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Correlation of the Kimmeridgian successions of the Normandy coast, northern France with those of the Dorset type area, southern England.

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Abstract

The Kimmeridgian Stage is represented in the cliffs of the Dorset type area and those in Normandy by richly fossiliferous marine mudstones and limestones. Taken together, these coastal exposures provide the only complete composite outcrop through this part of the Jurassic in the Sub-boreal Faunal Province. Detailed correlations between the two successions are presented here: these enable the Normandy-coast sections to be placed in their regional chronostratigraphical context. The Normandy outcrops are situated midway between those of the Dorset coast and Tethyan Faunal Province sections of the Loire Valley, and therefore offer a better prospect than any English section for inter-province correlation at this stratigraphical level.

1. Introduction

In England, the Kimmeridgian Stage is represented by the almost wholly argillaceous Lower Kimmeridge Clay Member of the Kimmeridge Clay Formation. The type sections of the formation and the stage are cliff outcrops on the south Dorset coast between the Isle of Portland (National Grid Reference SY 680 730) and Kimmeridge Bay (SY 901 790) (Figure 1). The highest part of the Lower Kimmeridge Clay (the upper part of the Eudoxus Zone and the Autissiodorensis Zone) and the whole of the Tithonian Upper Kimmeridge Clay (Elegans to Fittoni zones) are exposed in continuous cliff sections at Kimmeridge Bay. The remainder of the Lower Kimmeridge Clay is poorly exposed. The proposed World Stratotype Section for the Oxfordian-Kimmeridgian Stage Boundary at Black Head (SY 7239 8195) and that at nearby Ringstead Bay (SY 7486 8137) provide good exposures from time to time in the basal beds of the Kimmeridge Clay (Baylei Zone and lower part of the Cymodoce Zone), but much of the succession above that is poorly exposed and deeply weathered.

