Information Sheet 1C: Greystone Nappe: Lower Carboniferous, Lower Culm Group ('allochthon')

General description

The oldest rocks in the Meldon area are probably of very early Lower Carboniferous age and assigned to the Lower Culm Group of Ussher (1892). A combination of tectonic shearing and contact metamorphism however, has removed virtually all of their age diagnostic fossils: dating is primarily, therefore, based on lithostratigraphical correlations. The nature and origins of these rocks has been the subject of much discussion over the years and classical works on the area (e.g. Dearman, Dearman and Butcher and Edmonds *et al.* 1968) considered that the Lower Carboniferous sequence demonstrated a relatively simple succesion of 'formations', namely *the Meldon Slate-with-lenticles* (= *Shales-with-lenticles Group* of Dearman, 1959), the *Meldon Shale and Quartzite Formation* (including the '*Meldon Volcanic Beds'*; includes the *Lower Shale and Quartzite Group*, *Volcanic Group* and the *Upper Shale and Quartzite Group* of Dearman, 1959) and the Meldon Chert Formation (= the *Calcareous Group* of of Dearman, 1959).

Spectacular exposures of the Lower Culm Group in Meldon Quarry (Locality LC3) (Photo: Kevin Page 2005)

These interpretations considered that this sequence had been relatively simply folded into a broad anticline – or in the Meldon quarry area double anticline with a central syncline – inclined southwards. Geological mapping by the Univeristy of Exeter between Dartmoor and Bodmin Moor in the late 1970s and early 1980s (Sheets 337 and 338, part; British Geological Survey 1994, 1995) however, revealed a much more complex story for the Variscan in the region with well developed nappe tectonics (Issac, Turner and Stewart, 1982,

Issac 1985, etc). When applied to the Belstone-Meldon area by Selwood and Thomas (1984), this interpretation revealed the presence of the Greystone and Blackdown nappes, the former containing the

Lower Carboniferous succesion of the Meldon area, now realised to be allochthonous in origin. These nappes had been in turn folded by a later tectonic event, probably related to the intrusion of the Dartmoor granite (see Sheet 1G), to form the structure subsequently known as 'Meldon Anticline'.

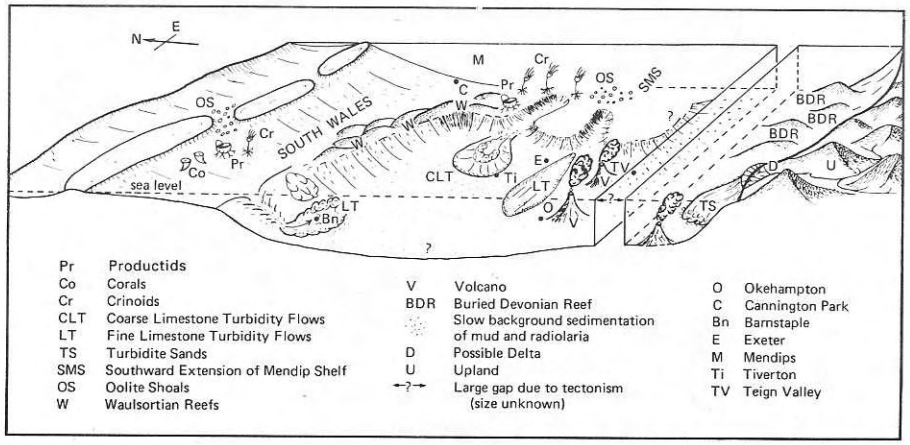
The Greystone Nappe has been described in detail by Turner (1982) at its type locality – Greystone Quarry – in East Cornwall and is believed to have been emplaced in the latest Lower Carboniferous as a result of gravity sliding from a submarine rise an unspecified distance to the south (Selwood and Thomas, 1984). Crucially, a closer re-examination of the apparent geological succession present in the area, revealed that several levels in the sequence showed the effects of intense shearing and fragmentation associated with the emplacement of nappe. In particular, the authors demonstrated that the quartzite lenticles of the Meldon-slate-with-lenticles '*Formation*', were mylonitic in origin, and that the whole unit was tectonically not sedimentologically formed by grinding, shearing and frictional heating as the Greystone Nappe slid northwards. Similar, narrower mylonitic bands are also present at higher levels in the Lower Culm Group in the Greystone Nappe, indicating that several other layers were being similarly sheared during movement.

