GENESIS AND DIAGENESIS OF SANTONIAN TO EARLY CAMPANIAN (CRETACEOUS) PHOSPHATIC CHALKS OF THE ANGLO-PARIS BASIN

VOLUME 1 : STRATIGRAPHY

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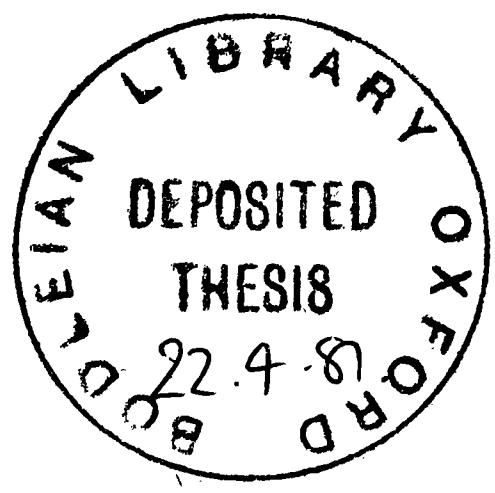

D.Phil Thesis

October 1980

Genesis and diagenesis of Santonian to early Campanian (Cretaceous) phosphatic chalks of the Anglo-Paris Basin

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D.Phil Thesis Abstract
Michaelmas 1980

The phosphatic chalks of the Anglo-Paris Basin are granular phosphorites of Santonian to early Campanian age. They were deposited in erosional cuvettes up to 1 km long, 250 m wide and 30 m deep, incised into white chalks. Most are situated in the Picardy region of northern France. Cuvettes are floored by strongly indurated and mineralized basal hardgrounds developed in intraclastic sediments. The hardgrounds are penetrated by prominent phosphatic-chalk filled Thalassinoides burrows and overlain by intraclast-pebble lags containing 'Terebella' phosphatica Leriche, Diblasus arborescens Parent and Lopha semiplana (J. Sowerby). Lithification occurred a few centimetres below the sediment/water interface in a sediment of increased permeability, and is geochemically discernible ~90 cm below the hardground surface. Glauconitization was restricted to replacement of clay minerals during the early development of the hardground, later phosphatization replacing carbonate. Actinocamax verus Miller occurs in basal phosphatic chalks and a bed of Gonioteuthis quadrata quadrata (Blainville) occurs at the summit. The Gonioteuthis Bed is commonly underlain by, but separated from, a bed of Offaster pilula (Lamarck). The proportion of faecal pellets, phosphatic ooliths, echinoderm fragments and benthonic foraminiferans decline above the basal hardgrounds as the phosphorites become finer-grained and less phosphatic. Inoceramid prisms or pelagic foraminiferans are the dominant component of poorer phosphatic chalks. Intraformational slump folds and hardground mélanges occur at the base of some successions. The palaeobiology of belemnites is considered in detail and it is concluded that the Gonioteuthis Beds were the products of mass-mortalities accompanying reproduction. Pelletal phosphate was formed by the replacement of carbonate during early diagenesis in an organic-rich, anoxic environment and water depths of <150 m. Current activity and subsurface anoxia were intermittent; colonization, bioturbation and winnowing alternating with quiescent, anoxic phases of mineralization. Phosphatic chalk cuvettes were eroded by a proto-Gulf Stream during a eustatic regression. Upwelling of this current was the main source of phosphate in the phosphatic chalks.

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"Le Phosphate" Sept. 1906

Abstract

Phosphatic chalks are chocolate-brown, granular phosphorites which were deposited in erosional cuvettes up to 1 km in length, 250 m wide and 30 m deep, incised into white chalks of the Coniacian to early Campanian. Most are situated in the Picardy region of northern France, but isolated examples occur elsewhere in the Anglo-Paris Basin. The deposits are Europes' largest sedimentary-phosphorite resource and were mined extensively around the turn of the century. Only two workings are currently exploiting phosphatic chalks - those at Nurlu and Hallencourt in Somme. Exposures remain in the Picardy region near Beauval, Faucouzy, Hardivillers, Hem-Monacu, Marcheville, Orville and Ribemont, in Yonne at St Martin-du-Tertre and in Ardennes at Villers-devant-le-Thour. In southern England a phosphatic chalk is exposed at Taplow (Bucks) and phosphatic horizons occur at Boxford, Downend, Lavant, Whitecliff Ledge and Winterbourne. Utilizing a combination of data from the literature and that gained from contemporary exposure, the litho- and bio-stratigraphy of over fifty localities are described in detail.

Phosphatic chalk cuvettes are floored by strongly indurated and mineralized basal hardgrounds which developed in winnow-coarsened sediment of late Coniacian to Santonian age. These basal hardgrounds are penetrated by prominent phosphatic-chalk filled Thalassinoides burrow systems and overlain by intraclast-pebble lags. The basal lags contain a prolific, varied and highly-distinctive fauna typified by the worm tube 'Terebella' phosphatica Leriche, the ahermatypic coral Diblasus arborescens Parent and thick-shelled oysters, particularly Lopha semiplana (J. Sowerby). In the axial region of the cuvette the phosphorite may be up to 17 m thick, having a rapidly transitional, sometimes sharp, top, overlain by white chalk.