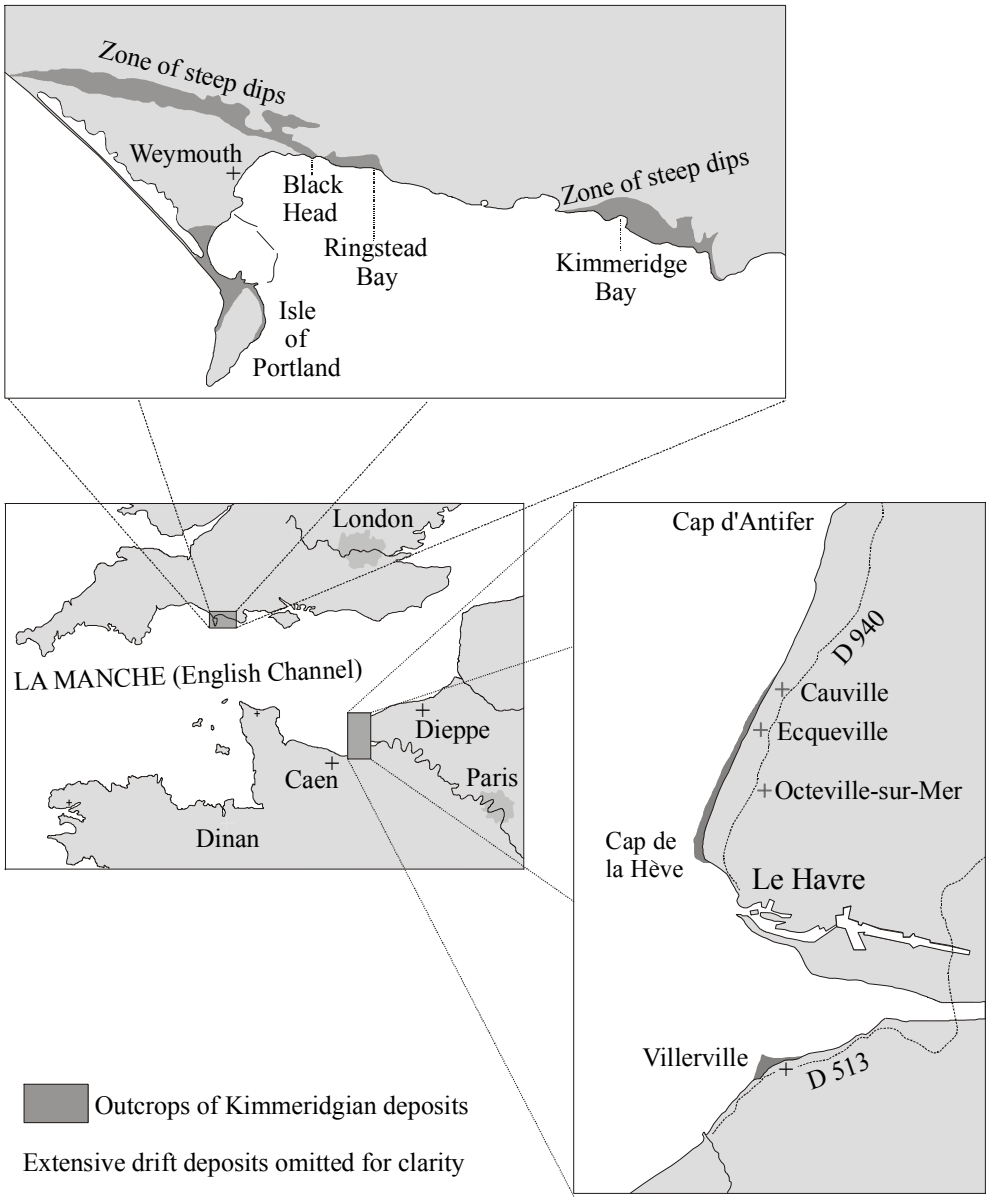

Figure 1. Geological sketch map showing the positions of sections referred to in the text.

The Kimmeridgian sections of the Dorset coast have steadily deteriorated during the past 100 years due to an increase in the amount of sea-defence works. Well exposed sections in the Cymodoce to Eudoxus zones recorded at Ringstead Bay in the 19th and early 20th centuries [23, 28] had become too degraded for detailed study by the 1930s [1], and many of the 1930s and later sections have themselves now disappeared. The only currently well-exposed Kimmeridgian sections in the Dorset type area are in the Baylei

Zone and lowest Cymodoce Zone at Black Head and Ringstead Bay, in small parts of the Eudoxus and Autissiodorensis zones at Ringstead Bay, and in the Eudoxus and Autissiodorensis zones at Kimmeridge Bay. In contrast to the deteriorating nature of the Dorset sections, the Kimmeridgian outcrops exposed in the cliffs between Le Havre and Cauville (Figure 1) are unprotected and are constantly renewed by marine erosion.

Comparison of the published descriptions of the Dorset and Normandy successions shows broad lithological and faunal similarities, but there is no published correlation to date that is sufficiently detailed to enable the chronostratigraphical sequences to be closely compared. In recent years, descriptions of the Kimmeridge Clay (mostly based on continuously cored boreholes) have combined the lithological, sedimentological, palaeontological and geophysical (wireline logs) data to produce a chronostratigraphy that is applicable to the Kimmeridge Clay throughout onshore Britain. The Lower Kimmeridge Clay has been divided into 35 chronostratigraphical units (referred to as KC 1 to KC 35) on the basis of combinations of what are believed to be isochronous sedimentary and palaeontological events [15, 17]. These units have been grouped into six sequences, each of which is bounded by a stratigraphical sequence surface (Km 1 to Km 6) [26].

Early descriptions of the equivalent sediments in Normandy concentrated on the biostratigraphy [19, 21, 22,]. A more recent description [24] has combined the palaeontological and lithological data. Some of the beds referred to as lumachelles in the French descriptions are re-interpreted here as lag deposits that rest on erosion surfaces that can be correlated with the English sequence boundaries. These enable chronostratigraphical correlations to be made between the Dorset and Normandy successions. Because of their continual renewal the Normandy sections now provide a better opportunity to improve our knowledge of the detailed biostratigraphy of much of the Sub-boreal Kimmeridgian than does any English section. The Normandy sections have the added interest that they were closer to the boundary between the Sub-boreal and Tethyan faunal provinces in Kimmeridgian times than the Dorset type section and they offer a better opportunity for inter-province correlation.

