Structural Geology Field Trip:

Fluids & Fractures in a Triassic -Lower Jurassic Rift Basin, Somerset

Field Trip Notes
27 May 2017
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Contents

Lilstock

Park at the end of the road and follow the footpath to the beach.

Exposure 1: Fault within the Langport Member of the Blue Lias Fm (interbedded mudstones & Limestone's), Early Jurassic 190-204 ma

Rigs at Hinckley Point

Thick fault gouge, buff coloured for a modest throw normal fault. Leached, oxidised, lots of fluid through it. Foot wall on right, hanging wall on left. Clear drag seen on beds adjacent to the fault. Looks like a good seal due to a thick shale gouge, cataclasite. Secondary cement may be present.

Exposure 2: Fractured pavement

Tensile cracks normal to tension. Stresses Sigma 2 and Sigma 3 possible the same and minor flips can impact the jointing patterns such as seen. Differences in the mechanical strengths / elastic properties of the rocks (Poissons Ratio) result in more or less faulting in different beds as seen in the photographs.

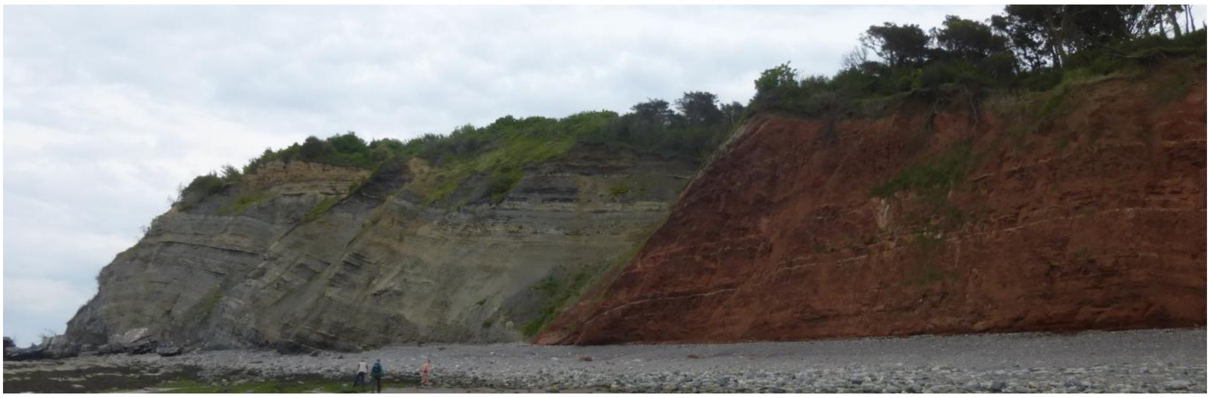
When a joint buffets against another it is younger that the joint it terminates at.
There are 3 types of joint,
fault, **far field stress** and **faults related to bending stresses**. Systematic tensile fractures on a bedding plane as seen here related to far field stress. Accommodated strain over a long time could occur during erosion of overburden and stress relief.

Good potential reservoir.

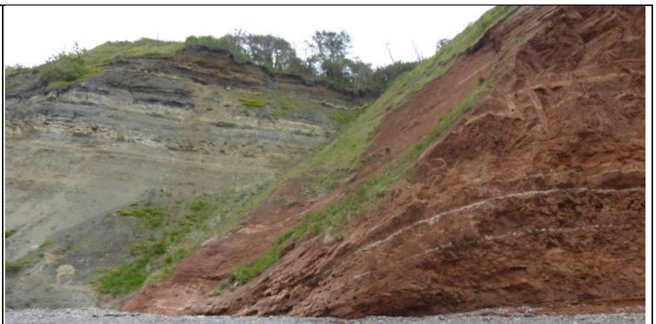
Hinckley point in the distance

Blue Anchor

Park at the west end of Blue Anchor Bay Road and make your way down onto the beach and head to the cliffs to the west.



Walking along the beach towards the cliff the fault between the Triassic Mercia Mudstone Group (red) 200-251 ma, is readily noticeable against the downthrown Triassic Penarth Group, Blue Anchor Fm (mostly mudstone) 200-217 ma



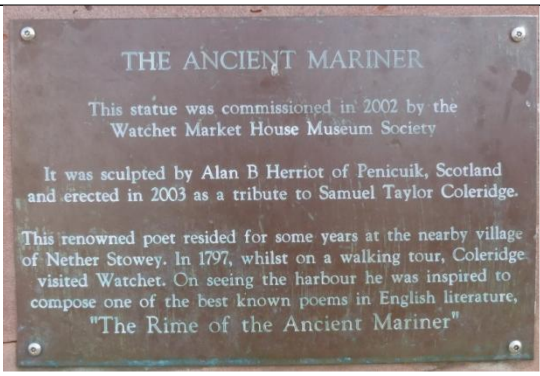
The drag of the bedding in the red beds forming the footwall of the fault is very obvious. The grey rocks exhibit noticeable bending and smaller multiple faults which can be attributed to the movement of the main fault separating the two groups.

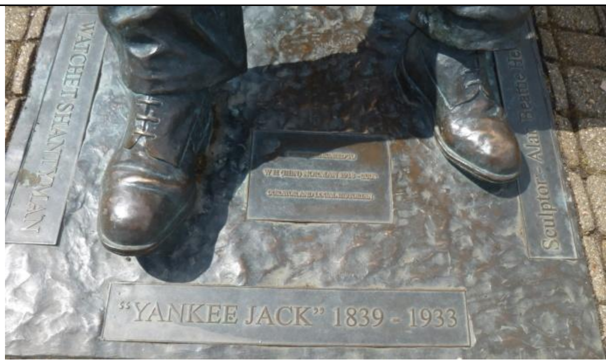
	
Significant volumes of gypsum and anhydrite are present within the Penarth Gp suggesting an oscillating environment of deposition between deltaic (dark organic rich beds), drying out sabka environment and periodic marine flooding depositing fossiliferous carbonates.	Fault plane lined with gypsum within the Penarth Gp.
	
Cliff face full of gypsum filled tension gases	Conjugate fractures ? En Echelon ? Riedal shears ? Tension Gashes filled with remobilised gypsum

A view of the Penarth Group looking back towards Blue Anchor. Bone beds (not seen) thought to be close to the top of the cliff face.

