism (to low greenschist facies) as in Brittany. The many granites of Jersey represent rocks from the magma chambers, below the volcanoes.

Figure 13: Jersey Shale - turbidite sequence

Figure 14: Rozel Conglomerate - continental deposit

There are multiple phases of igneous intrusion, dominantly granites and granitic rocks, with minor, older, diorites and gabbros, whereas in Brittany, the intrusions seen of equivalent age were dioritic (St Quay). Both groups of intrusive rocks are dated between 675–480 Ma and in Jersey are interpreted to have been emplaced post-deformation and -metamorphism. Both sets of igneous intrusions have produced localised thermal metamorphism with chlorite spots in the surrounding Brioverian sediments. The major faults also strike WNW-ESE in Jersey. Thus the same structural and depositional history has affected Jersey as Brittany.

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Ploumanach Granite on the Cote du Granite Rose - whilst in Brittany we visited this sequence. This granite pluton is late Variscan (290 Ma) and thus much younger than the Brioverian sequences, consequently I have kept its discussion completely separate from the other rocks.

It is interpreted as a series of intrusive fine to coarse-grained granitic bodies, formed during cauldron subsidence, with localised basic rocks in intimate association.

At Ile Tourony (Fig 15), micaceous laminae (once interpreted as 'sedimentary' structures) appeared to reflect downward dipping cone structures; I tentatively interpret these as 'fracture linings', where late-stage mica-rich fluids (possibly of a more basic lamprophyre magma) have passed up incipient fractures in the main granite.

At St Anne's beach, the acid and basic magmas co-existed at the same time as immiscible liquids (Fig 16) it appeared that the dark basic rocks formed discreet globules with an acidic feldspar-rich crystal mush and an intermediate mica-lamprophyre crystal mush 'filling the 'pore spaces' between the basic rock globules'. Whilst it is unusual for basic and acid rocks to occur together it is not unknown and they frequently appear to have come from immiscible liquids. Similar mixed basic and acidic rocks are present on Jersey and again they appear to have come from immiscible magmas. Similar Variscan-aged granite plutons occur in Devon and Cornwall.

The Kerleo quarry outcrop showed three different granites. Fig 17 shows a coarse grained granite on the left cross-cut by the finer granite on the right of the picture.

Figure 15: Micaceous laminae follow a structural junction and steeply dipping, curving cone-like features

Figure 16: At St Anne - Basic and acidic magmas

Fig 17: Kerleo Quarry -The Ploumanach granite

Figure 18: The group at St. Jacut

Thanks go to Graham Williams for organising a superb trip and also to Denis Bates for giving us the benefit of his vast knowledge and experience of this area. On behalf of the group (Fig 18), I must praise the patience and skill of the minivan drivers (Graham, Peter, Susan and Judith) and lastly Susan and Ann for their patience with us geo-enthusiasts during all weathers (mostly cold, windy but fine).

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