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On the Kimmeridgian successions of the Normandy coast, northern France.

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ABSTRACT

Kimmeridgian rocks crop out on the Normandy coast north and south of the Seine Estuary at Le Havre in a series of small foreshore and cliff exposures separated by beach deposits and landslips. A total thickness of about 45m of richly fossiliferous strata is exposed, ranging from the base of the Baylei Zone to the middle part of the Eudoxus Zone. The sections are mostly unprotected by sea-defence works and are subject to rapid marine erosion and renewal. Taken together, the Normandy exposures currently provide a more complete section through the low and middle parts of the Kimmeridgian Stage than any natural English section, including those of the Dorset type area. Descriptions and a stratigraphical interpretation of the Normandy sections are presented that enable the faunal collections to be placed in their regional chronostratigraphical context. The Kimmeridgian succession at outcrop on the Normandy coast contains numerous sedimentary breaks marked by erosion, hardground and omission surfaces. Some of these are disconformities that give rise to rapid lateral variations in the succession: biostratigraphical studies need therefore to be carried out with particular care.

1. Introduction

The Kimmeridgian rocks of the Dorset type area and the Normandy coast are richly fossiliferous marine mudstones and limestones. Neither area exposes a complete sequence at any one time because both are subject to change due to coastal erosion and landslip. The Dorset coastal outcrops have, in the past, provided the only complete section through the Kimmeridgian Stage in the Sub-boreal Faunal Province. However, they have become progressively more degraded in recent years due largely to coast-protection works. In contrast, the Normandy coast sections have remained unprotected, and although fragmentary and subject to rapid change due to active landslipping and an extensive cover of mobile beach sediments, they are now more completely exposed than their Dorset correlatives.

In Britain, the Kimmeridgian Stage[1] is represented by the almost wholly argillaceous Lower Kimmeridge Clay Member of the Kimmeridge Clay Formation. Natural outcrops of the formation of significant size are confined to the cliffs and foreshore at Filey Bay, Yorkshire [National Grid Reference TA 142 764] and to the Dorset coast between the Isle of Portland [SY 680 730] and Kimmeridge Bay [SY 901 790]. The Yorkshire sections are highly faulted and have yielded little stratigraphical information (Wright & Cox, 2001). In south Dorset, the type area for the Kimmeridge Clay and the Kimmeridgian Stage, the highest part of the Lower Kimmeridge Clay (upper Eudoxus Zone and the Autissiodorensis Zone) is wholly exposed in continuous cliff sections (Arkell, 1947, Cox & Gallois, 1981, Callomon & Cope, 1995). The remainder of the Lower Kimmeridge Clay is poorly exposed. Low cliffs at Black Head [SY 7239 8195] and Ringstead Bay [7486 8137] provide good exposures from time to time in the basal beds (Baylei Zone and lower Cymodoce Zone), but much of the Kimmeridgian sequence above that crops out in deeply weathered and tectonically disturbed sections in the steeply dipping limb of the Purbeck Monocline.

The exposures in the Lower Kimmeridge Clay in Dorset have steadily deteriorated during the past 150 years. Waagen (1865) and Salfeld (1914) recorded sections in the Cymodoce to Eudoxus Zones at Ringstead Bay which Arkell (1933) noted were too poor to be stratigraphically useful, and Arkell (1947) himself described sections in the Eudoxus Zone that are now obscured. Much of the section in the Cymodoce to Autissiodorensis Zones measured at Black Head by Cox and Gallois (1981) in the 1970s was degraded when examined by Birkelund *et al*. (1983) a few years later. At the present time, the only well exposed Kimmeridgian sections in the Dorset type area are in the Baylei Zone and lowest Cymodoce Zone at Black Head and Ringstead Bay, small sections in the Eudoxus and Autissiodorensis Zones at Ringstead Bay, and continuous cliff sections in the upper part of the Eudoxus Zone and the Autissiodorensis Zone at Kimmeridge Bay.

[1] There are two definitions of the Kimmeridgian Stage in current use: sensu gallico and sensu anglico. The former is now the internationally recognised standard. The latter is the equivalent of the Kimmeridgian Stage sensu gallico plus the Lower Tithonian Substage. All references to the Kimmeridgian Stage in this account refer to the Kimmeridgian sensu gallico.

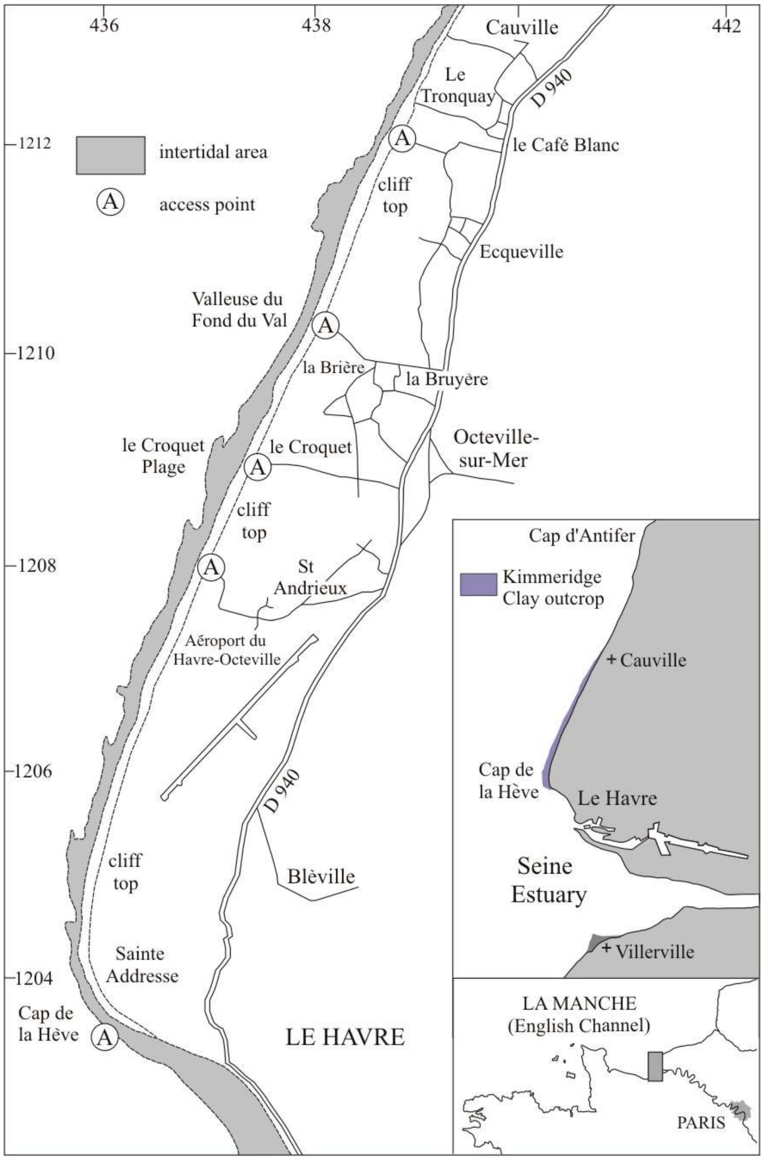

Figure 1. Geological sketch map showing the intertidal area between Le Havre and Cauville and the principal access points.