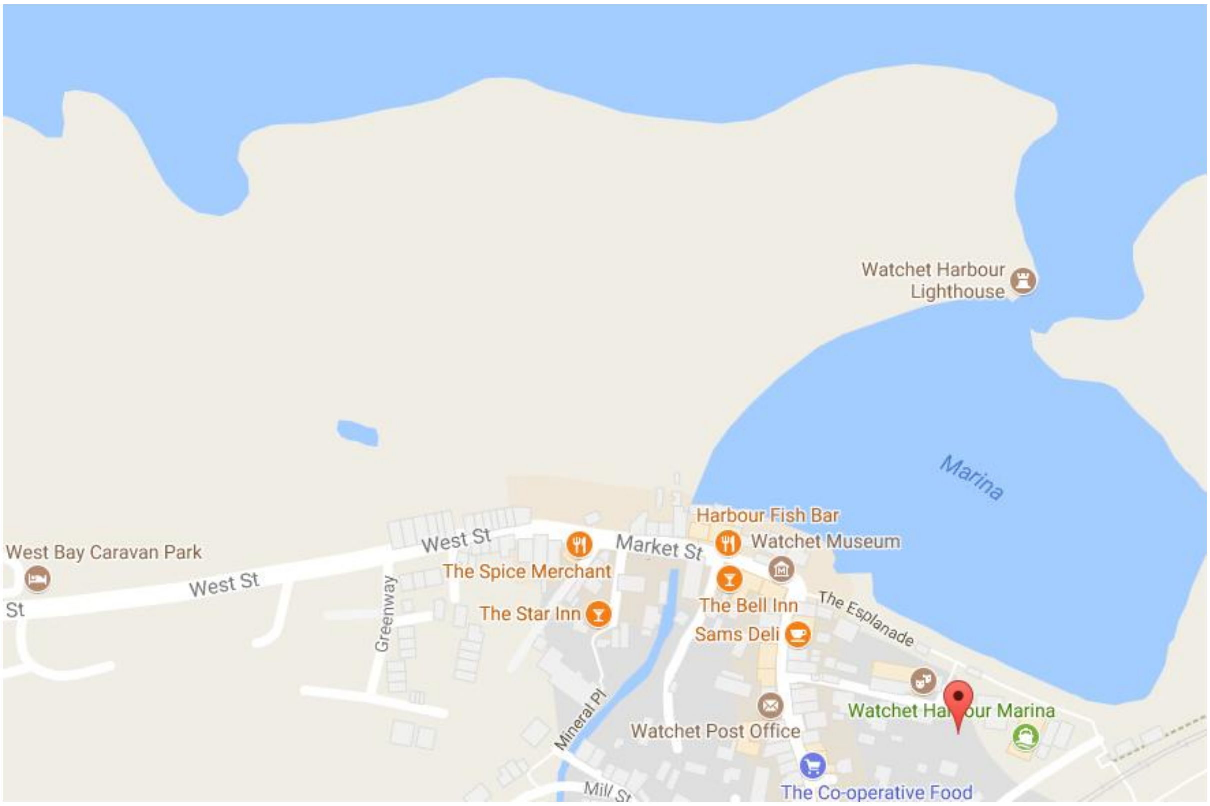
Watchet


"YANKEE JACK" 1839 - 1933


THE ANCIENT MARINER
This statue was commissioned in 2002 by the Watchet Market House Museum Society
It was sculpted by Alan B Herriot of Penicuik, Scotland and erected in 2003 as a tribute to Samuel Taylor Coleridge.
This renowned poet resided for some years at the nearby village of Nether Stowey. In 1797, whilst on a walking tour, Coleridge visited Watchet. On seeing the harbour he was inspired to compose one of the best known poems in English literature, "The Rime of the Ancient Mariner"


WATCHET SHANTYMAN
Sculptor - Alan
"YANKEE JACK" 1839 - 1933


The West Somerset Mineral Railway
The Mineral Line in Watchet
Explore the Mineral Line in Watchet
Iron ore has been mined on and off on the Brendon Hills for the past thousand years, but it was not until the 1850s that the iron mines became part of a significant industrial enterprise. This was a consequence of the Ebbw Vale Company, a long established ironworks in south Wales, developing the mines.
The West Somerset Mineral Railway was an 11 mile (18 km) long railway constructed from 1857 to 1864 to transport iron ore from the Brendon Hills to the harbour at Watchet.
From Watchet the ore was then shipped to south Wales for smelting in the Ebbw Vale furnaces. The ore found in the Brendon Hills was low in sulphur and phosphorus, and rich in manganese, which meant it was valuable for making Bessemer steel. The Bessemer process was the first inexpensive industrial process for the mass-production of steel.
At the peak of the West Somerset Mineral Railway's success more than two hundred men from Somerset and Cornwall were employed in the mines and on the railway, and they formed new communities along the "Old Mineral Line".
Although built specifically to transport ore, the railway was opened to passengers in 1865. This bold industrial venture had a profound effect on the rural landscape and local economy.
After thirty years the mines were closed due to the availability of cheap iron ore from Spain. From 1907 to 1914 parts of the line were re-opened to serve the Somerset Mineral Syndicate, the Watchet Briquetting Syndicate, and for trials of automatic train control.
The disused railway has remained a reminder of Exmoor's industrial past for the last hundred years. In 2007 the Heritage Lottery Fund awarded the West Somerset Mineral Railway Project a grant award to conserve key Mineral Line sites and improve public access.
You are standing where a horse used to pull wagons of iron ore over Market Street and onto the quay, to be unloaded into the 40 ton vessels that carried the ore to Newport in south Wales.
Follow the old line through the car park which used to be the Mineral Yard, and see where the ore was loaded on the West Pier. Visit the Museum, which has an exhibition on the Mineral Railway, and walk the trail to Washford, which follows the old Mineral Line track bed.
Panel Timezone



Park at the car park in Watchet then head west up West Street. A short way along West street there is a lane to the right which leads down to the embayment at the beach. Note The exposures are the cliffs to the west and access is not possible at high tide. Recommended that the exposures are viewed on a falling tide.

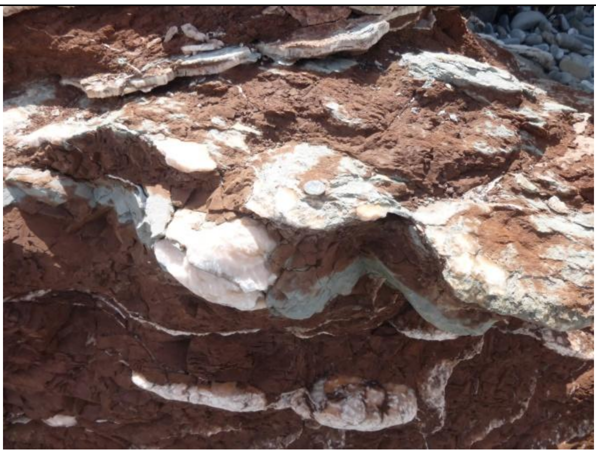
View west along Watchet Beach, Warren Bay. East west faults run parallel to the coast

Penarth Gp, Late Triassic. Supposedly was all red. Reducing saline fluids generated by hydrocarbon cracking, migrated through the higher perm layers reducing the iron oxide turning them green. Should also see along subtle cracks in the mudrocks.

Both red and green rocks are mudstone, with some silty lamina. The green rocks tend to be more laminated, but no visible permeability is evident. Unlikely conduits for saline fluids as supposedly compacted at time of saline fluid migration.