2. Correlation of the Dorset and Normandy successions

Stratigraphical summaries of the Kimmeridgian successions exposed on the Dorset and Normandy coasts are shown in Figures 2 and 3, together with their correlations. The Dorset succession and zonation is based on work on the cliff sections by numerous authors [2, 3, 4, 6, 8, 9, 10, 11, 13, 23, 25, 27, 28] and on continuously cored boreholes [9, 15, 17]. The Normandy coast succession is based on published descriptions [7, 12, 19, 21, 22, 24] with additions based on the sections visible in May, 2000, November 2001 and June 2002. Descriptions of the individual Normandy sections are given elsewhere [16].

The Normandy sections consist of a series of geographically separated exposures on foreshores and in low cliffs which, taken together, provide a continuous succession of about 45m of strata that range from the base of the Baylei Zone to a level in the middle part of the Eudoxus Zone. A low northerly dip (< 0.5°) in the Kimmeridgian rocks causes them to be unconformable overstepped by almost horizontal Cretaceous rocks when traced southwards from near Cauville to Le Havre (Figure 1). Geographical details of the sections and their access points are given elsewhere [24]. All the Kimmeridgian sections are overlain by collapsed Cretaceous material, with the result that sections appear and disappear as a result of frequent landslip activity. Erosion rates in the intertidal area are high, and the availability of sections on the foreshore is subject to rapid change due to the mobility of the beach deposits. Where more resistant lithologies form reefs on the middle and lower foreshores, they are swept clean of modern sediment most of the time.

The Baylei to Cymodoce zone successions in Dorset and Normandy are lithologically dissimilar. Both are highly condensed and contain major and minor erosion surfaces. These are especially obvious in the calcareous lithologies of the Normandy coast where they give rise to numerous hardground surfaces. The comparable succession on the Dorset coast, although even more condensed, consists predominantly of mudstones in which the erosional breaks are lithologically less pronounced.

In contrast, the Mutabilis and Eudoxus zones successions of both areas are almost wholly argillaceous, and their lithologies and the faunas can be matched in detail. This part of the Kimmeridgian of the Normandy coast was named the Formation des Argiles d'Octeville [20], and subsequently divided into two members, the Argiles du Croquet and

Argiles d'Ecqueville [24]. All the mudstone lithologies in the Argiles d'Octeville can be matched with lithologies in the Lower Kimmeridge Clay of the Dorset type area, and the order in which the more and less calcareous and more and less bituminous mudstones occur are similar.

2.1 Baylei and Cymodoce zones

The correlation between the Dorset and Normandy successions is summarised in Figure 2. In Normandy, the whole of the Baylei Zone and the Cymodoce Zone up to a level at the top of the Calcaires à Harpagodes are exposed in the cliffs and foreshore at Cap de La Hève (Lambert Zone 1 coordinates x=435,65 y=1203,80), and the higher part of the Cymodoce Zone is exposed on the foreshore at Le Croquet (x=437,25 y=1208,60), Octeville-sur-Mer [24]. The total thickness of the Baylei and Cymodoce zones has been estimated to vary between about 9 and 12m within the exposed sections [22]. The thickness of the comparable beds on the Dorset coast varies from about 7 to 20 metres within a few kilometres [11].

The Baylei Zone exposures in Dorset and Normandy have yielded few age-diagnostic fossils other than *Pictonia* spp. The Formation des Calcaires coquilliers contains *P. baylei* Salfeld and *P. normandiana* Tornquist together with the distinctive brachiopod *Torquirhynchia inconstans* (J. Sowerby). In Dorset, *Pictonia* is confined to the Baylei Zone (KC 1 to KC 4), and *T. inconstans* has only been recorded from KC 1. The most obvious lithological similarity between the Normandy and Dorset successions is the dark grey mudstone of the Formation des Argiles à Deltoideum delta and its Dorset equivalent KC 3, both of which contain beds crowded with the large oyster *D. delta* (Wm Smith), many with paired valves. The presence of lumachelles composed of *Nanogyra nana* (J. Sowerby) and *N. praevirgula* in the Argiles à Deltoideum delta and in KC 2 in Dorset (the Nana Bed) provides a further lithological similarity. The presence of *D. delta* in the Calcaires à Harpagodes is not stratigraphically diagnostic. Although *D delta* is abundant over a well-defined range in the late Oxfordian and early Kimmeridgian (Serratum to Baylei zones) in England [18], it has also been recorded in large numbers at one horizon in the upper part of the Mutabilis Zone [5].