Much of the detailed stratigraphy of the Kimmeridge Clay is known from continuously cored boreholes, notably those at Warlingham Borehole, Surrey (Callomon & Cope, 1971), in The Wash area (Gallois & Cox, 1976) and in south Dorset (Gallois, 2000). These have enabled the lithological, palaeontological and geophysical data to be combined to produce a chronostratigraphical scheme that has been applied to all the onshore sections in the Kimmeridge Clay in England. The Kimmeridgian Stage (Lower Kimmeridge Clay) has been divided into 35 chronostratigraphical units (referred to as KC 1 to KC 35) (see Gallois, 2000 for summary and references therein). This framework has been used as the basis for an interpretation of the sequence stratigraphy (Taylor *et al*., 2000).

This paper gives a revised description of the Kimmeridgian succession exposed on the Normandy coast, based on a review of descriptions in the French literature amplified by fieldwork carried out by the author in the years 2000-2002. Correlations between the successions in Normandy and Dorset reveal many similarities, but also some important differences. The lithological terminology used here for the Kimmeridgian mudstones is that of Cox and Gallois (1981) in which pale-grey weathering mudstones are referred to as 'highly calcareous' (calcium carbonate contents, excluding shells and cements, 25 to 55%), and organic-rich mudstones as 'bituminous' or 'oil shale' depending on organic content.

2. Normandy localities

North of the Seine Estuary

The key sections in the Kimmeridgian rocks in Normandy crop out in discontinuous cliffs (mostly 8 to 10m high) just above high-water mark that run northwards from Le Havre towards Cauville (Fig. 1). Accurate stratigraphical measurements can be made in the cliffs, but often only in weathered material. A low undulating northerly dip (< 0.5°) in the Jurassic rocks causes them to be unconformably overstepped by almost horizontal Cretaceous rocks (the Aptian Sables Ferrugineux Formation) when traced southwards from near le Tronquay to Le Havre (Fig. 2). The Cretaceous rocks are extensively landslipped and give rise to debris that has overridden the Kimmeridgian rocks and in places has disturbed them, and the unconformity is rarely exposed.

The Kimmeridgian sections are subject to rapid marine erosion in an area with a large tidal range (up to 8m) that is subjected to high-energy Atlantic waves. Erosion rates in the intertidal area and in the lowest cliffs are high with the result that sections on the higher foreshore change rapidly due to the mobility of the sand and shingle, and in the cliffs due to the frequency of the landslip activity. In the intertidal area, the mudstones are almost entirely covered by sand and storm-beach gravels for most of the time, but when swept clean by storms, they provide fresh sections in which sedimentological and faunal details can be observed, including pyritic preservation that is commonly lost in the cliffs. These exposures are, however, unreliable for stratigraphical measurement. Where harder lithologies crop out on the middle and lower foreshores they are swept clean of recent sediment most of the time. The lithostratigraphy referred to throughout this account is that of Samson *et al*. (1996).

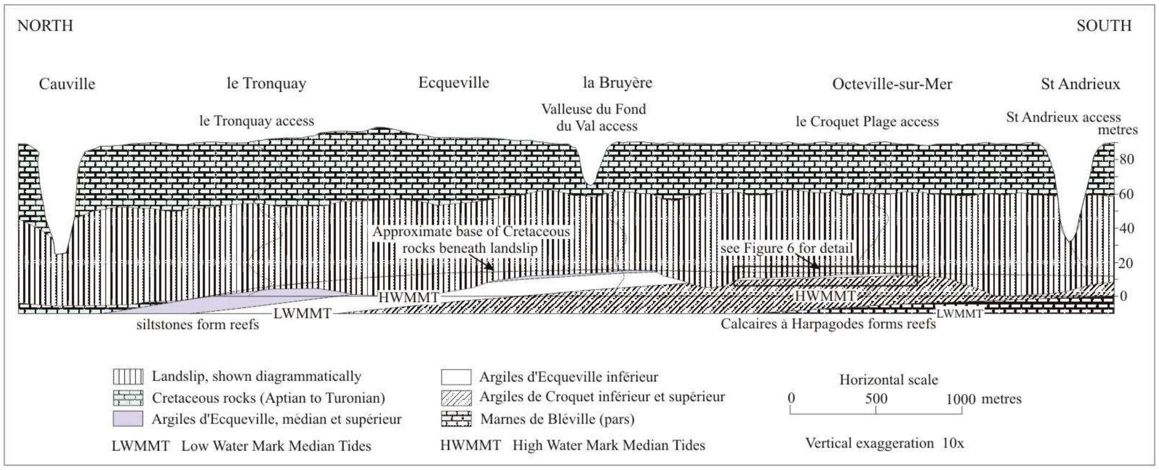

Figure 2. Geological sketch section showing the southerly overstep of the Argiles d'Octeville by Cretaceous rocks.

(i) *Cap de la Hève*

The sections in the Baylei Zone (Argiles à Deltoideum delta and Calcaires coquilliers formations) and Cymodoce Zone (Bancs de Plomb and Marnes de Bléville formations), including the oldest preserved Kimmeridgian strata, are well exposed in low *in situ* cliffs and on the upper part of the foreshore between the headland [Lambert Zone 1 Co-ordinates x=435,65 y=1203,80] and St Andrieux [x=436,70 y=1208,00] (Fig.1). Higher parts of the cliffs are in slipped and undisturbed greensands, Gault and Chalk. Access at both the southern and northern ends is via a promenade and a shingle beach, but is only safe on a falling tide.

(ii) *Le Croquet Plage, Octeville-sur-Mer*

The upper part of the Marnes de Bléville, including the junction with the overlying Argiles du Croquet inférieur, is well exposed in reefs on the lower foreshore. The Argiles du Croquet inférieur are patchily exposed on the upper foreshore beneath a veneer of highly mobile sand and gravel, and in a low cliff where their junction with the Argiles du Croquet supérieur is well exposed over a distance of several hundred metres. The full thickness of the Argiles du Croquet supérieur and the lower part of the Argiles d'Ecqueville inférieur are exposed in the same cliff. Access is by a path from a cliff-top carpark [x=437,60 y=1208,80].

(iii) *Valleuse du Fond du Val (also known as la Brière)*

Cliff and foreshore sections for several hundred metres north and south of the Chemin du Valleuse du Fond du Val [x=438,20 y=1210,25] expose the full thickness of the Argiles d'Ecqueville inférieur and médian, and all except the highest part of the Argiles d'Ecqueville supérieur. The Argiles du Croquet supérieur crops out in the intertidal zone, but is usually covered by beach deposits. Access to the sections was formerly via the 'chemin' (Samson *et al*., 1996), but in 1999 a landslip converted this into a vertical cliff with a 'cascade'. Access is now by a fisherman's path that is not for the fainthearted. Work on the beach is only safe on a falling tide.