Based on this reinterpretation, the following sequence of geological units can now be recognised in the Greystone Nappe of the Meldon – Okehampton Park district:

1. *Meldon Shale and Quartzite Formation*: This unit forms the lowest part of the geological succession of the Greystone Nappe in the Meldon area above the tectonically-generated 'slate-with-lenticles' unit. It is dominated by dark grey slates with interbedded thin, fine-grained sandstones, with an important sequence of explosive, acidic (i.e. relatively quartz-rich) volcanic rocks towards their middle, dominated by volcanic ashes ('tuffs') and 'agglomerate' – deposits full of blocks of lava and other rocks, fragmented by the eruptions (Edmonds et al. 1968). These rocks are equivalent to the Greystone Formation of the Mary Tavy–Launceston district (BGS 1994, 1995, Turner, 1982, etc.), although as the Meldon name has nomencaltural priority, the latter area should be considered as including the national type section for the unit.

Meldon Shale and Quartzite Formation in the sides of the railway cutting westwards from Meldon Viaduct (Locality LC1) (Photo: Kevin Page 2005)

The Formation was originally deposited in relatively deep seas, hence the dark shales, into which occasional turbiditic flows of sand arrived. Most volcanic activity would have been submarine although occasionally it is likely that cones of ash and agglomerate and even some lava built up on the sea floor and possibly emerged to form volcanic islands – Brent Tor, to the south-west is a possible example (Floyd et al. 1992). Due to metamorphism, no trace of fossils survive in the Meldon-Okehampton Park district, but in the Tavistock district, the Greystone Formation is known to be of early Carboniferous age (Tournaisian Series).



Palaeoenvironments of the Lower Carboniferous of the Culm Basin (after Thomas 1982). Used with the author's permission.

As the Formation in the Meldon area lies entirely within the metamorphic aureole of the Dartmoor granite, it shows varying degrees of thermal alteration. Mudrocks are typically converted into hard hornfels, but locally black shales, as in Meldon Quarry, are spotted with growths of the aluminium silicate mineral, chiastolite.

Commonly, however, the hornfels show spots of the iron sulphide pyrrortite. As in the Crackington Formation, sandstones are typically welded into quartzites and although the fragmentary texture of the volcanic rocks is often still visible, locally these rocks show a range of metamorphic minerals including biotite and garnets (Edmonds et al. 1968, p.130). The Formation is also injected by at least two doleritic dykes which are also folded and metamorphosed, indicating that they predate the emplacement of the Greystone Nappe. As with the host Formation, the dykes are also contact metamorphosed with pyroxene minerals largely replaced by actinolite and hornblende, feldspars recrystallised and amhibole replaced by biotite (Edmonds *et al.* 1968, p.131).

The most extensive exposures of the Formation are in Meldon Quarry (Locality LC3), although access to working areas is restricted for safety reasons. Elsewhere the Formation is well exposed in the West Okement river (Locality LC6), Red-a-Ven Brook (Locality LC4), the western Aplite Quarry at Meldon (Locality LC5) and the volcanic rocks form the prominent craggy ridge of South Down (Locality LC10).

2. *Firebeacon Chert Formation* (formerly 'Meldon Chert Formation'): Although described by Dearman (1959) as his '*Calcareous Group'* and later described by Edmonds *et al.* (1968) as the '*Meldon Chert Formation*', Sellwood and Thomas (1984) indicated that an appropriate name for the Formation, with priority, is the Firebeacon Chert Formation (named after Firebeacon Point, on the North Cornish Coast).

Banded cherts in Meldon Quarry (Locality LC3c area) (Photo: Kevin Page 2005)

The formation is dominated by well bedded chert, typically pale greyish in colour at outcrop. Virtually the only traces of fossils known in the Lower Culm Group of the area are moulds of siliceous radiolarian plankton from these cherts, recorded from close to Meldon Quarry by Dearman (1959), which have been recrystallised to quartz by metamorphism. The cherts suggest deep water conditions, potentially below the

Carbonate Compensation Depth (CCD) at which most calcium carbonate dissolves, the source of the silica being assumed to be derived largely from radiolarian skeletons.