Watchet Fault acting as a buttress during inversion causing severe buckling of the beds against the fault. Compressional structures are clearly seen in the hanging wall

The Watchet fault trend is a Carboniferous NNW Lineament. with an east west component from Eocene movements. The Carboniferous movement was left lateral and the Cenozoic movement was Right Lateral.

	 Plucking suggests the red Mercia mudstones have moved downwards
	Lots of bedded gypsum (Alabaster) within the Mercia mudstone deposited as evaporites. Gypsum remobilised and re-precipetated out in hydrofractures as the fibrous satin spar variety. The fibres form parallel to opening direction of the joint being filled.

Triassic Mercia Mudstone Group, sandstone - injectite

Triassic fluvial sandstone, coarse grained, good visual porosity with probably good permeability.

Thin sand injectite in Mercia Mudstone offset by later movement and injection of saturated CaS04 fluids. Gypsum bands are commonly parallel as well as oblique to the bedding. Does this imply that the maximum stress was no longer vertical and was sufficient to lift the overburden? Surely this would require compression. Faulting here was in several directions so this could have occurred on a local basis

Faults and joints all lined with CaS04

The slickenside's on the fault occurred before the precipitation of the Gypsum rich fluids. Subsequent movement is also evident

If all 3 stresses similar then get structures without any preference of direction.

The Mercia Mudstone exposures on the wave cut platform clearly show that the bedding is dipping to the south

Hydrocarbon Discussion

Kerogen cracking results in fluid volume expansion which if restricted can lead to overpressure within the source rock. (Buoyancy pressure along microfractures during the dewatering process is likely to enable migration to occur without the shale exploding. (Hydrocarbon chimneys in the overburden are generally seen above reservoirs that have had top seal failure. I don't recollect seeing these in source rocks). Compression of the rocks can cause overpressure if not relieved by fracturing.

Beef - horizontal fibrous calcite veins sourced from source rock - decarbolicoxidation reactions, seen further south.

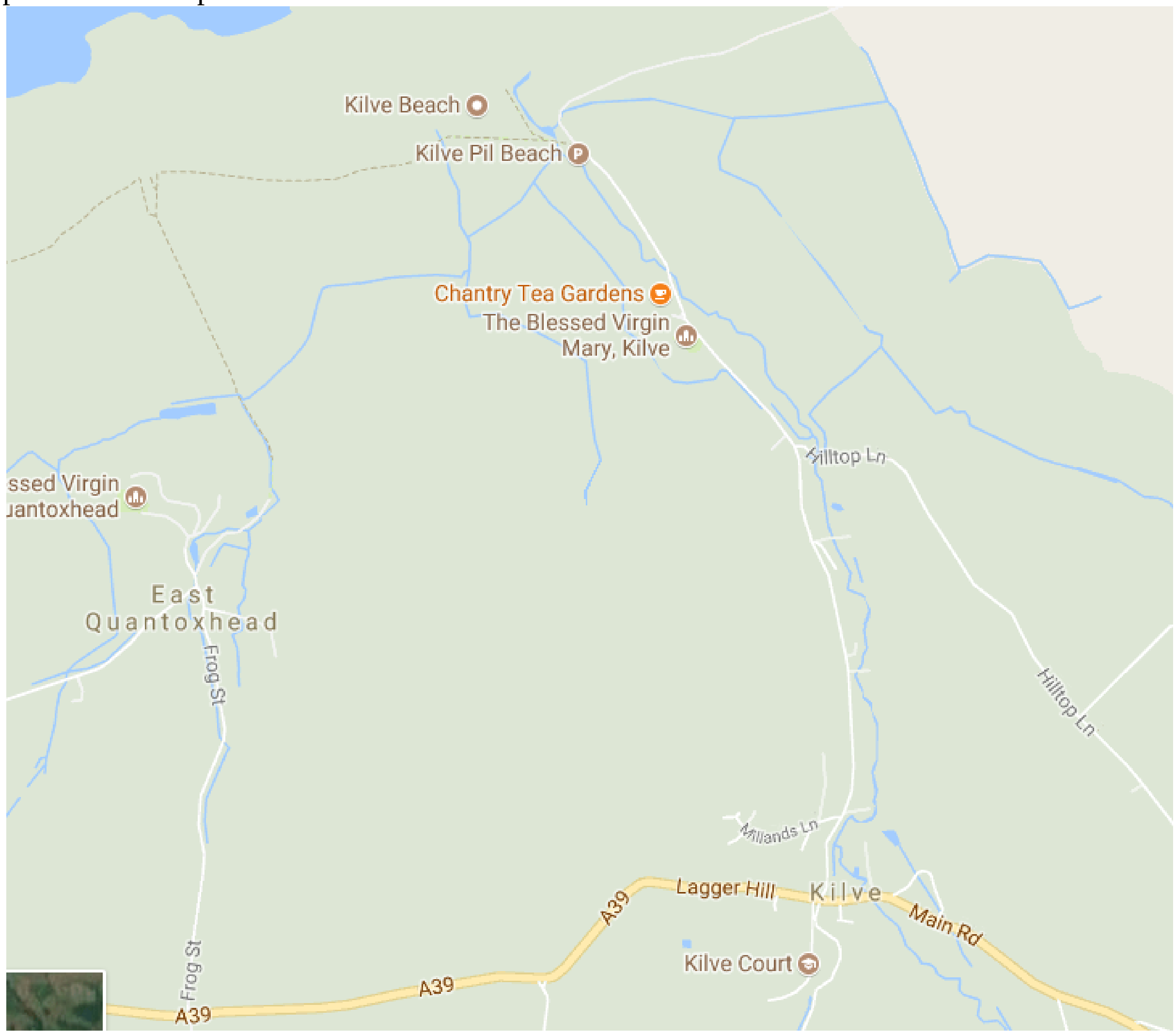
The underlying Carboniferous provides a massive kitchen to the basin

Are some of the features due to salt withdrawal as advocated by others?