(iv) *Le Tronquay (also known as le Café Blanc)*

Hard siltstones at the base of the Argiles d'Ecqueville supérieur form permanent reefs on the lower foreshore. Above this, the remainder of the member is obscured by beach deposits and residual landslip debris. The highest part of the member, including the youngest Kimmeridgian strata exposed on the Normandy coast, crops out on the upper foreshore and in small patches of degraded cliff. Access from the cliff top [x=439,10 y=1212,15] is by a fisherman's path that has been reasonably well maintained in recent years.

South of the Seine Estuary

(i) *Criqueboeuf*

Access to the beach [x=440,20 y=1191,20] via the Chemin de la Mer leads to patchy foreshore exposures in the Oxfordian Argiles brunes de Criqueboeuf, the Calcaires coquilliers and the Argiles à Deltoideum delta. The sections observed were too disturbed (by landslip) for accurate measurement in 2000, but have been well exposed from time to time and have been an important source of fossil material adjacent to the Oxfordian-Kimmeridgian stage boundary (e.g. Morris, 1968).

(ii) *Villerville*

The village is largely built on Cretaceous-rich landslip and Head deposits, but is fronted by a wide foreshore [x=439 y=1192] with extensive reefs that are swept free of sand from time to time. These are formed by the harder beds in the Calcaires coquilliers to Marnes de Bléville (Baylei and Cymodoce Zones). They have yielded much of the material in museum collections including the type specimens of *Rasenia erinus* (d'Orbignyi) and *R. berryeri* (Dolfuss) from the Calcaires à Harpagodes (Callomon in Cope *et al.*, 1980).

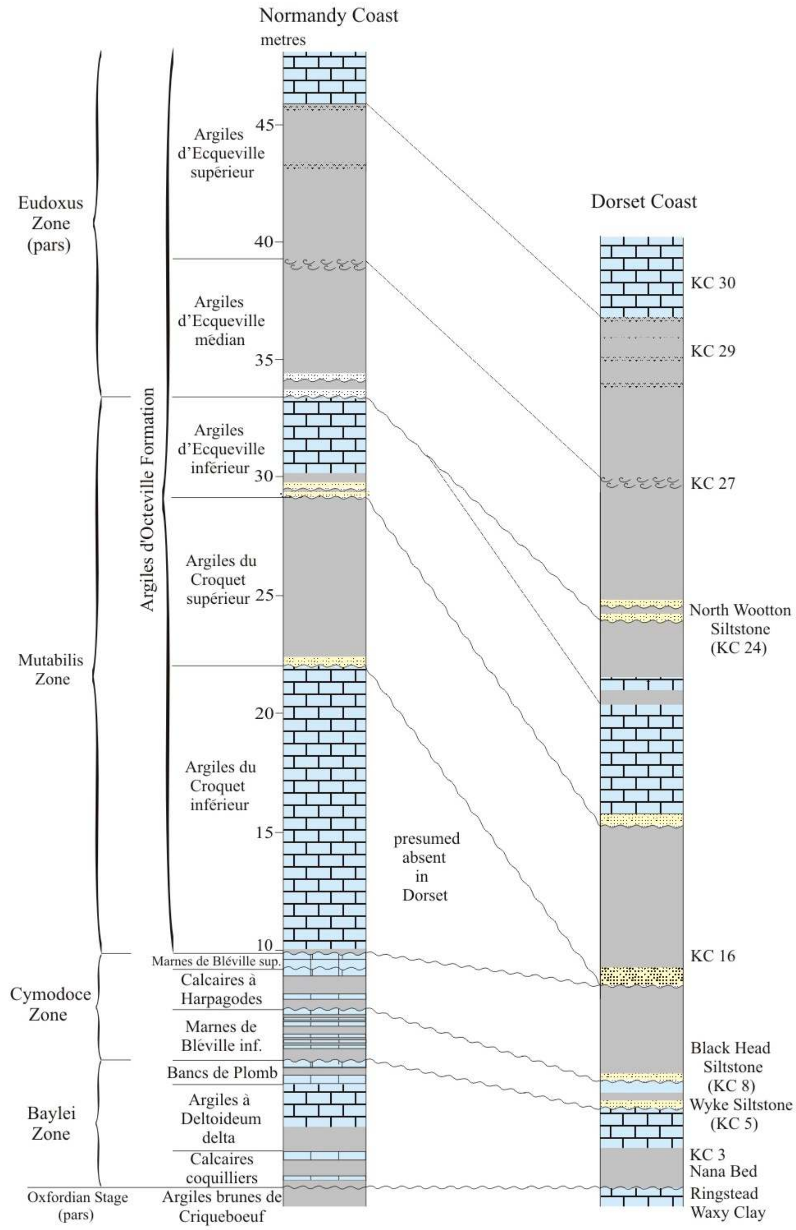

Figure 3. Generalised vertical section for the Kimmeridgian strata exposed on the Normandy coast (after Samson *et al*., 1996) and their correlation with the Dorset succession.

3. STRATIGRAPHY

The Kimmeridgian succession of the Normandy coast and its correlation with the Kimmeridge Clay of Dorset is summarised in Figure 3. The oldest part of the succession (Baylei and Cymodoce Zones) is lithologically dissimilar in the two areas. Both successions are highly condensed and contain several major erosion surfaces. Those in the predominantly calcareous lithologies of the Normandy coast give rise to prominent hardground surfaces, but those in the argillaceous Kimmeridge Clay equivalent are less pronounced. The bulk of the Kimmeridgian succession in both areas (Mutabilis and Eudoxus Zones) consists of almost wholly argillaceous lithologies in which the lithological and faunal sequences can be matched in detail. This part of the Normandy succession was named the Argiles d'Octeville Formation by Rioult and Guyader (in Mégnien, 1980), and was divided into two members (the Argiles du Croquet and Argiles d'Ecqueville) by Samson *et al*. (1996).

Stratigraphical summaries of the Kimmeridgian sequences exposed on the Normandy coast are shown in Figures 4 and 5. The lithostratigraphy is based on descriptions by Dangeard (1951), Rioult (1961), Guyader (1968) and Samson *et al*. (1996) with additions and emendations based on the sections visible in May, 2000, November 2001 and June 2002. The more argillaceous lithologies are rich in ammonites and bivalves at many levels. References to the ammonite biostratigraphy are included in the above publications with more detailed accounts in Debrand-Passard & Rioult (1980), Hantzpergue (1989) and Hantzpergue et al. (1997). Taken together, the sections north of the Seine Estuary expose about 45m of strata that range from the base of the Kimmeridgian Stage to a level within the middle part of Eudoxus Zone.