View of the ridge of Lower Culm Group west of Meldon Viaduct, including the old limestone quarry in Firebeacon Chert Formation at Meldon Pool (Locality LC7) (Photo: Kevin Page 2005)

The cherts often show well developed banding for instance in Meldon Quarry (Locality LC3) and in the eastern Aplite Quarry (Locality LC21) and are interbedded with dark shales and silica-rich mudrocks. They also locally include bedded limestones which are likely to have had a turbiditic origin, probably sourced from shallower water, platform areas. These limestones were once worked at Meldon Pool (Locality 7), a flooded limestone quarry, to produce agricultural lime and probably also mortar – remains of the kilns used to produce lime are still visible (Fletcher *et al.* 1997). The only indications of any fossills in the limestones are some vague references to the mussel-like bivalve shell *Posidonomya* from Meldon Pool which probably lived attached to floating sea-weed. Away from Meldon, however, for instance near South Tawton, some ammonoids have been recorded which indicate that at least the higher levels of the cherts are of late Viséan Series age (Edmonds *et al.,* 1968).

Characteristic green garnet crystals from the Lower Culm Group (Photo: Carol Mullin)

As with the Meldon Shale and Quartzite Formation below, the Firebeacon Chert Formation lies entirely within the metamorphic aureole of the Dartmoor granite and consequently shows the effects of this extreme heating. Where the rocks are dominated by pure cherts, the effects of metamorphism are limited but where the cherts are calcareous, spectacular reactions occured, in particular where alteration by circulating superheated mineral-rich fluids produced *skarn* deposits. In Meldon Quarry these reactions formed bands of fibrous white mineral wollastonite, mixed with many other new minerals including axinite. Elsewhere, reactions with chemical-rich fluids produced deposits with other metamorphic minerals such as garnets and the very rare tin-containing sphene malayite – probably known from only one other locaility in the British Isles. In addition, where the fluids were rich in metals such as copper and iron, economically viable 'bedded' ore deposits were formed as at Red-a-ven/Meldon Mine, Forest Mine and Homerton Mine (see Sheet 1F). Fuller listings of minerals recorded in the area are included within the locality information provided below.

'Calc-flintas' – metamorphosed calcareous cherts in Meldon Quarry with veins of metamorphic minerals including Wollastonite (Locality LC3k) (Photo: Kevin Page 2005)

Meldon Quarry shows the largest exposures of the Formation although its characters are also well seen in Red-a-ven Brook (Locality LC4) and the eastern Aplite quarry (Locality LC21).

Representative exposures in the Meldon area

LOCALITY	NGR	DESCRIPTION	REFERENCES
LC1: Railway Cutting south-east of Meldon village	55999219-56319225	Exposures in cutting sides showing shales and silty shale, often spotted, with thin beds of silty quartzite, typically dipping at 20o-40o NW or NNW. 'Normal limb of northern anticline', lode casts at 56269225 indicate way up (Lower Culm Group, Lower Carboniferous, including Meldon Shale and Quartzite Formation; Greystone Nappe))	Dearman and Butcher (1959), Edmonds *et al.* (1968, pp.25, 33).
LC2: West Okement river (below viaduct)	5643924 to 56429245 (LC2a); N of 56449240 (LC2b); 56519225 (LC2d); 56499277-56429245 (LC2e).	River bed exposures in Lower Culm Group of Greystone Nappe: LC2a - Including mylonitic horizon (= *'Meldon Slate-with-lenticles'*) (hard, finely banded brown, greenish grey and purple hornfels with seems of silty quartzite) exposed for over '450 yd', bounded by faults. LC2b - Includes massive tuff and agglomerate below viaduct, with shaly hornfels with thin quartzitic bands above and below (i.e. upstream and downstream) faulted against mylonitc unit at 56449240 (Meldon shale and Quartzite Formation). LC2 - NE of Meldon Pool (=LC7), shows inverted chert and calc-silicate hornfels on the east side of the river (Firebeacon Chert Formation) dipping steeply NNW and N. LC2d - Cherty hornfels and shale also exposed near the old limekiln (central syncline) (Firebeacon Chert Formation) L2e - Normal limb of the northern anticline, showing grey and white banded chert dipping 30o-40o NNW, apparently with junction with overlying Crackington Formation (?faulted); to the S. faulted against mylonitic unit. Anticline and syncline at 56439257 and 56439257 respectively (Firebeacon Chert Formation). (Lower Culm Group, Lower Carboniferous; Greystone Nappe))	Dearman (1959), Edmonds *et al.* (1968, pp.25, 30, 41, 168, 181).
LC3: Meldon Quarry	56909270 (LC3a); 56949206-57159220 (LC3b); 57049206 (LC3c); 56919208-57009221 (LC3d); 56769242-57039252 (LC3e); 57129260-56969266 (LC3f); 56899274-57169295 (LC3g); 57129303-	Large and geologically famous active aggregates quarry showing excellent exposures through metamorphosed Lower Culm Group of the Greystone Nappe. Structural geological features are of national importance (hence designation as Meldon Quarry SSSI) (see Parkhouse 2003 for a full description of exposures in the working quarry and Information Sheet 3 for further details concerning the SSSI). General location of features recorded by Edmonds *et al.* (1968) detailed below: LC3a - Fault bounded exposures of mylonitic unit (='Meldon Slate-with-lenticles') reported in 'Middle Bay' (1968) – including isoclinally folded purplish brown slaty and banded hornfels with small lenses and laminae of quartzitic siltstone. Thin sectiuons showed a quartz-biotite-cordierite composition. LC3b - Area showed both inverted and normal limbs of the southern anticline with shaly hornfels with minor silty quartzite in the Meldon Shale and Quartzite Formation dipping 60o-80o NNW (1968).	Beer and Fenning (1976), Dearman (1959), Dearman and Butcher (1959), Edmonds *et al.* (1968, pp.25, 27, 30, 33-37, 42, 89-91, 129, 132, 168, 169, 175, 176, 181, 207; pls 3a and 5A, 10A); Parkhouse (2003), Scrivener (2003), Howie (1965), Worth (1920), etc.