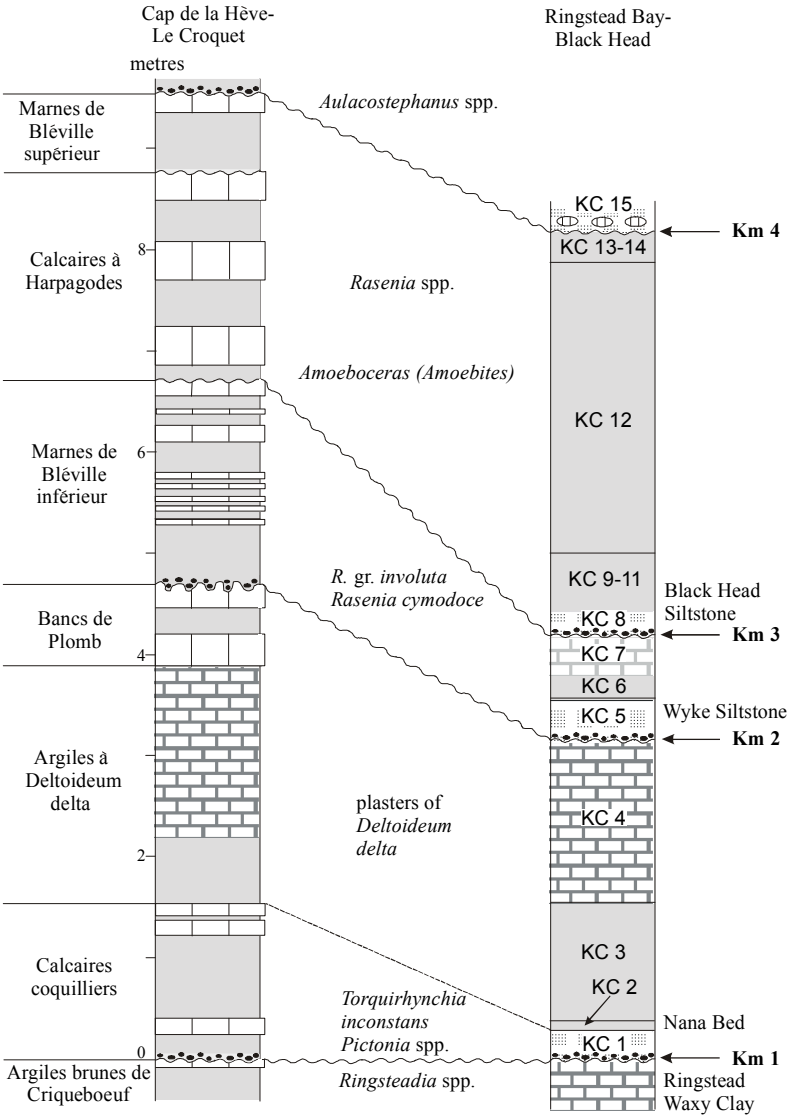

Figure 2. Correlation of the Baylei and Cymodoce zones successions: Formation des Calcaires coquilliers to Formation des Marnes de Bléville and English chronostratigraphical units KC 1 to KC 14.

The Formation des Bancs de Plomb, two limestone beds separated by a bed of shelly calcareous mudstone, 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 is much penetrated by burrow infillings of the overlying bed. This bioturbation has left columns and irregular masses of the limestone that have been undermined to produce pseudo 'pebbles' and

'nodules'. The hardground surface at the top of the Bancs de Plomb was included in the Formation des Marnes de Bléville by earlier authors [22, 24], but is interpreted here as the correlative of the major erosion surface at the base of KC 5 (the Wyke Siltstone) of the Dorset succession.

The Marnes de Bléville (inférieur et supérieur) and the intervening Calcaires à Harpagodes consist of thin, laterally variable beds of limestone capped by a mineralised and burrowed surface, each separated by highly calcareous mudstones crowded with shell grit. The presence of *Rasenia* spp. throughout this part of the succession indicates correlation with KC 5 to KC 14. In Dorset, the bases of KC 5 and KC 8 (the Black Head Siltstone) are marked by major erosion surfaces (Km 2 and Km 3).