Calcaires coquilliers to Marnes de Bléville formations (Baylei and Cymodoce Zones)

The earliest Kimmeridgian sediments in Normandy, the Calcaires coquilliers to Marnes de Bléville, are richly fossiliferous and well exposed, and have attracted the attention of numerous researchers and collectors. The litho- and bio-stratigraphy were reviewed by Breton (1998) and described in detail by Samson *et al*. (1996 and references therein). The following account is a summary of these and earlier works with particular reference to the faunal and sedimentological features that enable correlations to be made with the Kimmeridge Clay of the Dorset type area.

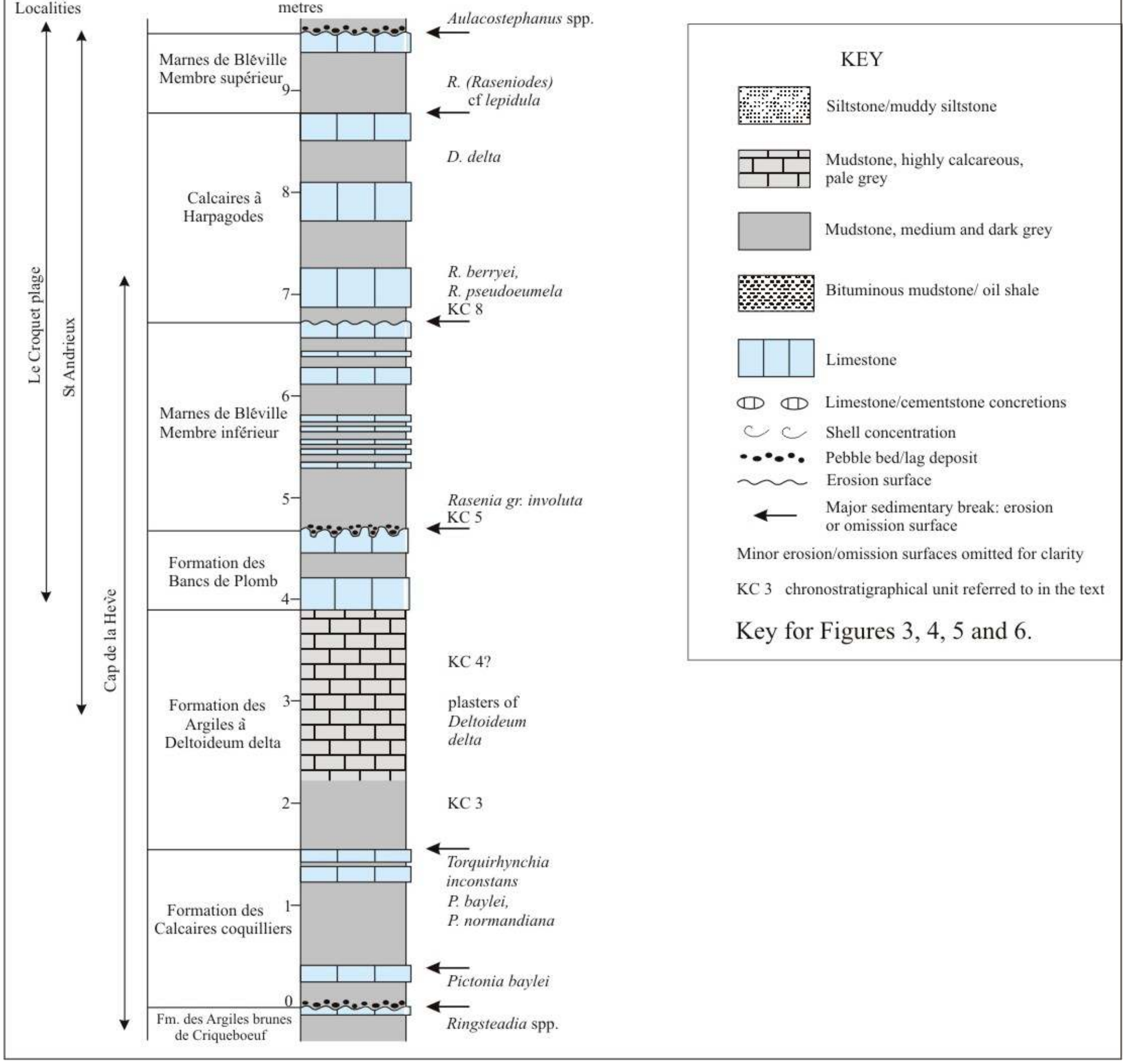

Figure 4. Baylei and Cymodoce Zones succession of the Normandy coast: Formation des Calcaires coquilliers to Formation des Marnes de Bléville (after Samson *et al*., 1996).

The total thickness of the Baylei and Cymodoce Zones strata at Cap de la Hève is about 9 m (Guyader, 1968). The thickness of the comparable beds at Black Head, Dorset is also about 9m, but the succession is laterally variable on the Dorset coast and varies from 7 to 20 m in thickness within a few kilometres (Cox and Gallois, 1981: fig 6). The Calcaires coquilliers contain *Pictonia baylei* Salfeld and *P. thurmanni* (Contejean) (Samson *et al*., 1995), a slightly younger fauna than that containing *P. densicostata*

Buckman that characterises the Baylei Zone (KC 1 to KC 4) exposures of the Dorset coast (Callomon and Cope, 1995). It suggests that the sedimentary break at the base of the Baylei Zone in Normandy is greater than that in Dorset (Hantzpergue, 1989).

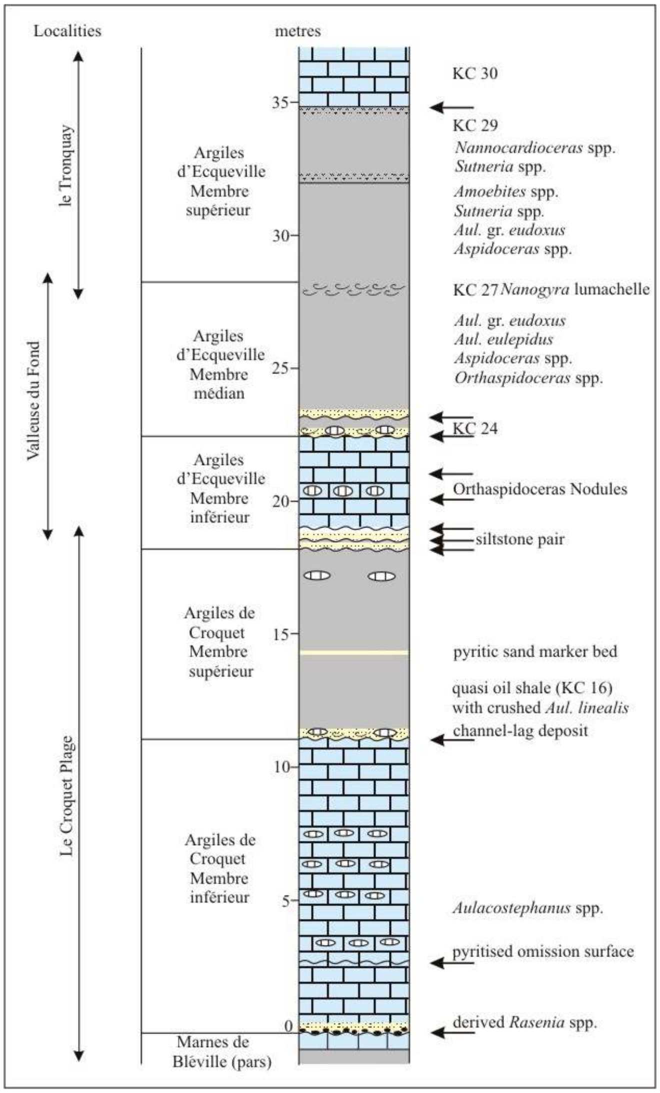

Figure 5. Mutabilis and Eudoxus Zones succession of the Normandy coast: Formation des Argiles d'Octeville (after Samson *et al*., 1996).