	56979296 (LC3h); 57009220-57159220 (LC3l); 56809240-56989246 (LC3j); 56989295-56979298 (LC3k); 56689254 (LC3l).	LC3c - Fine grained dolerite and hornfels with common sulphide minerals recorded (1968) (Meldon Shale and Quartzite Formation). LC3d - Normal limb of southern anticline included (in 1968) hornfels in the Meldon Shale and Quartzite Formation with tuffs faulted against Firebeacon Chert Formation to the NE. Meldon Shale and Quartzite Formation also seen in northern anticline with volcanic units (tuff dominated) developed within shaly-hornfels with thin beds of silty quartzite (seen in normal and inverted limbs with dips often around 40o-70o NW/NNW). LC3e ('Gullet Back') - Included (in 1968) the inverted limb of northern anticline, and showed a similar sequence in the t Meldon Shale and Quartzite Formation to LC3d (1968). LC3f - Sample from Meldon Shale and Quartzite Formation recorded as a quartz-actinolite-biotite hornfels (1968). LC3g area - Flat-lying isoclinal folds recorded in grey hornfels overlying tuff and hornfels (Meldon Shale and Quartzite Formation) with thin Firebeacon Chert Formation above (1968). LC3h - Thinly bedded and grey hornfels with some pyrhortite and chlorite overlying dark grey chiastolite slate, again with pyrrhortite (Meldon Shale and Quartzite Formation) (1968). LC3i - Greyish-green, black and white banded cherty and calc-silicate hornfels (Firebeacon Chert Formation; northern limb of southern anticline; dip 30o S) (1968). LC3j - Greyish brown and reddish brown weathered silts and cherts with minor folding and faulting (Firebeacon Chert Formation); dips 55o-80o NW-NNW (inverted limb of northern anticline) (1968). Hornfels from the north bay of the quarry in the 1960s included quartz-feldspar-diopside-chlorite-calcite; diopside-albite-quartz-calcite, quartz-diopside-minor scapolite; and quartz-diopside-scapolite mineralogies, the last also included pyroxene-rich bands with scattered scapolite; pyrrortite also recorded. LC3k - Recorded by Dearman (1959, pp.73-75) and Edmonds *et al*. (p.42) and viewed 10/05, now corresponds to a long face on the northern side of the workings, beside a haul road. The exposure shows well bedded cherts with black and white 'calc-flintas', reported as including relatively coarse idocrase-grossularite-diopside-wollastonite hornfels with some very limited molybdenite-arsenopyrite-chalcopyrite mineralisation, and veins of white, wollastonite 'marble' with a fibrous-rosette texture. Cross-cutting calcite-heulandite veins also recorded. Additional minerals recorded from calc-silicate hornfels in Meldon Quarry included rhodonite and bustamite, with rhodochrosite, including rhodonite-bustamite hornfesl with tephroite and the managanese garnet, spessartine. Several metamorphically altered dolerite dykes are also present in Meldon Quarry and form an important part of the aggregates	