Four assemblage horizons (I to IV) have been identified in the Cymodoce Zone in England [4]. The oldest of these, characterised by *Rasenia* cf. *cymodoce* (d'Orbigny), is confined to the Wyke Siltstone [5]. On the Normandy coast *R. cymodoce* has only been recorded as an impression on the top surface of the Bancs de Plomb [24], a single specimen that was previously identified as a *Pictonia* [22]. 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. Horizon II, characterised by *Rasenia (Rasenia) involuta* Spath, has been recorded from KC 6-7 in England and from the Marnes de Bléville inférieur. Horizon III, characterised by *Rasenia (Zonovia)* gr. *evoluta* Spath occurs in KC 12 but has not been recorded in Normandy. Horizon IV, characterised by *R. (Semirasenia) askepta)* Ziegler and finely ribbed *Rasenia (Raseniodes)* cf. *lepidula* (Oppel) occurs in KC 13-14 and the Marnes de Bléville supérieur.

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. In England and northern France it precedes a rapid expansion of the geographical extent of the Sub-boreal Province and a breakdown of barriers that had inhibited faunal migration in the late Oxfordian and early Kimmeridgian. In France it marks the final submersion of the

Séquanian barrier and the opening of the Anglo-Norman depositional basin to tethyan influences [14]. In the English succession it correlates with sequence boundary Km 4 [26].

2.2 Mutabilis and Eudoxus zones

The Kimmeridgian succession in Normandy above the Km 4 erosion/transgression surface, the Formation des Argiles d'Octeville, consists of mudstones that are lithological directly comparable to their correlatives in the Kimmeridge Clay of Dorset. Both successions contain major erosion surfaces that mark stratigraphical sequence boundaries. Those in the Kimmeridge Clay maintain their relative stratigraphical positions over large areas with the result that laterally persistent lithological and faunal marker beds in the intervening strata enable the succession to be divided into reliable chronostratigraphical units. For example, between sequence boundaries Km 5 and Km 6 chronostratigraphical units KC 17 to KC 23 are present throughout the onshore outcrop and subcrop area of the Kimmeridge Clay between Dorset and Yorkshire (an area of about 35,000 km²), except for small areas close to the London Platform tectonic high where erosion at the base of the overlying sequence (base of KC 24) has locally removed KC 22 and KC 23.

The lateral persistence of individual thin marker beds suggests that the Kimmeridgian was a tectonically quiet period in England with little lateral variation in depositional environments at any particular time. In contrast, the correlative erosion surfaces in the Normandy coast succession give rise to pronounced lateral variations. The best documented of these, the erosion surface at the base of the Argiles d'Ecqueville (Km 5 equivalent) at Le Croquet Plage cuts out the 6m-thick Argiles du Croquet supérieur and comes to rest on the Argiles du Croquet inférieur in a distance of only 350m. This suggests that in Normandy there were at times marked local differences in sea-bed topography. These might have been related to minor tectonic activity associated with the Séquanian positive area a few tens of kilometres south of the Normandy coast [14].