All deposits are of Santonian (mid M. coranguinum Zone) to early Campanian (O. pilula Zone) age, the bulk of the phosphorite being post U. socialis Zone. The age of the oldest phosphorite varies from site to site but the stratigraphically lowest contain Actinocamax verus Miller and Gonioteuthis granulata (Blain-

ville). A bed of Gonioteuthis quadrata quadrata (Blainville) with rare Belemnitella praecursor Stolley occurs at the summit of most phosphatic chalks. This Gonioteuthis Bed is commonly underlain, but separated from, an Offaster Bed containing abundant Offaster pilula (Lamarck) and rare Echinocorys cincta Brydone. Comparison of zonal thicknesses of phosphatic and white chalks indicates that phosphatic chalks are severely attenuated when compared with white chalks from elsewhere in the basin. They are, however, only marginally thinner than white chalks in their immediate vicinity, suggesting that attenuation is a regional characteristic.

Three major types of chalk are defined: white chalk, hardground chalk and phosphatic chalk. White chalks are the dominant lithology of the Upper Cretaceous in the Anglo-Paris Basin. They are white coccolith-biomicrites containing accessory skeletal carbonate and traces of terrigenous and 'authigenic' minerals, and are essentially parallel-beddded and subhorizontal, bedding being picked out by marl seams, nodular-flint lines and erosion surfaces. Carbonate was deposited as zooplankton faecal pellets which produced thixotropic substrates. Deposition occurred at depths of 150 - 300 m in a tropical or subtropical sea of normal salinity.

Basal hardgrounds are major synsedimentarily-lithified horizons in the succession. They show considerable morphological variation, reflecting the interaction of bioturbation, cementation, scour and abrasion, bioerosion and mineralization. Hardground chalks commonly contain a high proportion of sand and pebble-grade mineralized and unmineralized intraclasts and shell debris. Basal hardgrounds have glauconitized and phosphatized surfaces coated by phosphate-skin complexes. Mineralization also affects the walls of burrows and borings and is intimately associated with organic structures, including the phosphate skins which are believed to be replaced organic mats. Lithification occurred a few centimetres below the sediment/water interface in a sediment of increased permeability. Cement (probably low-Mg calcite) was introduced from seawater, flushed through the sediment by currents and bioturbation; the presence of early-diagenetic pyrite is indicative of anoxic, sulphidic diagenesis.

Phosphatic chalks are defined as having $\geqslant 5\%$ P_2O_5 due to the presence of

appreciable quantities of granular phosphate. They are burrowed throughout and display a number of structures produced by the interaction of bioturbation and mineralization. Their granular component consists of phosphatized sediment: intraclasts, ooliths, faecal pellets; and bioclasts: foraminiferans, comminuted inoceramid, echinoderm and bryozoan debris, sponge spicules, bone fragments, elasmobranch teeth, teleost otoliths and scales, and ostracodes. The matrix is an unmineralized white chalk. The composition of the pelletal material changed during the evolution of the cuvette. The proportion of faecal pellets, ooliths, echinoderm, bone fragments and benthonic foraminiferans declined as the phosphorite became finer-grained and less phosphatic. Thus coprolitic and oolitic microfacies characterise basal beds while inoceramid prisms or pelagic foraminiferans are the dominant component of poorer phosphatic chalks higher in the succession. Calcisponge and echinoderm biocalcarenites were deposited in several areas during the early Campanian.

The coarse sediment and algal borings associated with basal hardgrounds and phosphatic chalks are indicative of stronger currents and shallower water (<150 m) than during the deposition of white chalks. Mixed rocky and sandy substrates resulted in a prolific and diverse biota which aided phosphatization by concentrating phosphorus at the seafloor, and producing organic mats, faecal pellets, bioclasts etc. which are highly susceptible to mineralization during early diagenesis.

In the axial region of phosphatic chalk cuvettes, high current regimes produced strongly-indurated basal hardgrounds associated with a pronounced hiatus and overlain by a thick, coarse, rich phosphorite. Towards the margins, declining current activity resulted in less erosion, weaker lithification and thinner, finer, less-phosphatic sediments. Intraformational slump-folding occurred in the basal hardground and oldest phosphatic chalk, producing local hardground mélanges in the lowest phosphorites.

Late diagenesis is characterised by silicification of bioclasts and the formation of flint nodules. Silicification was a multistage process involving the liberation of silica from biogenic opal-A, the early-diagenetic formation of opal-CT lepispheres at sites of organic matter, and the subsequent migration of

silica during late diagenesis combined with the transformation of opal-CT to chalcedonic α-quartz. Flaser seams, stylolites and late-diagenetic pyrite and cementation also occur.

Geochemical and mineralogical variation in white-hardground-phosphatic chalk successions from Beauval and Nurlu quarries are examined and analysed statistically. All three lithofacies consist of low-Mg calcite, carbonate-fluorapatite, α-quartz, glauconite, 'goethite' and clay minerals. White chalks are geochemically similar to modern coccolith oozes. Basal hardgrounds have a 30 cm strongly-indurated summit passing down into progressively less-indurated lower levels until lithification is apparently absent below 60 cm. Nevertheless, lithification is geochemically discernible up to ~90 cm below the surface, cementation producing enrichments in Fe, Mn and Mg but depletion in Sr. Glauconitization predates phosphatization, being restricted to the replacement of clay minerals during the early stages of hardground development, while lithified carbonate remained in contact with seawater. Phosphatization occurred by the replacement of carbonate (with possible subordinate precipitation) during burial of the hardground.