In Dorset, the distinctive brachiopod *Torquirhynchia inconstans* (J. Sowerby) has only been recorded from the sandy basal bed of the Kimmeridge Clay (KC 1), where it is common. In Normandy, rare specimens of *T. inconstans* have been collected from the highest part of the Calcaires coquilliers (Samson *et al*., 1995). The most obvious lithological similarity between the Normandy and Dorset successions is the dark grey mudstone of the Argiles à Deltoideum delta and its Dorset equivalent KC 3, both of which contain beds crowded with the *Deltoideum delta* (Wm Smith), many with paired valves. The presence of lumachelles composed of *Nanogyra nana* (J. Sowerby) in the Argiles à Deltoideum delta and in KC 2 in Dorset (the Nana Bed of Arkell, 1933) provides a further link.

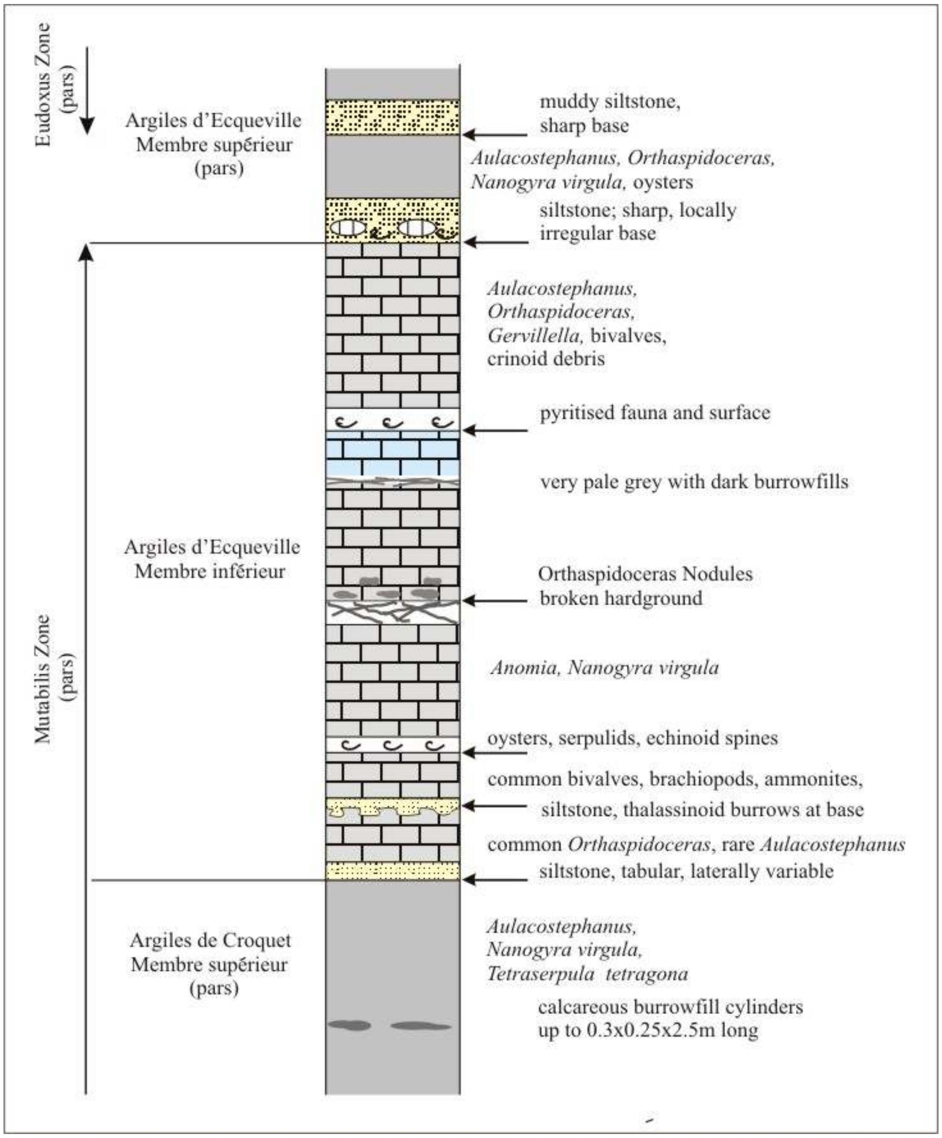

Figure 6. Detail of Argiles d'Ecqueville inférieur: additional faunal details from Samson *et al*., 1996.

The Bancs de Plomb consists of two limestone beds separated by a bed of shelly calcareous mudstone, and is the probable correlative of the highly calcareous mudstone KC 4 of the Dorset succession. The upper surface of the Bancs de Plomb is capped by a complex phosphatised and glauconitised hardground surface that has left columns and irregular masses of the limestone that have been undermined to produce pseudo-nodules. These were interpreted as limestone clasts and included in the Marnes de Bléville by earlier authors (Rioult, 1961, Samson *et al*., 1996). They are interpreted here as part of the Bancs de Plomb, and the hardground surface as the correlative of the major erosion surface at the base of KC 5 (the Wyke Siltstone) of the Dorset succession. A single specimen of *Rasenia cymodoce* (d'Orbigny), originally identified as a *Pictonia* (Rioult, 1961), has been recorded as an impression on the top surface of the Bancs de Plomb (Hantzpergue in Samson *et al*., 1996). It cannot now be said with certainty whether it came from above or below the complex erosion surface that separates the Bancs de Plomb from the overlying Marnes de Bléville.