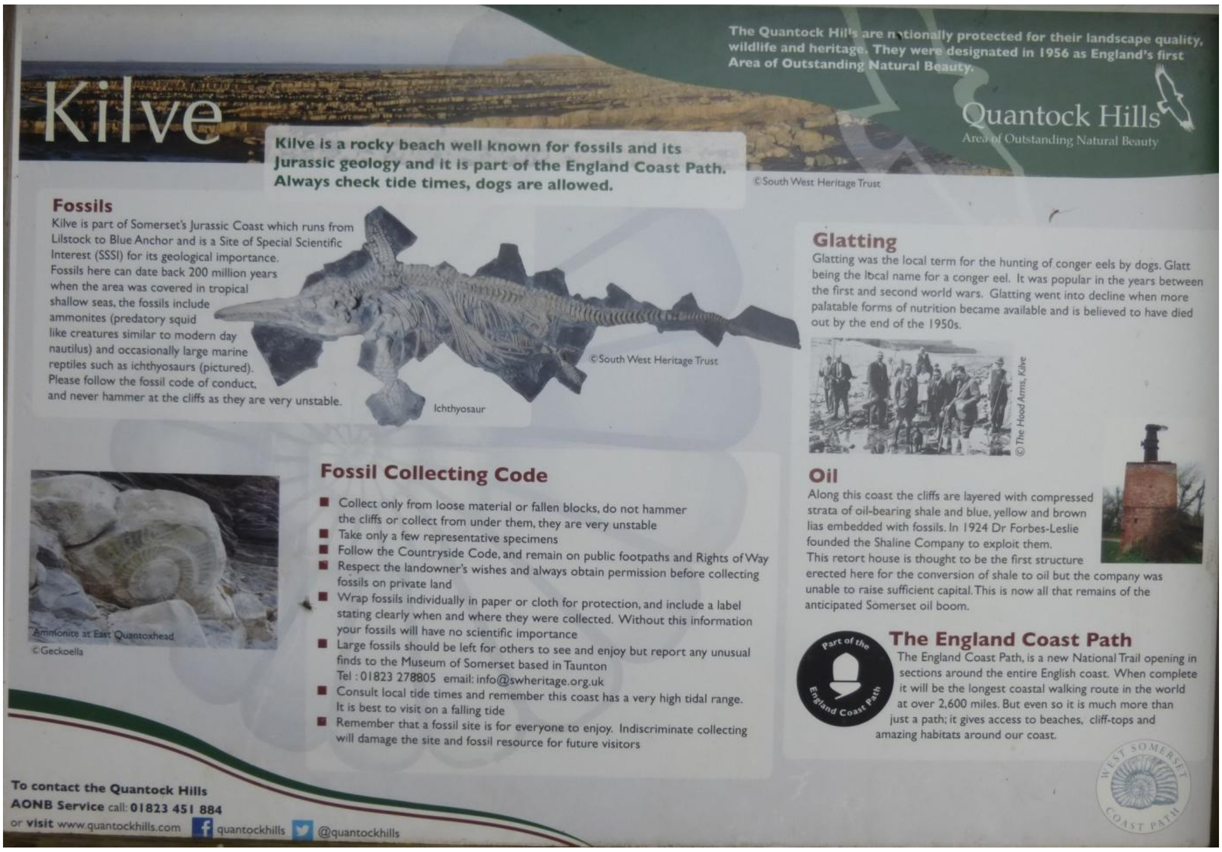
Inversion very European process and is evident in the East Irish Sea, Western Ireland Corrib field. This process tends to lead to partially filled reservoirs with breached seals.

Kilve

Turn off the A39 at Kilve and head towards Kilve Beach. At the end of the road there is a car park and a footpath leads down to the beach.



At the car park stands a disused retort for extracting oil from shales and an information sign on the diversity of interest at this location.


Kilve
The Quantock Hil's are n:tionally protected for their landscape quality, wildlife and heritage. They were designated in 1956 as England's first Area of Outstanding Natural Beauty.
Quantock Hills
Area of Outstanding Natural Beauty
Kilve is a rocky beach well known for fossils and its Jurassic geology and it is part of the England Coast Path. Always check tide times, dogs are allowed.
©South West Heritage Trust
Fossils
Kilve is part of Somerset's Jurassic Coast which runs from Lilstock to Blue Anchor and is a Site of Special Scientific Interest (SSSI) for its geological importance. Fossils here can date back 200 million years when the area was covered in tropical shallow seas, the fossils include ammonites (predatory squid like creatures similar to modern day nautilus) and occasionally large marine reptiles such as ichthyosaurs (pictured). Please follow the fossil code of conduct, and never hammer at the cliffs as they are very unstable.
©South West Heritage Trust
Ichthyosaur
Glatting
Glatting was the local term for the hunting of conger eels by dogs. Glatt being the local name for a conger eel. It was popular in the years between the first and second world wars. Glatting went into decline when more palatable forms of nutrition became available and is believed to have died out by the end of the 1950s.
© The Hood Arms, Kilve
Ammonite at East Quantoxhead
©Geckoella
Fossil Collecting Code
Collect only from loose material or fallen blocks, do not hammer the cliffs or collect from under them, they are very unstable
Take only a few representative specimens
Follow the Countryside Code, and remain on public footpaths and Rights of Way
Respect the landowner's wishes and always obtain permission before collecting fossils on private land
Wrap fossils individually in paper or cloth for protection, and include a label stating clearly when and where they were collected. Without this information your fossils will have no scientific importance
Large fossils should be left for others to see and enjoy but report any unusual finds to the Museum of Somerset based in Taunton
Tel : 01823 278805 email: info@swheritage.org.uk
Consult local tide times and remember this coast has a very high tidal range. It is best to visit on a falling tide
Remember that a fossil site is for everyone to enjoy. Indiscriminate collecting will damage the site and fossil resource for future visitors
Oil
Along this coast the cliffs are layered with compressed strata of oil-bearing shale and blue, yellow and brown lias embedded with fossils. In 1924 Dr Forbes-Leslie founded the Shaline Company to exploit them. This retort house is thought to be the first structure erected here for the conversion of shale to oil but the company was unable to raise sufficient capital. This is now all that remains of the anticipated Somerset oil boom.
Part of the England Coast Path
The England Coast Path
The England Coast Path, is a new National Trail opening in sections around the entire English coast. When complete it will be the longest coastal walking route in the world at over 2,600 miles. But even so it is much more than just a path; it gives access to beaches, cliff-tops and amazing habitats around our coast.
West Somerset Coast Path
To contact the Quantock Hills AONB Service call: 01823 451 884
or visit www.quantockhills.com quantockhills @quantockhills

Background

Carboniferous Hercynian / Variscan EW axis. The actual thrust belt 200km to the south. Serpentine (hydrated mantle) seen at the Lizard. North Somerset in the central part of the Variscan foredeep with deposition of marine clastic rocks as seen at Bude.

NS strike slip faults from Carboniferous tectonics, but are still active. Pull apart basins. Reactivated in Right lateral strike slip

During Triassic to early Jurassic there was a period of rifting. Early Cretaceous inversion took place due to rotation of the Iberian plate which created compressional stresses in this area. Fission track data suggests that the stressed were early Cretaceous (not Alpine).

Bristol channel & south Celtic sea basins sits on back of Johnston thrust (Variscan) goes down to Moho. Low angle thrust. Comes to surface in Pembrokeshire. Extension of the Variscan thrusting but later as the mountain building process running out of energy with time.

Current Alpine tectonics occurring 1200 km to the south with the collision of the African and European plates. This event does cause stress in this area and as far north as the north sea. Further north the dominant stresses are created by the opening of the Atlantic.