Phosphatic chalk belemnites are studied in detail because of their abundance here but rarity in white chalks. The occurrence of large 'populations' of belemnites in various Gonioteuthis Beds has enabled the application of statistical techniques in the identification of Gonioteuthis species and taphonomic analysis. G. q. quadrata is the subspecies identified in these beds although G. granulata, G. granulataquadrata (Stolley), A. verus and Belemnellocamax ex gr. grossouvrei (Janet) occur in older phosphorites. The taphonomy of the guards indicates that burial was rapid and reexhumation rare or short-lived. The occurrence of juveniles is consistent with a shallow-water environment, which was the belemnites' normal habitat because of greater food availability. Belemnites are concentrated on hardgrounds because of the concentration of prey but also because they were prefered breeding sites and therefore the recipients of large numbers of cadavers following the mass-mortalities which accompanied reproduction. The virtual mutually-exclusive relationship between A. verus (characteristic of basal beds only) and Gonioteuthis (common in the upper parts of most successions) in phosphatic chalks is due to environmental and/or evolutionary changes.

Examination of the marine chemistry of phosphate and the distribution of modern seafloor-phosphorites yields a number of parameters which are utilised in a reconstruction of the depositional environment of phosphatic chalks. At the present-day, phosphorites are being deposited on the Peru-Chile and SW African shelves, but most other seafloor phosphorites are of Mio-Pliocene age and none are closely-comparable to the extensive epicontinental phosphorites of the late Cretaceous and early Tertiary. A close association between organic matter, anaerobic diagenesis and phosphatization is seen in both modern deposits and phosphatic chalks. Unweathered phosphatic chalks contain disseminated pyrite, reduced iron and probably have high organic-matter contents. Similarly, Recent seafloor phosphorites are associated with strongly-reducing, organic-rich oozes, although they differ in their formation in siliceous rather than carbonate sediments. As with modern phosphorites, phosphatization in phosphatic chalks was a rapid post-burial process occurring immediately below the sediment/water interface, prior to the dissolution of aragonite and disintegration of faecal pellets and some animal soft-parts. A close association with organic processes is seen in both phosphatic chalks and hardgrounds. Phosphate was liberated from decaying organic matter in the sediment, which produced a highly-alkaline environment which favoured phosphate replacement and precipitation. Phosphatization in the modern oceans is concentrated at the boundary between oxic and anoxic seafloors. Similarly, in phosphatic chalks the faunal and sedimentological data indicates intermittent rather than continuous anoxia below the sediment surface. The bimodal grain-size distribution of phosphatic chalks, the coexistence of ooliths and faecal pellets and other sedimentological properties indicate that current activity also occurred during discrete periods rather than being continuous. It is concluded that colonization, bioturbation and winnowing alternated with quiescent, anoxic phases of mineralization.

The morphology, constancy of orientation and environmental interpretation of phosphatic chalk cuvettes indicate that they were eroded by a permanent ocean current. Their formation during the Santonian to early Campanian was partly due to a eustatic regression enabling the ocean current to achieve significant erosional effects and thereby form the cuvettes which acted as entrapment basins

for the phosphorite. The absence of major phosphatic chalks in the Anglo-Paris Basin prior to the Santonian may be attributed to palaeoceanographical changes. Since phosphorus is biolimiting, the high organic-productivity indicated by the phosphorite must have been the result of high phosphate contents in seawater. Upwelling is the main mechanism which produces high phosphate abundances in the modern oceans and is consistently associated with seafloor phosphorites. A palaeoceanographical reconstruction of the Anglo-Paris Basin during the late Cretaceous indicates that here upwelling may be attributed to the establishment of a proto-Gulf Stream which intruded the basin, and was deflected and caused to upwell along a trend which parallels the London-Brabant Massif and western Ardennes.

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Acknowledgments

I wish to convey my thanks to Pete Woodroof and Andy Gale for field assistance and many invaluable discussions concerning chalk and phosphorite sedimentology. Field assistance at various times was also provided by Ann Richardson, Bob Kirby, Guy Plint and David Ward.

Excavation of the Winterbourne and Boxford quarry sites was organised by the Geology Section of the Nature Conservancy Council and help was received from George Black, Bill Wimbledon and David Veitch. Many landowners kindly gave permission to examine quarries on their property; encouragement from the "Compagnie Française de Phosphates" is gratefully acknowledged.

The geology departments at the Universities of Oxford and Glasgow provided much of the equipment and raw-materials utilised in the preparation of this thesis. Alan Wilson, John Arden and the technicians of the geochemistry and microprobe laboratories in the Department of Geology and Mineralogy, University of Oxford gave valuable help with analytical techniques. Walter Christensen kindly supplied comparative statistical data for belemnite 'populations' from Belgium and Germany.