		resource at the site. Two types recorded: Type 1 = ophitic albite dolerite; Type 2 = fine grained albite-biotite rock with variable porphyritic albite). Dykes are up to at least '50 ft' thick and near the surface can show incipient 'onion-scale' weathering features. Intrusion along fault planes seems characteristic. At a microscopic scale, the metadolerites show actinolite and hornblende replacing original pyroxenes with oligoclase-andesine feldspars; accesory minerals included ilmenite – altered to leucoxene and sphene – apatite, pyrrhortite and chalcopyrite. Veins in biotitised dolerite of Type 2 have also yielded löllingite, in association with muscovite, oligoclase, schorlite, quartz and accessory apatite and carbonate. LC3l (NW corner of the quarry site) - Dolerite dyke reported intruding black hornfelsed shale and cut by small faults (1968). (Lower Culm Group, Lower Carboniferous; Greystone Nappe))	
LC4: Red-a-Ven Brook / Meldon Aplite Quarries SSSI (part)	56849201-56929182 (LC4a); 56719202 (LC4b); 56979173 (LC4c).	Inverted limb of southern anticline well exposed in the brook (characteristic dips 50o-70o to the NW or NNW), with the normal limb downstream, near the Aplite quarries (with characteristic dips 25o-40o to the NW or NNW). Includes volcanic units of the Meldon Shale and Quartzite Formation, overlain and underlain by metamorphosed shales and quartzites (Lower Culm Group, Lower Carboniferous; Greystone Nappe) LC4a area - Includes grey shaly hornfels with minor silty quartzite in the river bed and adjacent crags above the eastern bank. Thin dolerite dyke also present. Structurally overlain upstream by '190 ft' of volcanic units, including tuffs (at 56939187) and agglomerate (at 56939186) and then '75 ft' of further grey shaly hornfels with occasional thin quartzite bands (56939185-56959182) (Meldon Shale and Quartzite Formation). LC4b - Interbedded tuff and hornfels of normal limb of southern anticline present in stream between and above Aplite quarries, faulted against hornfels of inverted limb (Meldon Shale and Quartzite Formation). LC4c – Stream confluence exposes mineralised cherts with a c. 0.9-1.2m greenish-brown pyrite-rich bed with some arsenopyrite and traces of chalcopyrite (Firebeacon Chert Formation).	Dearman (1959, p.95), Dear and Butcher (1982), Edmonds *et al.* (1968, pp.26, 33, 34, 40).
LC5/A2: Meldon Aplite Quarry (west) / Meldon Aplite Quarries SSSI (part)		Exposure of normal limb of southern anticline showing shaly hornfels of the Meldon Shale and Quartzite Formation, overlain by bedded and massive tuff dipping at around 40-45o. Metasediments cut by a major aplite dyke. Narrow veins of aplitic material cut the country rock on either side of the main dyke. Hornfels locally rich in pyrhortite with axinite films in places, volcanic units locally with garnet and actinolite crystals (partly removed by mineral collectors in the late 1970s). Ferruginous, weathered fault gauge on upper bench of quarry formerly yielded quartz crystal. Forms part of Meldon Aplite Quarries SSSI (see also Sheet 1E, Locality A1/A2) (Lower Culm Group, Lower Carboniferous; Greystone Nappe).	Dearman (1959, p.93), Edmonds *et al.* (1968, pp.27, 33, 168), *per. obs*. (c. 1978-2005).
LC7: Meldon Pool	564921	Disused quarry formerly working a limstone lenticle in the Firebeacon Chert Formation – now flooded. Inverted thick-bedded recrystallised limestone with grey hornfels and shale visible in	Worth (1920), Edmonds *et al.* (1968, pp.29, 40,