Faulting

Rock faces have high friction need some lubrication to move ?
Brittle deformation requires high pore pressures. Cannot occur unless effective stress is very small. Two processes suggested for the creation of high pore pressure, **inversion, hydrocarbon generation**. Compaction due to compression creates pore pressure (wringing the sponge). Pore pressure build up until seal breached then have rapid loss.

Brittle cracks open instantaneously. Was it kept open by asperities? Vein fills get nuclei keeping fracs open. Does the vein fill occur instantaneously or does it grow? 0.3micron calcite vein takes 100 hrs to fill. Fault plane mineralised grew in a shear strain field. Vein fill all calcite coming from the limestone beds. Steps in slickenside's face the direction of movement of opposite wall. As faults accumulate movement they become smoother. Faults reactivated. Generations of slickenside's

For a fracture to open parallel to surface then the pore pressure must have exceeded lithostatic. Pore pressures momently exceeding lithostatic. Lots of bedding parallel veining suggest that Sigma 1 was not vertical (for a period). *(I can only envisage this during periods of compression-RP).*

Hydrocarbons

Vitrinite Reflectance (Ro) is 0.4 in the Lias at this location which is in the in the early oil window indicating temperatures of 60-70 degrees, corresponding to circa 2 km of burial.

Vitrinite fragments are remnants of plant cell walls. Oil is generated from Ro of 0.4. Ro> 1.3 generates gas. Ro >2 -3 dry gas. Ro > 3 cooked - no further hydrocarbon production

Hydrofractures and fluid flow inter-related

Mudstones

Mudstones are deposited as laminated muds however they quickly lose their lamina due to bioturbation. Lamina within mudstones is good indicator that environment of deposition was anaerobic. The dark grey thinly laminated shales are organic rich source rock.

Strike slip faults extend out across the foreshore

Shape of syncline abutting against fault (upper left) represents displacement gradient along the fault

Faults in the Lias

The lithologies consist of organic rich marine mudstones with thin limestone beds. Secondary calcite cementation is common along faults and fractures.

EW fault. Hanging wall beds bend upwards showing fault is normal

The fault plane has secondary calcite cementation capturing the movement shown by the slickensides

Subsequent movement indicate possible local upward movement (compression) of the hanging wall as indicated by the plucking of the calcite on the footwall as shown in the picture to the left.

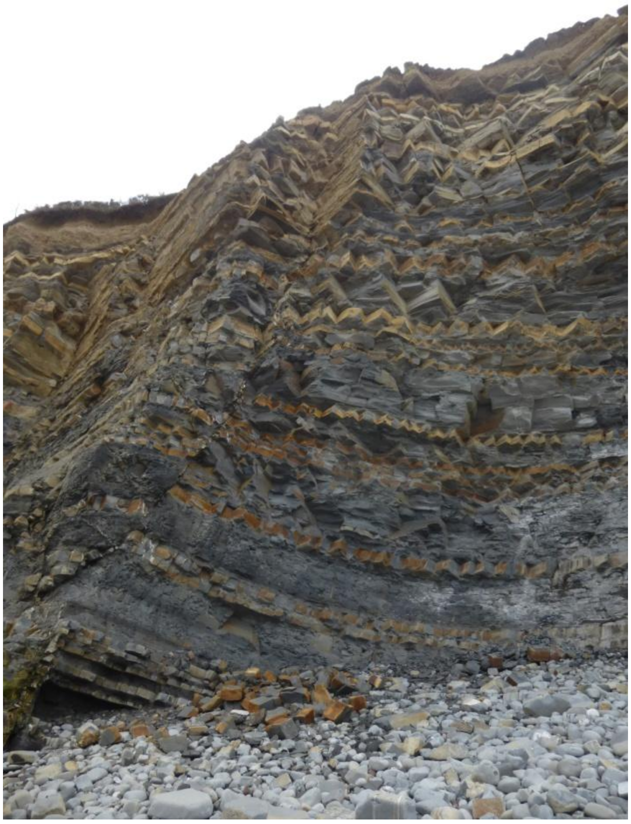
Plucking of the calcite on the footwall commonly show that the fault is normal

Clear evidence of this fault running parallel to the beach can be seen at beach level (here and to right)

Pictures of the wavecut platform from the cliffs show this fault and other parallel faults very clearly

 Very little drag seen in this exposure of the same fault being viewed above.	 Fault zone accommodating the breaking beds
	

This Liasic shale limestone sequence is clearly faulted. A normal fault with the footwall to the right and the hanging wall to the left. The fault zone is quite broad with fault planes at oblique angles to the main fault. In addition there appears to be faults running into the cliff face in a different direction to the main fault. This implies that the maximum horizontal stress direction has changed through time



The competent limestone stringers stick out like teeth. This is because 2 sets of joints are present at circa 90 degrees to each other as a result of changes in the maximum horizontal stress directions.

Calcite veining show that this piece of rock has been shattered due to stress directions in several directions. Probably a cataclasite formed along a fault.

Sand Volcanoes

Fluidised sediments (sand and clay) will inject into and through overlying sediments during compaction in order to allow the pressure build up to escape and equalise with the surrounding sediment. Such features include sand and mud volcanoes as seen here.

Relay Ramps

Faulting can create barriers in reservoirs. Commonly faults tend to generate multiple fractures and the throw of a fault is not uniform along its length. Consequently a reservoir may not have sand against sand at one end of the fault, but at the other end of the fault the reservoir is in communication due to ramps. The flow within the reservoir then tends to be tortuous. This jointed pavement shows small scale ramps