Jim Kennedy, Pete Woodroof, Andy Gale, Walter Christensen, Richard Bromley, Hugh Jenkyns, Tim Palmer and Bob Kirby read through and greatly improved early drafts of the manuscript - though no one of these is likely to agree with all the ideas expressed in this thesis. Katrina Delargy and Kass Young helped considerably with the preparation of the phosphatic chalk distribution map, and Ann Richardson shared the proof-reading, thereby lightening this daunting task. Many friends and colleagues, particularly Bol Bray, Mike Watson, Tim Barratt and Mike Cooper, provided valuable discussion. 'Hook Norton' and 'Ronceval' gave necessary inspiration when required.

I gratefully acknowledge a NERC postgraduate research grant at the University of Oxford which provided the finance for the research presented in this thesis. NERC, Wolfson College Oxford and Oxford University supplied funds for attendance of the IAS 1978 Congress in Jerusalem at which initial results of this work were presented.

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1.1 Aims and scope

Phosphate rock (phosphorite) is exploited as a source of elemental phosphorus for industrial applications and for the production of fertilizer. Around 80% is used for fertilizer. The rate of phosphate application in the developed world in 1976 was 10.4 kilograms per hectare of agricultural area compared with 2.4 kilograms per hectare for the developing countries (Burnett and Sheldon, 1979). In parts of Western Europe, where intensive farming is practised, rates are as high as 133 kilograms per hectare; elsewhere in the world some poor countries use virtually no phosphate fertilizer. Clearly the discovery and development of low-cost phosphate-rock supplies is essential to improve the food supply within the developing world. It is generally recognised, however, that our understanding of the geology of phosphate deposits, used for assessing and exploring for phosphorite resources, is far from complete. The purpose of this thesis, therefore, is to examine in detail Western Europe's only major phosphate deposit - the phosphatic chalks of the Anglo-Paris Basin, in order to formulate a depositional model which might be applicable to other phosphate deposits elsewhere in the world.

During the last few decades of the nineteenth century, the Upper Cretaceous phosphatic chalks of Picardy, northern France, were one of Europe's main sources of phosphate. The concentration of deposits in the Somme valley, however, meant that the start of the First World War essentially halted production. By this time many of the richer deposits had been exhausted and the industry was already declining. Between the wars, competition from cheap North African and other phosphates dealt the final death-blow and subsequent production has been restricted to a handful of family concerns meeting local requirements for phosphate fertilizer.

Phosphatic chalks have been described in a large volume of literature produced at the turn of the century. Since that time fundamental advances have been made in sedimentary geology. Our knowledge of sedimentary structures, sedimentary geochemistry, stratigraphy and palaeoecology have all been developed or greatly improved. Oceanographical studies have revealed phosphorites forming

on the present seafloor, and advances in Recent sedimentology, physical oceanography, marine chemistry and ecology have clarified our understanding of the oceans as a dynamic system. The advent of plate tectonics has enabled us to project these findings into palaeoceanographical models that are predictive as well as explanatory.

1.2 Approach

As with any sedimentary succession, interpretation first requires documentation of the vertical and lateral changes that accompany the deposition of each unit. Relevant information concerning the location, gross-morphology, lithology and age of each deposit was collated from an extensive literature survey, and then each site was visited to collect as much additional data as possible. Sadly, the number of extant exposures is now limited, and only three - Beauval, Nurlu and Hardivillers quarries, now (1979) provide any amount of lateral exposure.

Field documentation of the lithostratigraphy and sedimentology of each locality was accompanied by collection of the macrofauna, carefully localised with respect to the lithostratigraphy. Faunal identifications were confirmed in the laboratory on prepared specimens (now deposited in the Oxford University Museum). Faunal successions were compared between localities and with existing biostratigraphical schemes.

More than fifty, large (>30 cm), representative block-specimens were collected for detailed examination of the major lithologies at each locality. These were faced to display the main sedimentological structures, and then subsampled for petrographical and geochemical study. A total of ~300 oriented thin-sections were examined and thirty-nine geochemical samples were analysed for ten major and minor elements. The ultrastructure of selected components was elucidated using SEM and electron microprobe.

Unlike many previous authors, observations were not restricted to the phosphorite. Details were recorded for the under- and overlying chalks, and lateral as well as vertical lithological changes were recorded. Equivalent successions

elsewhere in the region were examined for comparative purposes. All scales of observation were made on each deposit, from the kilometre-scale extent and geometry of each phosphate 'basin', to the micron-scale ultrastructure of individual mineralized grains. Geographical, sedimentological, structural, faunal, mineralogical and geochemical analyses were made to extend the scope of the study as far as practicable. It is only by such an integrated approach that the true nature of the facies can be appreciated and no relevant information concerning its genesis or diagenesis overlooked.

1.3 Plan and presentation

Terms are defined in the relevant sections of the thesis. The introductory chapter includes a review of existing biostratigraphical schemes for the Chalk of the Anglo-Paris Basin and defines the zonation used here. Data obtained from both the literature survey and field observation are amalgamated in the form of locality descriptions which provide the basis for interpretation. Even with individual sites, lateral exposure is rarely sufficient to enable a unique composite-lithostratigraphy to be constructed. Consequently, each section is described in detail and then sections are brought together in a final discussion for each locality. Litho- and biostratigraphical characteristics are incorporated in a brief discussion of the sedimentology of each site. This data is then synthesised and expanded in the next chapter. The sedimentology of the deposits is discussed from petrographical and morphological standpoints and is interpreted by reference to known carbonate and phosphorite depositional environments.