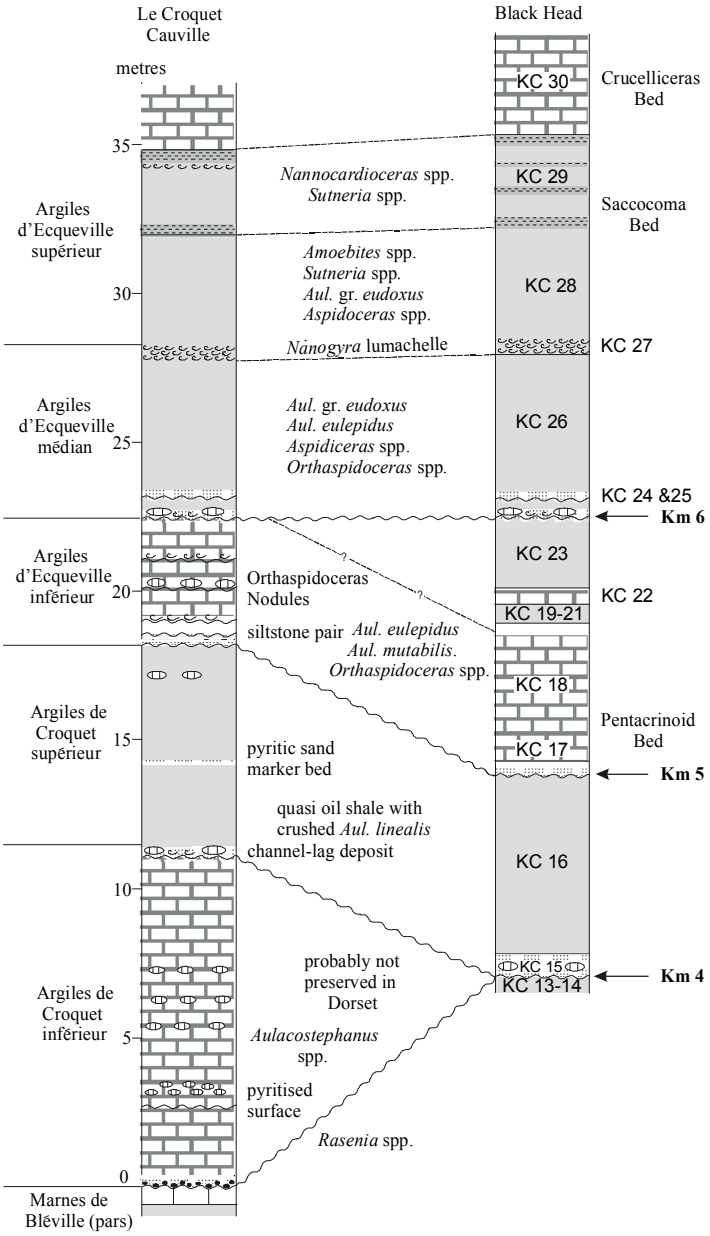

Figure 3. Correlation of the Mutabilis and Eudoxus Zone successions: Formation des Argiles d'Octeville and English chronostratigraphical units KC 15 to KC 30.

In the present work, four sequence boundaries have been recognised in the Argiles d'Octeville, each marked by a major erosion surface. Minor erosion surfaces are common within the lower part of the succession (Figure 3). The lowest part of the formation, the Argiles de Croquet inférieur, is the least well exposed part of the formation and its fauna the least well documented. At the type section, on the foreshore at Le Croquet Plage

(x=437,25 y=1208,80), it consists of up to 11m of calcareous mudstone that readily weathers to a soft pale grey clay. As a result, the outcrop is covered by beach sand for much of the time and only the lowest bed and the junction with the underlying Marnes de Bléville is well exposed. Calcareous mudstone concretions occur at several horizons within the member and it contains at least two erosion surfaces marked by burrowed surfaces overlain by pyritised concentrations of shells and shell debris. Large crushed specimens of *Aulacostephanus* indicative of the Mutabilis Zone are common at some levels, and the gritty shell-rich beds contain common oysters and rhynchonellid brachiopods.

The base of the Argiles du Croquet supérieur is marked by a major erosion surface overlain by a shelly, pebbly channel-lag deposit with secondary calcareous concretions. This is overlain by fissile, bituminous mudstones that are locally crowded with crushed *Aulacostephanoides linealis* (Quenstedt) [24]. This distinctive combination of lithology and fauna can be closely matched with parts of KC 16, the oldest organic-rich lithology in the English Kimmeridgian succession. The identification of KC 16 immediately above the erosion surface at the base of the Argiles du Croquet supérieur suggests that the erosion surface is the correlative of that at the base of KC 15. This implies that in England erosion at this level has removed any representative of the Argiles du Croquet inférieur (Figure 3).

At Le Croquet Plage, the Argiles de Croquet supérieur are overlain disconformably by the Argiles d'Ecqueville inférieur, a highly condensed 4m-thick succession of calcareous mudstones and siltstones. In the low cliffs to the north and south of the le Croquet Plage access path, the basal erosion surface can be seen to progressively cut out marker beds in the Argiles de Croquet supérieur in a southerly direction. The most prominent of the marker beds, a thin (10mm thick) bed of bioturbated pyritic sand that is presumed to be a storm-generated deposit, is present up to 300m south of the path.