Jurassic Fossils

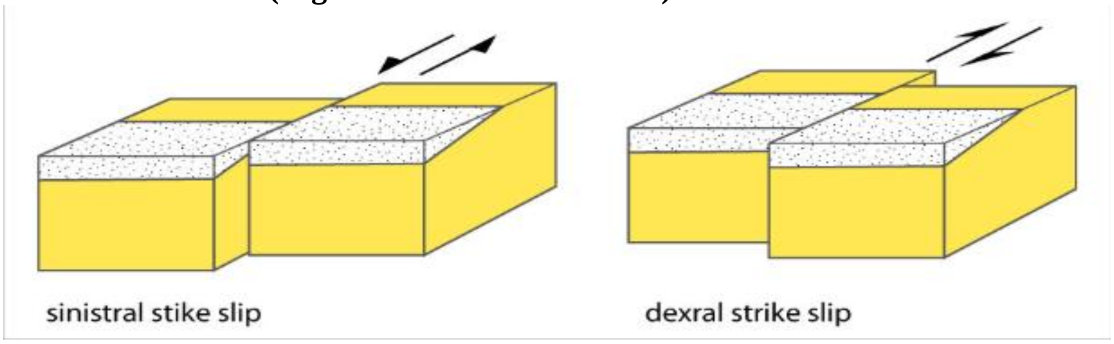




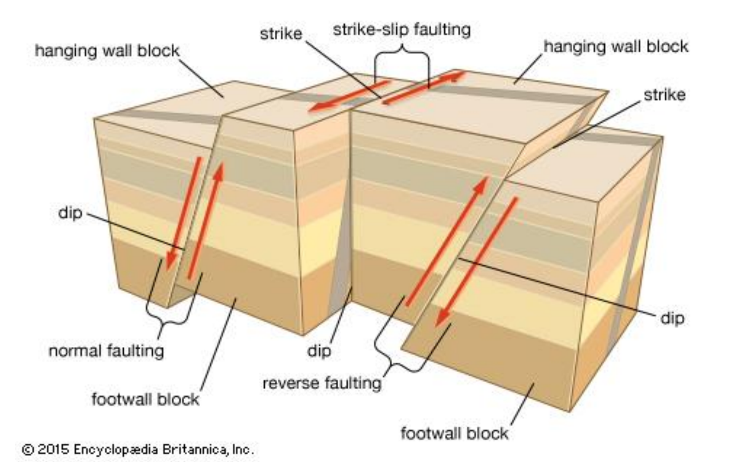


Useful Structural Geological Terms (Wikipedia)

Dextral & Sinistral (Right lateral & Left Lateral)

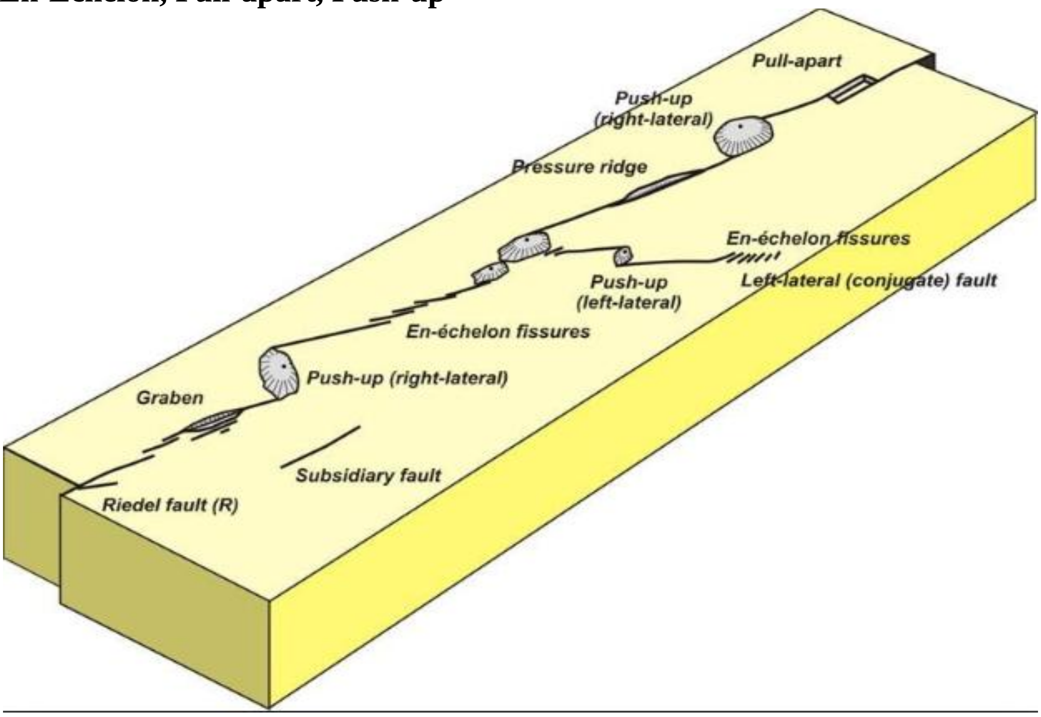


Hanging wall, Footwall & Strike-slip

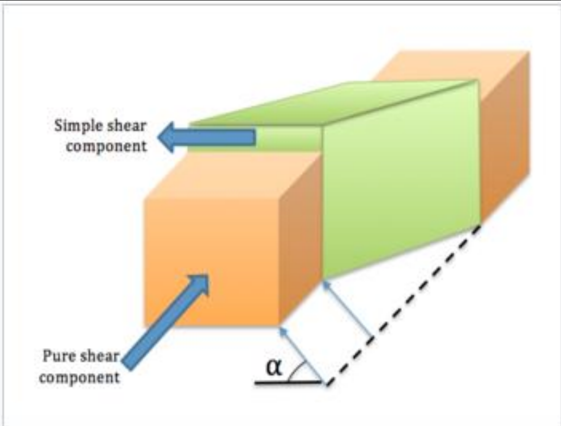


Footwall looks like a boot. The hanging wall rests on the footwall

En-Echelon, Pull-apart, Push-up



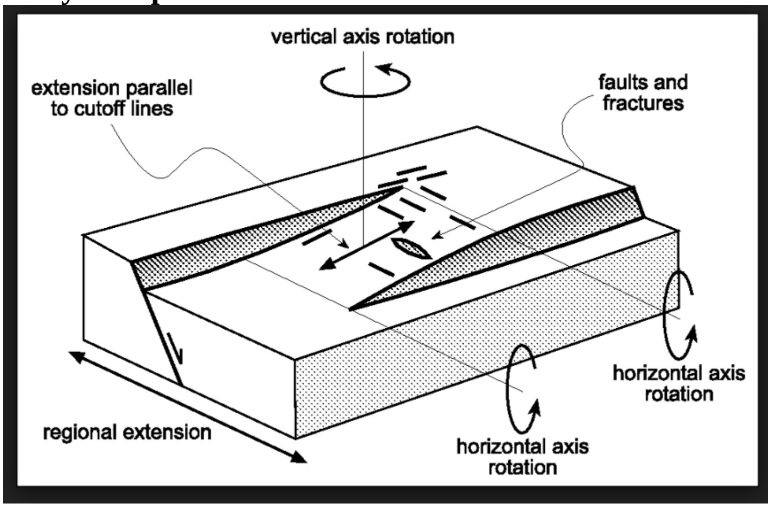
Transpression



Simple model for *transpression*: strike-slip zone with an additional and simultaneous shortening across the zone. Also induces vertical uplift.

In geology, transpression is a type of strike-slip deformation that deviates from simple shear because of a simultaneous component of shortening perpendicular to the fault plane. This movement ends up resulting in oblique shear. It is generally very unlikely that a deforming body will experience "pure" shortening or "pure" strike-slip. The relative amounts of shortening and strike-slip can be expressed in the convergence angle alpha which ranges from zero (ideal strike-slip) to 90 degrees (ideal convergence). During shortening, unless material is lost, transpression produces vertical thickening in the crust. Transpression that occurs on a regional scale along plate boundaries is characterized by oblique convergence.[1] More locally, transpression occurs within restraining bends in strike-slip fault zones.