Ambiguous data provided by these primarily observational approaches are in-part clarified by a study of the geochemistry of the deposits. Belemnites are the only fauna of biostratigraphical importance that are abundant throughout phosphatic chalk successions, and these are discussed in detail in the subsequent chapter. More extensive taxonomic or palaeoecological studies are outside the scope of the present work although the main echinoid-morphotypes are presented in an appendix.

The final two chapters deal with present knowledge concerning the distribu-

tion and depositional environment of modern seafloor phosphorites, and finally a synthesis of the environmentally significant information presented throughout the thesis. This is utilised to propose a model for the depositional environment of phosphatic chalks. Analytical methods and results, and statistical formulae are presented in the relevant appendices.

1.4 Upper Cretaceous stages

The Cretaceous System is divided into upper and lower parts, the Upper Cretaceous corresponding approximately to the 'Chalk Formation' of earlier authors. Phosphatic chalks are restricted to a limited part of the Upper Cretaceous of northern France and southern England - the Coniacian to Campanian, and it is the stratigraphy of these stages which will be considered in detail here. None of the stages have stratotypes within the Anglo-Paris Basin, and furthermore they all lie within a different faunal province. The situation is eased considerably, however, by the Senonian (a superstage incorporating the Coniacian, Santonian and Campanian Stages) stratotype being situated within the Basin.

1.4.1 Senonian

D'Orbigny erected the Senonian Stage in 1842 for the white chalk of Sens in northern Yonne; the Turonian Stage being introduced for the sediments below the base of the Senonian. In 1857, however, Coquand proposed a subdivision of the Senonian into three substages. Coquand's work was based in the Aquitaine Basin of western France and it is here that the stratotypes for his Coniacian, Santonian and Campanian Substages remain. The biostratigraphy of the stratotypes was based on ammonites, rudists and orbitoid foraminiferans. These groups provide a firm basis for a nearly world-wide correlation, although there remains some disagreement over the location of the boundaries in the type areas (Séronie-Vivien, 1959, 1972; van Hinte, 1965; van Gorsel, 1973; Platel, 1977).

Unfortunately, ammonites and rudists are rare in, and orbitoid formainiferans wholly absent from, the white and phosphatic chalks of the Anglo-Paris Basin.

Consequently the Chalk has been subdivided on the basis of the dominant macrofauna, echinoids and (in the upper part) belemnites (Hébert, 1863a, 1866, 1872a, b, 1875a; Barrois, 1876, 1878a, b; Lambert, 1878, 1879). This method of zonation was applied to the English succession by Hébert (1874) and Barrois (1876) and extended by Jukes-Browne and Hill (1903, 1904), Rowe (1899, 1900, 1901, 1903, 1904, 1908), Griffith and Brydone (1911), Brydone (1912, 1913, 1914, 1915, 1917, 1932a, b, 1939), Gaster (1924, 1925, 1929, 1932, 1937, 1939, 1941, 1944, 1951) and Wright and Wright (1942). Rawson et al. (1978) provide the most comprehensive review. English authors have, until recently, been reluctant to apply stage names to the Upper Chalk, while Griffith and Brydone (1911) and Gaster, as recently as 1951, although utilising the Senonian Stage, included the unequivocally Turonian Holaster planus Zone within it.

Although Coquand (1857) erected his substages as subdivisions of the Senonian, the correlation between the type Senonian and the other stratotypes poses the same problems as encountered with any correlation between the Aquitaine and Anglo-Paris Basins. However, the base of the Senonian must also be the base of the Coniacian and its top the top of the Campanian (or base of the Dordonian), Coquand's original intention. The Maastrichtian Stage is excluded, since it was not included in d'Orbigny's (1842) original designation, nor are there sediments of this age preserved in the Senonian type area. Coquand's (1857) substages have been subsequently elevated to full stage status both in France (e.g. Dalbiez, 1959) and England (e.g. Hancock, 1972; Rawson et al., 1978). Nevertheless, some authors (e.g. Bignot and Aubry, 1973) still regard the Senonian as a stage.

1.4.2 Coniacian

The Coniacian Stage was introduced by Coquand in 1857. The stratotype is located in the town of Cognac, Charente, in the northern part of the Aquitaine Basin. More recent work on the type area has been published by Arnaud (1877) and Séronie-Vivien (1956, 1959, 1972). The type section consists of two formations: Formation K (Arnaud, 1877, 1883; Fig. 1.1) which is composed of 6 m of sands and sandy limestones with Ostrea auricularis Brogniart but no other fossils

of correlative value (Séronie-Vivien, 1972), and Formation L (Arnaud, 1877, 1883) consisting of 7 - 8 m of glauconitic sandy-limestones containing O. auricularis, Placenticeras polyopsis Dujardin and Paratexanites bourgeoisi (d'Orbigny). Although ammonites are present in the upper unit, they are absent in the lower, but this lack of zonal indices was compensated for by de Grossouvre (1901), who recognised that the base of the Coniacian and the base of the Senonian must be, by definition, synonymous. The base of the Craie de Villedieu has been regarded as being equivalent to the base of the type Senonian (Sornay, 1957), and its rich ammonite fauna was utilised by de Grossouvre (1901) for his zonation of both the Coniacian and Santonian. He erected two assemblage zones for the Coniacian: a lower assemblage Zone of Barroisiceras haberfellneri (von Hauer), which includes Tissotia, Barroisiceras (the so-called Barroisiceras of the Craie de Villedieu and of Aquitaine are in fact Forresteria (Reesideoceras) petrocoriensis (Coquand) (= gallicum Basse) fide Basse, 1947; W.J. Kennedy pers. comm.) and early Peroniceratinae such as Peroniceras, and an upper