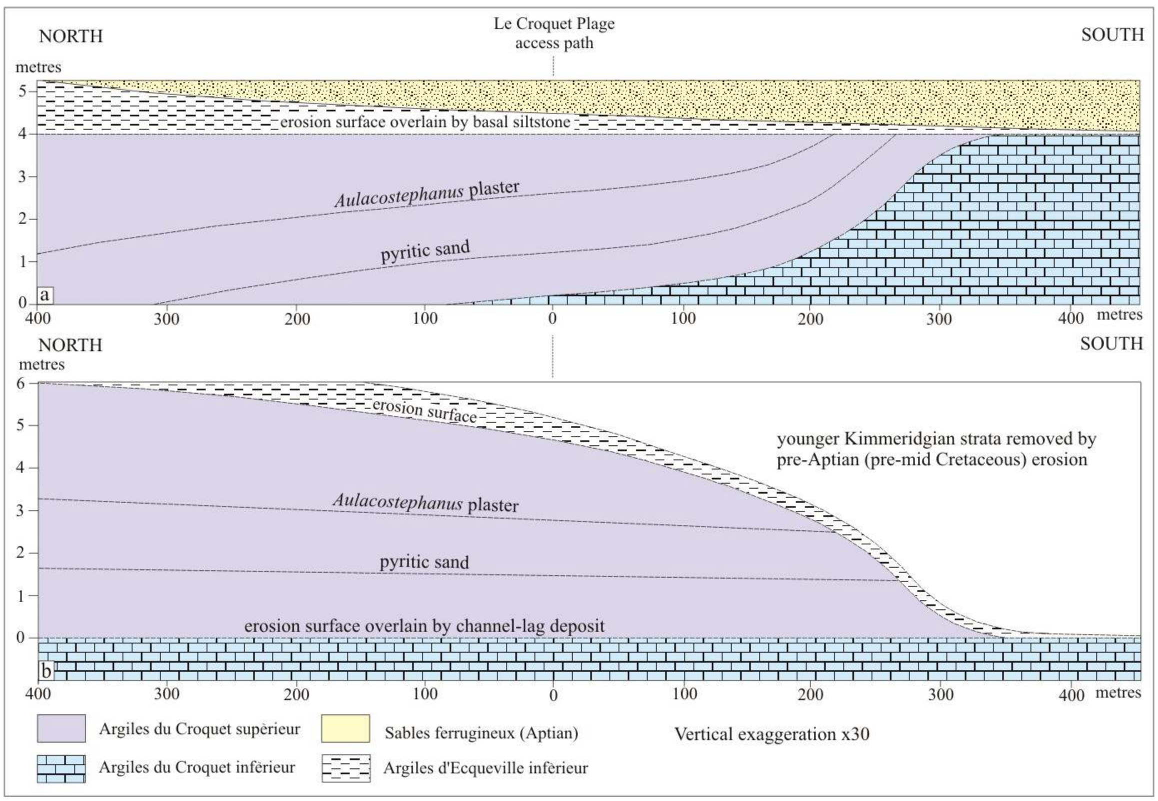

Figure 7. Erosive contact of the Argiles d'Ecqueville with the Argiles du Croquet at le Croquet Plage. a: as exposed in the cliffs b: restoration using the erosion surface at the base of the Argiles du Croquet supérieur as datum.

The Marnes de Bléville (inférieur et supérieur) and the intervening Calcaires à Harpagodes consist of thin, laterally variable beds of limestone, each capped by a mineralised and burrowed surface, separated by highly calcareous mudstones crowded with shell grit. *Rasenia* is present throughout much of this part of the succession (Hantzpergue, 1989; Hantzpergue *et al*., 1997). In England, Callomon (in Birkelund *et al*., 1978) recognised four assemblage horizons (I to IV) in the Cymodoce Zone. The oldest of these, characterised by *Rasenia* cf. *cymodoce* (d'Orbigny), is represented on the Normandy coast by the *R. cymodoce* referred to above. Horizon II, characterised by *Rasenia (R.) involuta* Spath, has been recorded from the Marnes de Bléville inférieur. Horizon III, characterised by *Rasenia (Zonovia)* gr. *evoluta* Spath is represented in Normandy by *R*. *pseudoeumela* (Tornquist) in the Calcaires à Harpagodes. Horizon IV, characterised by *R. (Semirasenia) askepta* Ziegler and finely ribbed *Rasenia (Raseniodes)* cf. *lepidula* (Oppel), is represented in the Marnes de Bléville supérieur.

Argiles d'Octeville Formation (Mutabilis and Eudoxus Zones)

The top of the Marnes de Bléville is taken at a major erosion surface that is marked by a burrowed and bored limestone overlain by a silty mudstone with common shell brash and phosphatic pebbles. The latter include casts of *Rasenia* spp. derived from the underlying beds. This erosion surface marks an abrupt upward change in Normandy from predominantly calcareous to almost wholly argillaceous lithologies.

The lithostratigraphy and biostratigraphy of the Argiles d'Octeville were described by Samson *et al*. (1996, pp. 6-14) who included a measured section for the strata visible at that time. The principal difference between that account and the present account is the recognition here of several major and numerous minor erosion surfaces in the lower and middle parts of the formation. These play an important part in the understanding of the local stratigraphy, of lateral variations within it, and the correlation with the Dorset type section. Most of the lithologies referred to by Samson as lumachelles or shelly mudstones are interpreted here as concentrations of whole and broken shells in channel-lag deposits or winnowed concentrations that rest, with or without obvious downcutting, on an erosion surface. The most striking example of this is the overstep of the Argiles d'Ecqueville across the Argiles du Croquet in the cliffs at le Croquet Plage (Fig. 6).

The following composite section was measured in 2000-2002. The more prominent marker beds, those that can be correlated with individual beds of Samson *et al*. (1996), are indicated: e.g. XI 4 to XI 6, the Nanogyra lumachelle at the top of the Argiles d'Ecqueville médian. Some of the member/sub-member boundaries have been revised downwards here to take account of the erosion surfaces.

Argiles d'Octeville Formation

Argiles d'Ecqueville Member

Argiles d'Ecqueville supérieur 6.55m seen	*Thickness* m
9 Mudstone, pale and very pale grey, calcareous; deeply weathered; decalcified traces of indeterminate bivalves and ammonites; erosion surface at base overlain by patchy concentrations of shell debris	0.50 seen
8 Mudstone, medium and dark grey with extensive network of pale grey burrowfills from bed above including low-angle *Rhizocorallium*	0.12
7 Mudstone, medium to pale grey with bioturbation mottling; sparsely shelly but with several shell plasters composed of whole and broken bivalves and ammonites including abundant *Nanogyra virgula* Defrance (large form), '*Astarte*', myids and other bivalves, *Amoeboceras (Amoebites)*, *A. (Nannocardioceras) anglicum* (Salfeld) (as whole specimens, burrowfill concentrations and shell dust) and *Aspidoceras* spp., and less common *Aulacostephanus* spp. (including *eudoxus* group) and *Sutneria eumela* (d'Orbigny)	0.50
6 Mudstone, medium grey; deeply weathered; possibly slipped in part	1.35
5 Mudstone, bituminous interbedded with oil shale; brownish grey fissile weathering; shelly with '*Astarte*', '*Lucina*', *Protocardia*, *Amoeboceras (Amoebites)* and *A. (Nannocardioceras)*	0.40
4 Mudstone, pale grey, calcareous; prominent marker bed	0.40
3 Mudstone, interbedded pale and medium grey, faintly silty; bioturbated throughout; *Aspidoceras*, *Laevaptychus* and oysters the only common fossils	2.70
2 Mudstone, bituminous, brownish grey; fissile weathering	0.32
1 Mudstone, pale grey, calcareous	0.26