Relay Ramps



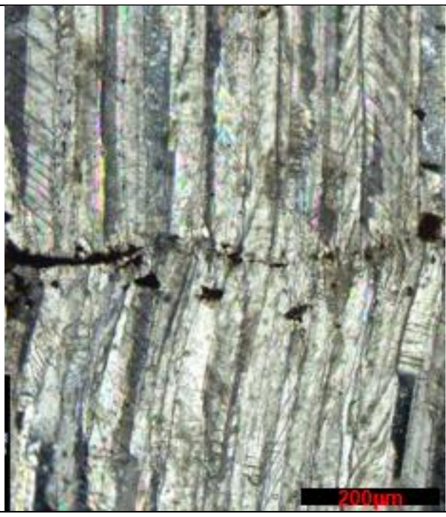
Inversion

In structural geology **inversion** or **basin inversion** relates to the relative uplift of a sedimentary basin or similar structure as a result of crustal shortening. This normally excludes uplift developed in the footwalls of later extensional faults, or uplift caused by mantle plumes. "Inversion" can also refer to individual faults, where an extensional fault is reactivated in the opposite direction to its original movement.

"Inversion is extruding the fill of a rift basin" - Jonathan Turner

Beef Calcite. Beef rock forms when calcite crystals grow like fibres usually forming flat slabs in the layers of mud.

Beef veins form symmetrically from the edge to the centre, showing crystal terminations, oil or bitumen residue, and occasionally a central open void (Fig. 1). This pattern of formation suggests that overpressure may have produced the original opening and that hot fluids attempting to escape are responsible for the formation of beef.



These results are consistent with the hypothesis put forward by Rodriques et al. (2009) that overpressure and horizontal compression was responsible for the Vaca Muerta beefs. Clumped isotope measurements of Vaca Muerta beef indicate that the calcite in the beef was formed at a temperature of approximately 110°C in concert with the burial depth of the Vaca Muerta Formation. If these calcite veins indeed represent the burial depth, the clumped isotope method would be an excellent tool to track the burial history of sedimentary basins and to assess at which depth burial diagenesis is most important.

Ref: *TEMPERATURE OF FORMATION OF THE VACA MUERTA "BEEF" DETERMINED BY CLUMPED ISOTOPES. Ralf J. Weger, Donald F. McNeill, Sean Murray, Peter K. Swart, Gregor P. Eberli, and the Vaca Muerta Team*

Cataclasite: A cohesive and non foliated rock consisting of angular clasts in a finer grained matrix formed by brittle fragmentation due to shearing along faults. It is a metamorphic rock.

Slickenside's

In geology, a slickenside is a smoothly polished surface caused by frictional movement between rocks along the two sides of a fault. This surface is normally striated in the direction of movement. The plane may be coated by mineral fibres that grew during the fault movement, known as *slickenfibres*, which also show the direction of displacement. Due to irregularities in the fault plane exposed slickenfibres typically have a stepped appearance that can be used to determine the sense of movement across the fault. The surface feels smoother when the hand is moved in the same direction that the eroded side of the fault moved, as the surface steps down in that direction, like the scales on a fish when stroked from the head.

Poissons Ratio

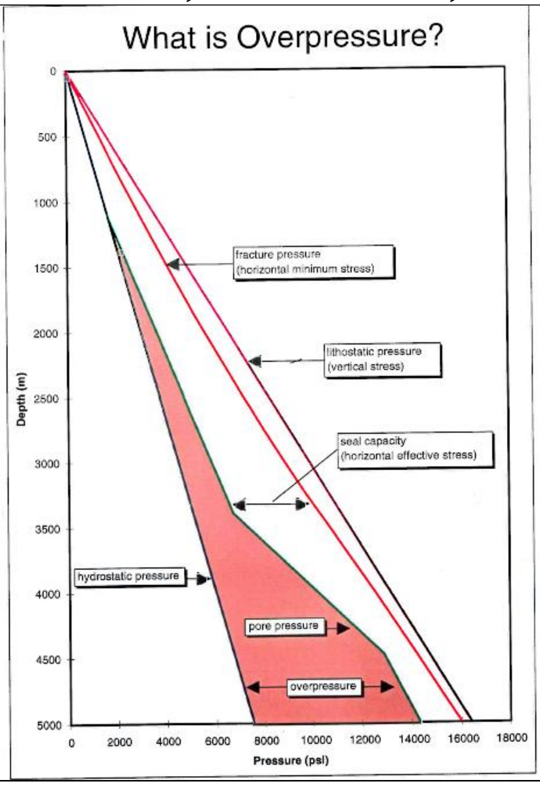
http://civilblog.org/2015/02/13/what-are-the-values-of-modulus-of-elasticity-poissons-ratio-for-different-rocks/

Poisson's ratio measures the ratio of lateral strain to axial strain at linearly elastic region. For most rocks, the value of Poisson's ratio ranges in between 0.15 to 0.40. Typical values of modulus of elasticity of some common are given in the table below.

Values of Poisson's Ratio for Some Common Rocks

Types of Rocks	Name of Rocks	Average Values of Poisson's Ratio (ν)
Igneous Rocks	Basalt	0.14 – 0.20
	Diabase	0.125 – 0.25
	Gabbro	0.125 – 0.25
	Granite	0.125 – 0.25
	Syemite	0.25
Sedimentary Rocks	Dolomite	0.08 – 0.20
	Limestone	0.10 – 0.20
	Sandstone	0.066 – 0.125
	Shale	0.11 – 0.54
Metamorphic Rocks	Gneiss	0.091 – 0.25
	Marble	0.25 – 0.38
	Quartzite	0.23
	Schist	0.01 – 0.20

Pore Pressure, Fracture Pressure, Overburden Pressure, Effective Stress



Overpressure is any pore pressure in excess of hydrostatic pressure.

The effective stress (min) is the Fracture Pressure minus the Pore Pressure at and specific depth

In relaxed basins the maximum stress Sigma 1, is the overburden (vertical) stress. The minimum stress is Sigma 3, generally accepted to be the Fracture Pressure. Sigma 2 is somewhere between Sigma 1 and 3.

Mohr's Circle
Geologists and engineers calculate normal and shear stresses from the orientation and magnitude of two of the three principal stresses using the Mohr diagram. This diagram graphically illustrates in two dimensions the complex mathematical relationships between the components that make up a traction.

A useful graphical technique for finding principal stresses and strains in materials. Mohr's circle also tells you the principal angles (orientations) of the principal stresses without your having to plug an angle into stress transformation equations.

Starting with a stress or strain element in the XY plane, construct a grid with a normal stress on the horizontal axis and a shear stress on the vertical. (Positive shear stress plots at the bottom.)