	COQUAND 1957	ARNAUD 1877		DE GROSSOUVRE 1901		HAUG 1908		RAWSON et al. 1978	
Senonian	Dordonian	Dordonian	S	Campanian	*P. neubergicus*	Maastrichtian	*P. neubergicus*	Maastrichtian	*P. neubergicus*
			R						
			Q						
	Campanian	Campanian	P		*H. vari*		*B. polyplocum*		*B. polyplocum*
						Campanian	*H. vari*	Campanian	*H. vari*
					M. delawerense		*M. delawerense*		*M. delawerense*
					D. bidorsatum		*D. bidorsatum*		*D. bidorsatum*
	Santonian	Santonian	N	Santonian	*P. syrtale*	After de Grossouvre (1901)			
			M		*T. texanum*				
	Coniacian	Coniacian	L	Coniacian	*P. emscheris*				
			K		*B. haberfellneri*				

Fig. 1.1 Development of Coniacian - Campanian ammonite zonations. Generic names have been revised to those in current use.

assemblage Zone of Paratexanites emscheris (Schlüter) typified by Paratexanites spp., including P. bourgeoisi (d'Orbigny). Clearly Formation L lies within the latter of the two zones.

1.4.3 Santonian

The Santonian Stage was erected by Coquand (1857) as a substage, in the same area of the Aquitaine Basin as the type Coniacian. The name originates from the town of Saintes, Charente-Maritime, but as well as the type locality, Coquand described and assigned to the Stage a variety of sections in the white chalk of the Dronne Valley (Charente). Lithologically the type Santonian consists of white chalks and limestones with flints; hardgrounds are present at some levels (Rawson et al., 1978). The macrofauna is abundant and varied with gastropods, oysters, brachiopods, bryozoans, various echinoderms and rare ammonites. In places this abundance of macrofauna produces distinctive rock types such as bryozoan-rich chalks and oyster beds. The microfauna is richer than that of the type Coniacian but is unfortunately depleted in planktonic forms, arenaceous foraminiferans predominating. The biostratigraphy of the stage in the type sections remains uncertain and no base or top have been defined, although Séronie-Vivien (1972) has suggested that the base of the Santonian is marked by the appearance of a species of Daviesina, which occurs 11 m above the base of the type section at Javrezac.

Arnaud (1877) divided the type sections into two Formations, M and N (Fig. 1.1), which he correlated with sequences in the Anglo-Paris Basin. De Grossouvre (1889) refered the stage to a zone of Placenticeras syrtale Morton, but his later work (1901) on the rich Santonian ammonite faunas of the Corbières, Aude, resulted in him dividing the stage into two assemblage zones: a lower Zone of Texanites texanum F. Roemer, which in Aquitaine occurs in association with P. syrtale (but is rare elsewhere at this level), and an upper Zone of P. syrtale in which the index ammonite occurs with various species of Pachydiscus. Both of the zonal indices have been found in the vicinity of Saintes (Séronie-Vivien, 1972 p.136).

1.4.4 Campanian

The Campanian type sections were described by Coquand (1856) from the hill slopes of 'La Grande Champagne' in the region of Auberre-sur-Dronne, Charente; he introduced the term 'Campanian' in 1857 and designated a type area in 1858. Coquand (op cit.) regarded the Campanian as being the white chalk with Pycnodonte vesicularis (Lamarck), the various beds overlying this horizon (his Formations Q, R and S) he refered to his Dordonian Stage. Arnaud (1877) designated the beds with P. vesicularis as Formation P, the upper limit of which he drew below Coquand's (Fig. 1.1), at the incoming of Orbitoides media (d'Archiac); he went on to describe a series of ammonite assemblages from throughout the Aquitaine Basin. De Grossouvre (1897) demonstrated that Arnaud's Formation S was a local facies of Formation R, while Formation R contained the same fauna as Formation Q; consequently disputing the status of the Dordonian Stage and regarding it as the upper part of the Campanian. Arnaud (1897) later agreed with De Grossouvre's (1897) facies interpretation but proved that the ammonites from his Formations Q and R were different from those within Formation P, concluding that the Dordonian was a viable stage. De Grossouvre (1901) later suggested that the Dordonian was a junior synonym of the Maastrichtian, but nevertheless still regarded it as being the upper part of the Campanian (he did not recognise a Maastrichtian Stage). He consequently divided his Campanian into four ammonite zones characterised (from top to bottom) by: Pachydiscus neubergicus (von Hauer), Hoplitoplacenticeras vari (Schlüter), Menabites (Delawerella) delawerensis (Morton) and Diplacomoceras bidorsatum (Roemer).