Argiles d'Ecqueville médian 5.65m

5 Lumachelle, crowded with *Nanogyra virgula* (small variety) (XI 4 to XI 6); sharp base and top; pyritised *Aspidoceras* on upper surface	0.60
4 Mudstone, medium and pale grey, mottled with bioturbation; slightly silty; small oysters, serpulids, *Amoeboceras* and *Aulacostephanus* spp. (including *eudoxus* group) the only common fossils	4.10
3 Siltstone, muddy with variable calcareous cement; forms prominent pale-weathering rib; burrowed erosion surface at base	0.20 to 0.25
2 Mudstone, medium grey; abundant *Nanogyra virgula* and thick-shelled oyster debris; *Aulacostephanus* spp. and *Orthaspidoceras* spp. also present	0.40 to 0.45
1 Siltstone, tough, calcareous; forms prominent marker bed in cliffs and reefs in the intertidal area (X 13); locally densely cemented in middle part to form calcareous concretions; concentration of whole and broken shells including abundant oysters at base; resting on burrowed erosion surface	0.28 to 0.30

Argiles d'Ecqueville inférieur 4.10m

11 Mudstone, medium grey, with very common *Nanogyra virgula* in top 0.35m, less common below; sparsely shelly but with crushed *Aulacostephanus* spp. and *Orthaspidoceras* spp. at several levels	1.10
10 Mudstone, dark grey; shelly with pyritised oysters and other bivalves, serpulids and ammonites including *Aulacostephanus* spp. and *Orthaspidoceras* spp.; omission surface at base	0.15
9 Mudstone, pale grey passing up into medium grey	0.20 to 0.30
8 Mudstone, very pale grey with prominent dark grey burrowfills (X 7); forms a laterally persistent marker bed	0.05
7 Mudstone, medium grey, with a basal concentration of calcitic shell debris including *Nanogyra virgula*, other oysters and serpulids resting on an omission surface marked by a sharp colour	

change; calcareous nodules with well preserved *Orthaspidoceras* spp. (X 5) overlie calcareous burrowfill nodules in the lowest part of the bed	0.78
6 Mudstone, very pale grey with low-angle dark grey burrowfills in top 0.15m; sparse calcitic fauna with clay casts and traces of thin aragonitic shells	0.90
5 Mudstone, medium and dark grey, very shelly with prolific crushed and fragmentary fauna, pyritised in part (X 3?); abundant *Gervillella*, oysters, serpulids, fish scales, *Aulacostephanus (Aulacostephanoides) eulepidus* (Schneid) and *Orthaspidoceras*, and rarer *Trigonia*, and *Laevaptychus* as pyritic films; omission surface at base	0.10
4 Mudstone, medium grey; few fossils except for oyster-rich bed at base with common *Orthaspidoceras* and rarer *Aulacostephanus* welded to top of bed below by pyritic and calcareous cement	0.20 to 0.30
3 Siltstone, pale grey, calcareous; laterally variable; forms prominent rib (IX 9); locally with middle parting of pyritised shells including oysters, serpulids and echinoid spines; irregular base with *Thalassinoides* and other burrows	0.08 to 0.15
2 Mudstone, pale grey, weakly calcareously cemented with rare cementstone doggers (0.6x0.5x0.1m thick); almost barren; laterally variable due to erosion at base of overlying bed	0.20 to 0.30
1 Siltstone, pale grey, weakly calcareous; forms prominent well-jointed rib (IX 9); planar top with common *Orthaspidoceras* and rarer *Aulacostephanus*; bioturbated throughout; wavy, irregular base locally cuts down up to 0.1m into underlying bed; traces of very fine-grained sand locally at base; sharp lithological contrast and burrowing at base	0.10.to 0.25

Argiles du Croquet Member

Argiles du Croquet supérieur up to 6.0m seen

10 Mudstone, medium grey; pale grey in highest part; sparsely fossiliferous with *Aulacostephanus* spp.; large calcareous burrowfill nodules (up to 2.5m long) locally at base	0.85
9 Mudstone, pale grey, sparsely and very sparsely shelly; parting of very fine-grained sand at base with *Aulacostephanus* preserved as rotted brown films	1.30
8 Mudstone, dark grey; shelly with abundant crushed oysters, serpulids and *Aulacostephanus* at base including large forms up to 0.45m in diameter	0.30
7 Mudstone, medium grey passing up into pale grey; sparsely shelly	1.30
6 Mudstone, medium and pale grey; moderately shelly with well-preserved *Thracia*, oysters and *Aulacostephanus* spp. including *Aulacostephanoides* cf. *eulepidus*,	0.30
5 Sand, very fine grained, laminated; pyritic with pyrite concretions; trace fossils on upper surface; sand-filled burrows extend down 50mm into underlying bed; laterally persistent marker bed; possible omission surface at base	up to 10mm
4 Mudstone, medium and dark grey; shell plasters at top and base with abundant '*Astarte*', *Nanogyra*, *Thracia*, crushed oysters and finely ribbed *Aulacostephanoides*	0.30
3 Mudstone, interbedded pale and medium grey; locally includes lenticular siltstone up to 80mm thick; sparsely fossiliferous but with shell plasters at several levels; *Thracia*, oysters, crushed large and small *Aulacostephanus* spp.	2.35
2 Mudstone, brownish grey, weakly bituminous; laminated with fissile weathering; plasters of crushed *Aulacostephanus linealis* (Quenstedt) at several levels (IX 1); thin (50mm) lenticular bed of siltstone locally in middle part	0.40
1 Siltstone, calcareous; very prominent marker bed in cliffs (VIII 13);	

shelly and very shelly with whole and broken bivalves, brachiopods and ammonites, including common *Gervillella*, *Lopha*, *Pholadomya*, trigoniids, rhynchonellids and *Aulacostephanus* spp.; locally densely cemented to form large doggers; irregular, highly bioturbated contact overlain by concentration of shell grit and debris and pyritic and phosphatic concretions; rests with marked colour contrast on underlying bed	0.18 to 0.20
Argiles du Croquet inférieur 10.84m	
12 Mudstone, pale grey with some darker burrowfills; calcareous; deeply weathered with few fossils preserved; laterally impersistent siltstone up to 70mm thick in upper part	3.60
11 Siltstone, muddy, medium grey with septarian cementstones up to 0.2m thick (VIII 9)	0.20
10 Mudstone, pale grey with some darker burrowfills; calcareous; deeply weathered with few fossils preserved	0.80
9 Siltstone, muddy, medium grey with closely spaced septarian cementstones (VIII 7)	0.10 to 0.12
8 Mudstone, pale grey with some darker burrowfills; calcareous; deeply weathered with few fossils preserved	0.90
7 Siltstone, muddy, medium grey with clusters of septarian cementstones (VIII 5)	0.10 to 0.12
6 Mudstone, pale grey with some darker burrowfills; calcareous; deeply weathered with few fossils preserved	1.40
Mudstone, medium grey passing up into pale grey	0.30
5 Siltstone, muddy, medium grey with two (locally three) lines of septarian cementstones up to 0.2m across; most of upper cementstones nucleated on *Aulacostephanus* or bivalves	0.40
4 Mudstone, medium grey passing up into pale grey; omission surface at base overlain by concentration of shell debris and common serpulids, oysters, rhynchonellids and partially phosphatised *Aulacostephanus* spp.	0.30