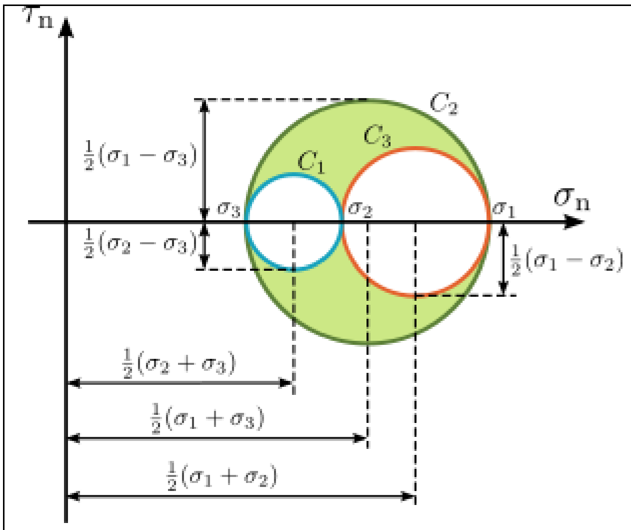
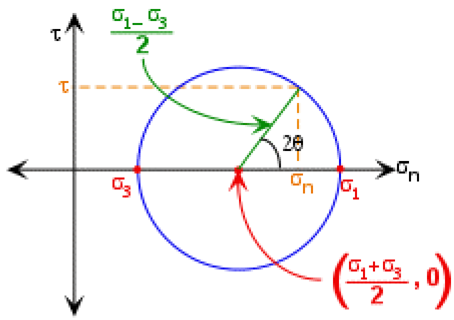


Figure illustrates a circle constructed from Equation **.** The circle represents the locus of all possible normal and shear stresses for a given state of stress acting on planes whose normals make an angle of θ degrees to σ_1.

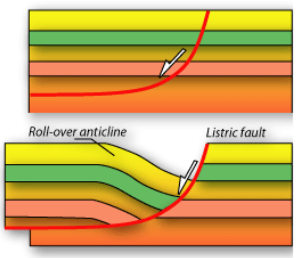


The abscissa, σ_n , and ordinate, τ_n, of each point on the circle, are the magnitudes of the normal stress and shear stress components, respectively, acting on the rotated coordinate system. In other words, the circle is the locus of points that represent the state of stress on individual planes at all their orientations, where the axes represent the principal axes of the stress element.

Mohr's circle moves to left with higher pore pressure - Jonathan Turner

Listric Faults (*www.geosci.usyd.edu.au)*

The second main type of **faults** found in extensional regimes, **listric faults** can be defined as curved normal **faults** in which the **fault** surface in concave upwards; its dip decreases with depth



Listric faults in deltaic and salt settings, not so much here - Jonathan Turner

Vitrinite reflectance *wiki.aapg.org/Vitrinite_reflectance*
This is a measure of the percentage of incident light reflected from the surface of **vitrinite** particles in a sedimentary rock. It is referred to as %R_o. Results are often presented as a mean R_o value based on all **vitrinite** particles measured in an individual sample.25 Jun 2015

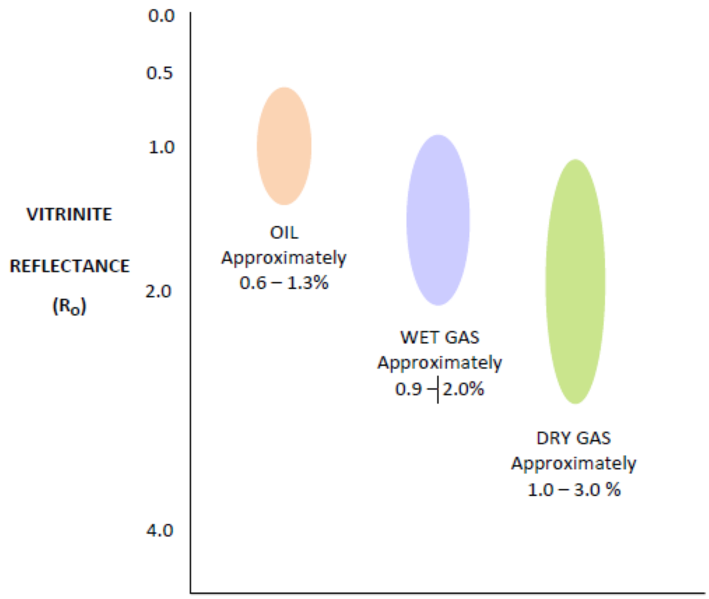


Figure 1 Vitrinite reflectance (Ro) values indicating hydrocarbon type
(based on droplet diagram first presented by W.Dow in the Journal of Geochemical Exploration 1977)

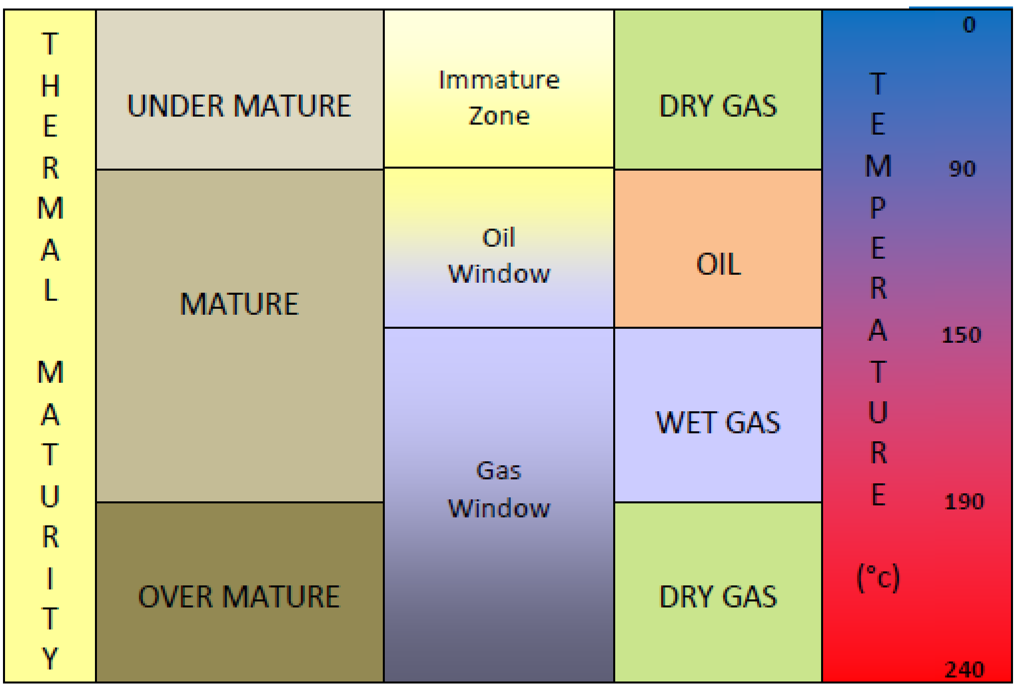


Figure 2 Maturity zones

Ref: BGS: Users Guide Vitrinite Reflectance data Open Report OR/14/055