Haug (1908) in his study of the French Maastrichtian divided that stage into two zones, an upper Zone of P. neubergicus and a lower Zone of Bostrychoceras polyplocum (Roemer). The lower of these zones corresponded to the upper part of De Grossouvre's (1901) undivided Zone of H. vari. Some authors (Dalbiez, 1959; Rawson et al., 1978) have reverted to Arnaud's (1897) junction between the Campanian and the Maastrichtian (Fig. 1.1) and place the limit of the Campanian at the top of the B. polyplocum Zone. Platel (1977), however, still regards the P. neubergicus Zone as being the uppermost zone of the Campanian and does not

recognise any Maastrictian in the Campanian type area. The Maastrichtian is now generally regarded as being coextensive with the range of Scaphites (Hoplo-scaphites) constrictus (J. Sowerby) and its base is marked by the entry of Belemnella lanceolata lanceolata (Schlottheim).

1.5 Coniacian to Campanian zones

Chalk zonations have a long and complex history extending back into the middle of the last century. It was soon realised by workers such as Mantell, that fossils provided the key to the division of the Chalk, but it was not initially regarded as being important to distinguish between lithostratigraphical and biostratigraphical units. This is amply demonstrated by Hébert's (1863a, 1866) zonal scheme which combines the two concepts without any regard to such considerations (Fig. 1.2). The limitations of these early zonations has been recognised

HEBERT 1863a,b 1866	HEBERT 1872a,b 1875a	BARROIS 1878a,b	LAMBERT 1878 1879			THIS WORK
Craie à *Belemnitella mucronata*	Craie à *Belemnitella mucronata*	Craie à *Belemnitella mucronata*	Assise à *B. mucronata*	P	Zone à *Magas pumilus*	*Belemnitella langei* Zone *Belemnitella minor* Zone
				O	Zone à *Micraster brongniarti*	*Belemnitella mucronata* Zone
Craie à *Belemnitella quadrata*	Craie à *Belemnitella quadrata*	Craie à *Belemnitella quadrata*	Assise à *B. quadrata*	N	Zone à *Offaster corculum*	*Gonioteuthis quadrata* Zone
				M	Zone à *Offaster pilula*	*Offaster pilula* Zone
Craie à *Micraster coranguinum*: Craie à *Micraster coranguinum*; Craie à silex caries	Craie à *Micraster coranguinum*: Craie à silex caries	Craie à *Micraster coranguinum*: Craie à *Marsupites*	Assise à *Micraster coranguinum*	L	Zone à *Marsupites ornatus*	*Marsupites testudinarius* Zone
				K	Zone à *Micraster coranguinum*	*Uintacrinus socialis* Zone
				J	Zone à *Echinocorus conicus*	*Micraster coranguinum* Zone
				I	Zone à *Epiaster gibbus*	
Craie à *Micraster cortestudinarium*: Craie à silex zonés	Craie à *Micraster coranguinum*: Craie à silex zonés	Craie à *Micraster coranguinum*: Craie à *I. involutus*	Assise à *Micraster cortestudinarium*	H	Zone à *Holaster placenta*	*Micraster decipiens* Zone
Zone à *Holaster placenta*	Zone à *Micraster cortestudinarium*	Craie à *Micraster cortestudinarium*		G	Zone à *Micraster cortestudinarium*	
Zone à *Holaster planus* et *Micraster breviporus*	Craie à *Micraster breviporus*	Craie à *M. breviporus*: Zone à *E. brevis*		F	Zone à *Epiaster brevis*	
		Zone à *H. planus*			Zone à *Holaster planus*	
					Zone à *Holaster icaunensis*	

Fig. 1.2 Correlation of macrofaunal zonations of the Coniacian - Campanian of northern France. Double line indicates the base of the Coniacian.

by contemporary geologists but the influence of lithology on the present zonal scheme has received much less acknowledgment; even authors such as Rowe (op cit.) and Brydone (1912) who, although professing to adhere to biostratigraphical principles, commonly took convenient lithological changes as their zonal boundaries. The aim of this review is to clarify the meaning of the Coniacian to Campanian zones and where necessary, to redefine them on a biostratigraphical basis. It is only by such a review that a zonal scheme may be applied meaningfully to the sequences to be considered.

Chalk zones are of a relatively long duration (1 - 4 million years; Van Hinte, 1976) when compared to those established in other Systems. This is mainly due to the general lack of common, rapidly-evolving forms (in particular ammonites) which form the basis of most other Mesozoic zonations. A comprehensive microfaunal zonation has only been developed in the last decade and consequently remains in a state of flux. At the present time (1979) the zonation is no more precise than that utilising macrofossils; it does of course have distinct advantages over the latter for the dating of poor exposures and cores.