3 Mudstone, pale and medium grey with bioturbation mottling	0.30
2 Mudstone, pale grey, calcareous; sparsely fossiliferous; most of outcrop concealed by beach deposits; less than 10% seen	c 2.30
1 Mudstone, silty and muddy siltstone, medium grey (VIII 1); gritty and shelly with phosphatic pebbles enclosing derived *Rasenia* spp.; preserved as cemented veneer and as infillings of the burrowed, bored and guttered surface of the underlying limestone; indigenous fauna includes oysters, other bivalves and *Aulacostephanus* spp.	up to 50mm
Marnes de Bléville Formation (*pars*)	
Limestone, muddy, shelly in part (VII 4); tough, forms prominent reef; irregular hardground surface at top	0.25

The Argiles du Croquet inférieur consist of relatively uniform, highly calcareous mudstones that weather to a soft pale grey clay. They include two or more sedimentary breaks marked by winnowed shell-grit horizons, and several lines of septarian concretions. The principal exposures, on the foreshore at Le Croquet Plage, are largely covered by beach deposits most of the time. The section described here (measured in 2000) is more complete than those described by Rioult (1961) and Samson *et al*. (1996), but adds little new stratigraphical information. The mudstones are sparsely fossiliferous, but the presence of poorly preserved *Aulacostephanus mutabilis* (Sowerby) throughout much of the succession is indicative of the Mutabilis Zone.

The sub-member is overlain, probably disconformably, by a richly fossiliferous channel-lag deposit that is here placed at the base of the Argiles du Croquet supérieur. This distinctive bed is well exposed over a distance of about 350m southwards from the access path at Le Croquet Plage. At 250m north of the path, temporary sections in a slipped mass showed the erosion surface to be underlain by a complexly fractured, burrowed and bored hardground. This was overlain by dark grey mudstone crowded with shell grit (0.30m) and a pyritised bivalve lumachelle (0.10m) with common pieces of wood. The basal bed of the Argiles du Croquet supérieur is overlain by fissile, bituminous mudstones that are locally crowded with crushed *Aulacostephanoides linealis* (Quenstedt) (Samson *et al*., 1996, fig. 17), a distinctive combination of lithology and fauna that can be closely matched with KC 16 of the English succession. This indicates that the underlying erosion surface is the correlative of that at the base of KC 15. It implies that erosion at this level in England has removed any representative of the Argiles du Croquet supérieur and that the Normandy succession is more complete at this stratigraphical level than any yet recorded in England.

The Argiles du Croquet supérieur contain several laterally persistent, distinctive lithologies that enable the local stratigraphy to be interpreted. In the middle part of the sub-member, a thin (up to 10mm thick) bed of bioturbated pyritic sand and an *Aulacostephanus* plaster can be used to demonstrate the nature of the local overstep of the Argiles d'Equeville across the Argiles du Croquet supérieur (Fig. 6). Samson *et al*. (1996, p.14) recorded a thickness variation of 0.2 m to 9 m in the Argiles du Croquet inférieur. The thickest preserved succession beneath the overstep crops out on the lower foreshore 800 m north of the Valleuse du Fond access: it was not exposed at the time of the present work.

The Argiles d'Ecqueville inférieur is an incomplete, condensed succession of calcareous mudstones and siltstones with at least five erosion surfaces and several omission surfaces marked by bioturbation, mineralisation (mostly pyrite) and concentrations of shell debris. *Orthaspidoceras* spp., including *O. lallierianum* (d'Orbigny) and *O. orthocera* (d'Orbigny) are abundant at several levels including one in which complete specimens are well preserved in calcareous concretions that form a laterally persistent marker bed. *Aulacostephanus* including *Aul. mutabilis* (Sowerby) and *Aul*. (*Aulacostephanoides) eulepidus* are also present. The fauna is indicative of the upper part of the Mutabilis Zone. The profusion of *Orthaspidoceras* can be matched with a similar abundance at this stratigraphical level on the Dorset coast (Van der Vyver, 1986).

An erosion surface at the base of the Argiles d'Ecqueville médian marks a change to more stable depositional environments in which a few omission surfaces are present, but disconformities are probably absent. At the top of the sub-member a lumachelle composed largely of the oyster *Nanogyra virgula* can, surprisingly, be matched in lithological and faunal content with a similar bed at the same stratigraphical horizon (KC 27) throughout the English Kimmeridge Clay. The lumachelle crops out almost continuously from about 250 m to 900 m north of the Valleuse du Fond access path where it is the youngest prominent marker bed in the Normandy cliffs. Northwards from there, sections in stratigraphically higher beds are intermittently exposed in the intertidal zone and in low cliffs that are mostly disturbed by landslip. The youngest Kimmeridgian strata currently exposed on the Normandy coast are deeply weathered shelly mudstones, oil shales and highly calcareous mudstones with species of *Amoeboceras*, *Aspidoceras*, *Aulacostephanus* and *Sutneria*, the correlatives of KC 29 and KC 30 of the English succession.

4. Summary and Conclusions

Because of their continual renewal by marine erosion, the Normandy sections currently provide the best natural outcrops of the lower and middle parts of the Sub-boreal Kimmeridgian Stage. In addition, they lie close to the carbonate-rich Sub-tethyan sections of the Berry region (Debrand-Passard and Rioult, 1980) and offer a better prospect than any English section for inter-provincial correlation at this stratigraphical level. The descriptions and stratigraphical interpretation presented here are designed to enable the extensive faunal collections made from the Normandy sections to be placed in their regional chronostratigraphical context. The sections are richly fossiliferous and provide the opportunity to improve our knowledge of the biostratigraphy, particularly that of the Mutabilis Zone which is probably stratigraphically more complete in Normandy than in England. Large-scale plots of the sections have been placed on open file with Dorset Group of the Geologists' Association and the Muséum d'Histoire Naturelle in Le Havre.

The older part (Baylei, Cymodoce and Mutabilis Zones) of the Kimmeridgian succession at outcrop on the Normandy coast is highly condensed. It contains numerous sedimentary breaks marked by erosion, hardground and omission surfaces. Some of these are disconformities that give rise to rapid lateral variations in the succession: biostratigraphical studies need therefore to be carried out with particular care. The later part of the succession (Eudoxus Zone) contains fewer sedimentary breaks and can be correlated in lithological and faunal detail with the English succession.

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