		overhanging NW face, dipping at 65o. Disseminated pyrrhortite recorded. (Lower Culm Group, Lower Carboniferous, including Firebeacon Chert Formation; Greystone Nappe).	pl.3B, 168, 207),), Fletcher *et al.* (1997).
LC8: Railway cutting	56679260-56719268	Intermitant exposures of slaty hornfels with silty streaks; 37o N dip at 56699264 (Lower Culm Group, Lower Carboniferous; Greystone Nappe, including mylonitic unit (= 'Meldon Slate-with-lenticles')).	Edmonds *et al.* (1968, pp.30).
LC10: South Down	55529092 (LC4a) – 556912 (LC4b)	Surface exposures and crags dominated by volcanic unit in the Meldon Shale and Quartzite Formation(Lower Culm Group, Lower Carboniferous; Greystone Nappe) LC10a - Southern slopes show exposures of the inverted limb of the southern anticline, with banded slaty hornfels and fine-grained quartzite, structurally overlying massive tuff and agglomerate (exposed to the SE) with shaly hornfels and quartzite below. LC10b - Highest parts of South Down formed by massive and banded tuff and agglomerate, overlain by hornfelsed shale.	Edmonds *et al.* (1968, pp.31, 33, 168).
LC11/M3: Homerton Mine	55499067	Shaft and adit on west side of SW extension of Meldon Reservoir, and probably partly submerged by it. Meldon Shale and Quartzite Formation recorded with shaly hornfels and chiastolite slate. Former contains pyrite, arsenopyrite and chalcopyrite (dips 40o-50o NW). Firebeacon Chert Formation recorded subsurface (see also Sheet 1F, Locality M3) (Lower Culm Group, Lower Carboniferous; Greystone Nappe).	Dines (1956, p.752, as 'Forest Mine'}, Edmonds *et al.* (1968, pp.32, 40, 205).
LC12: West Okement River (above confluence with Red-a-ven Brook)	56429181 (LC12a); 56429185 (LC12b); 56419199 (LC12d)	Exposures in bed and banks of river show partial sequence through Lower Culm Group (Lower Carboniferous) sequence of the Greystone Nappe – majority of former section now flooded beneath Meldon Reservoir (= LC12c). LC12a - Meldon Shale and Quartzite Formation recorded in river, including hornfelsed shale with thin quarzite bands, typically with dips NW–NNW at around 70o (inverted limb of southern anticline). Volcanic units formerly exposed upstream but now submerged by reservoir. LC12b - Exposes the northern limb of the southern anticline including shaly hornfels of the Meldon Shale and Quartzite Formation dipping NW below the Firebeacon Chert Formation. To the south, boulders suggest the presence of volcanic units. LC12d - Firebeacon Chert Formation in the normal southern limb of the central syncline includes chert and cherty hornfels dipping at 25o-45o. At the confluence with Red-a-ven Brook, green calc-silicate hornfels dip at 80o S, with cherty hornfels downstream dipping at 30o-35o NW.	Edmonds *et al.* (1968, pp.32, 33).
LC13: Crags on W side of West Okement River, between dam and Meldon Pool	56379176 (LC13a), 56239209-56309217 (LC13b)	LC13a - Meldon Shale and Quartzite Formation exposed in high crags, including hornfelsed shale with thin quarzite bands, typically with dips NW –NNW at around 70o. LC13b - Shows crags of banded tuff and hornfels (normal limb of southern anticline, dipping 40o-50o NW to NNW. (Lower Culm Group, Lower Carboniferous; Greystone Nappe).	Edmonds *et al.* (1968, pp.32, 33).
LC20/M1: Red-a-ven / Meldon Mine /Meldon Aplite	57019177	Firebeacon Chert Formation dominates mine dump material. Forms part of Meldon Aplite Quarries SSSI (Lower Culm Group, Lower Carboniferous; Greystone Nappe) (see Sheet 1F, Locality	Dearman and Butcher (1959), Dearman and El

Quarries SSSI (part)		M1 for further details).	Sharkawi (1965b), Edmonds *et al.* (1968, pp.40, 132, 168, 204, 205).
LC21/A2: Meldon Aplite Quarries (east) / Meldon Aplite Quarries SSSI (part)	56719202-56789207	Dominated by Firebeacon Chert Formation, with shaly hornfels in the upper part of the Meldon Shale with Quartzite Formation present only near entrance (normal limb of southern anticline). Latter area formerly yielded common axinite. Quarry face shows up to '65 ft' of banded chert cut by branches of aplite dyke. Dip is around 30o NW. Forms part of Meldon Aplite Quarries SSSI (Lower Culm Group, Lower Carboniferous; Greystone Nappe) (see also Sheet 1E, Locality A1/A2).	Edmonds *et al.* (1968, pp.33, 40, 168).
LC22: Western end of Black Down	58109231	Banded cherty hornfels dipping at 45o N (Lower Culm Group, Lower Carboniferous, including Firebeacon Chert Formation; Greystone Nappe)).	Edmonds *et al.* (1968, pp.42).

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