The Argiles d'Ecqueville inférieur contains at least five erosion surfaces and several omission surfaces marked by bioturbation, mineralisation (mostly pyrite) and concentrations of shell debris. *Orthaspidoceras* is abundant at several levels including one in which complete specimens are well preserved in calcareous concretions. *Aulacostephanus* including *Aul. mutabilis* (Sowerby) and *Aulacostephanoides eulepidus*

(Schneid) are also present. The fauna and lithologies indicate correlation with KC 18 to KC 23, albeit with several sedimentary gaps. The distinctive Supracorallina Bed of the English succession [1] has not been recorded in Normandy, but the profusion of *Orthaspidoceras* can be matched with a similar abundance at this stratigraphical level on the Dorset coast [27].

The base of the Argiles d'Ecqueville médian is also marked by a major erosion surface that is well exposed in the cliffs (x=1210,50 y=438,30) south west of Ecqueville (la Bruyère in museum collections). This is the correlative of sequence boundary Km 6 and marks the base of the Eudoxus Zone. It was followed by a rapid transgression that gave rise to the most diverse and widespread ammonite assemblages in the Kimmeridgian of the Sub-boreal province. There is no major erosion surface above this stratigraphical level within the stage in the English succession, and the same is probably true in Normandy. As a result, the Dorset and Normandy successions can be matched in lithological and faunal detail.

In both areas, the basal erosion surface is marked by a calcareous siltstone with secondary concretions and a rich and diverse shelly fauna. Close above this a second siltstone (KC 25) that marks another erosion surface is followed by a transgressive pulse. In Dorset and Normandy, the siltstones mark the incoming of species of *Aspidoceras*, *Aulacostephanus* of the *eudoxus* group and, a little higher in the succession, species of *Amoeboceras* (*Nannocardioceras*) and *Sutneria*. The lithological successions show remarkable similarities. On the Normandy and Dorset coasts dark grey mudstones with *Aulacostephanus eudoxus* (d'Orbigny), *Aulacostephanoides eulepidus, Aul. mutabilis,, Aspidoceras* spp. and *Sutneria eumela* (KC 26) are overlain by a lumachelle composed almost entirely of the small oyster *Nanogyra virgula* (Defrance) (KC 27). This is overlain on both coasts by shelly dark grey mudstones (KC 28) and interbedded mudstones and oils shales (KC 29) with common *Amoeboceras (Amoebites)* spp*., Amoeboceras* (*Nannocardioceras*) *anglicum* (Salfeld), *Aspidoceras longispinum* (Sowerby), *Aulacostephanus* spp., *Sutneria eumela* (d'Orbigny) and large forms of *Nanogyra virgula*.

The youngest Kimmeridgian strata currently exposed on the Normandy coast are deeply weathered pale grey highly calcareous mudstones in low cliffs north of Ecqueville

(x=1211,50 y=438,70) and south of Cauville (x=1212,10 y=439,10) (le Tronquay in museum collections). The lithologies and fauna (including species of *Amoeboceras*, *Aspidoceras*, *Aulacostephanus* and *Sutneria*) are those of KC 30 of the English succession. The distinctive Crussolliceras Bed, a widespread marker that can be recognised even from small fragments, has not been recorded in Normandy. When allowance is made for the northerly dip of the Jurassic rocks and the rate of overstep of the Cretaceous rocks, it seems likely that higher beds in the Argiles d'Ecqueville will crop out on the foreshore west of Cauville from time to time in an area that is at present covered by thick beach deposits.

3. Summary and Conclusions

The early parts (Baylei and Cymodoce zones) of the Kimmeridgian successions at outcrop on the Dorset and Normandy coasts are highly condensed and lithologically dissimilar. Detailed correlations can, however, be made between them because of the similarities in their faunas and sequence stratigraphies. Both successions contain prominent sedimentary breaks that coincide with major changes in the ammonite assemblages. The later parts (Mutabilis and Eudoxus zones) are lithologically and faunally closely similar in both areas, although there are differences in the abundances of some ammonite genera. For example, *Orthaspidoceras* is more abundant over a greater stratigraphical range in Normandy than in Dorset, and is rare or unknown in more northerly parts of England. There is currently no good permanent exposure through the full thickness of the Mutabilis Zone in England, and the Normandy sections are therefore especially important for future study. There is also scope for additional work in Normandy to try to identify particular fossils that have been shown in the English succession to provide isochronous marker beds over large areas. These include flood occurrences of pentacrinoids (in KC 18), *Nicaniella* (in KC 22), *Saccocoma* (in KC 29) and *Crussolliceras* (in KC 30) [15,17].

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