1.5.1 *Micraster decipiens* Zone (*M. cortestudinarium* of authors)

Hébert (1863a) was the first author to use *M. 'cortestudinarium'* as a zonal fossil when he grouped together his Zones of *Holaster planus* et *Micraster breviporus*, *Holaster placenta* and the 'Craie à silex zonés' into a 'Craie à *M. cortestudinarium*' (Fig. 1.2). In later papers (1872a, b, 1875), however, he replaced the Zone of *H. placenta* by a Zone of *M. cortestudinarium* and abolished his earlier term 'Craie à *M. cortestudinarium*'. Barrois (1878a, b) then reutilised the original term 'Craie à *M. cortestudinarium*' as a synonym of Hébert's (op cit.) Zone of *M. cortestudinarium*. Lambert (1878, 1879) further complicated the picture by coining the term 'Assise à *M. cortestudinarium*' which he subdivided into a Zone of *H. placenta* (H), a Zone of *M. cortestudinarium* (G) and a Zone of *Epiaster brevis* (F). The reintroduction of a *H. placenta* Zone in combination with a lower *M. cortestudinarium* Zone, makes a correlation between his scheme and the earlier ones uncertain. Lambert (in de Grossouvre, 1901) replaced the

name M. cortestudinarium (Goldfuss) by M. decipiens (Bayle) (the former may not even occur in the Anglo-Paris Basin), a revision only recently recognised by English authors (Stokes, 1975, 1977; Rawson et al., 1978).

The English application of the M. cortestudinarium Zone also originates from Hébert (1874), who assigned the upper part of the "chalk with abundant flints and many fossils", coming above the H. planus Zone at St Margaret's Bay (north of Dover, Kent) to the M. cortestudinarium Zone. Soon afterwards, Barrois (1876) determined the extent and distribution of the zone throughout England. The base of the zone is marked by the disappearance of abundant H. planus Mantell, Micraster corbovis Forbes and M. leskei (Des Moulins) (Rowe, 1900); rare H. planus continue on up into the M. 'cortestudinarium' Zone (Rowe, 1900; Jukes-Browne and Hill, 1904) so that only the Micraster provide a certain zonal guide. However, the M. cortestudinarium Zone sensu Hébert (1874) does not correspond to the total range Zone of M. decipiens, which extends up into the lowest third of the overlying M. coranguinum Zone, where it is replaced by Micraster coranguinum (Leske) (Peake in Hancock, 1972). Griffith and Brydone (1911) consequently included all beds containing M. decipiens in the M. cortestudinarium Zone, a practise followed by Peake and Hancock (1961) in Norfolk. Such a total range Zone of M. decipiens is a more readily applicable unit than has been used previously, but it has not received wide acceptance. This is probably because, over most of southern England, the M. cortestudinarium Zone sensu Hébert (1874) is lithologically a distinct unit of richly-fossiliferous nodular chalks and hardgrounds which, at the top, passes into massive white chalks with few macrofossils other than large-inoceramid fragments. This change in the abundance of fossils is accompanied by a change in the shape of Echinocorys from gibbous to taller, flatter-based forms (Peake in Hancock, 1972).

Stokes (1975, 1977) has argued that, in the lower part of the M. cortestudinarium Zone, M. decipiens is less common than M. normanniae Bucaille, a form that appears at the summit of the underlying H. planus Zone. He therefore subdivides the M. cortestudinarium Zone into a lower M. normanniae Zone as used in Normandy (Cayeux, 1967) and (following the usage of de Grossouvre, 1901) an upper M. decipiens Zone. The M. normanniae Zone sensu Stokes is therefore a concurrent

range zone, since both Micraster occur within it. This contrasts to the French application of the zone, since there it is apparently a total range zone (Cayeux, 1967). This disparity diminishes the value of the zone, which will not be utilised here. It is suggested, therefore, that a total range Zone of M. decipiens is a more workable zone than the old M. cortestudinarium Zone. Guide fossils include Sternotaxis placenta (Agassiz) in the lower part, and 'low zonal' M. coranguinum and Volviceramus involutus (J. de C. Sowerby) in the upper part, which also commonly contains abundant large broken fragments of Platyceramus.

1.5.2 Micraster coranguinum Zone

Hébert (1863a) designated the 'Craie à Micraster coranguinum' for the upper division of his 'craie marneuse' the middle division of which he subdivided off as his 'Craie à M. cortestudinarium'. In 1872 (1872a, b) he redefined the zone to include an upper bed with 'carious flint' and a lower one with 'zoned flint'; the latter of these he had previously (1866) assigned to the 'Craie à M. cortestudinarium'. Prior to this he had reevaluated his 'craie marneuse' and repositioned the M. coranguinum Zone as the lower part of a 'craie blanche' (Fig. 1.2).

The M. coranguinum Zone was introduced into England by Hébert (1874) who stated that it corresponded to Whitaker's (1865a) 'St Margaret's Chalk', Dowker's (1870) 'Ramsgate Chalk' and included the greater part of the 'Margate Chalk'. Barrois (1875a) followed this usage but later (1875b) excluded the upper portion (Fig. 1.3) which he refered to a new 'Zone à Marsupites'. In 1876 he removed a portion of the upper part of the M. cortestudinarium Zone and added this to the base of the M. coranguinum Zone . This established the M. coranguinum Zone as it has generally been applied to English sequences.

Barrois (1878) later applied this bipartite division in France (Fig. 1.2), but there he used the term 'Craie à Marsupites' as an approximate equivalent of Hébert's (1866) chalk with carious flint and a 'Craie à Inoceramus involutus' for that authors beds with zoned flint. However, as pointed out by Jukes-Browne and Hill (1904), in England cavernous flints are more abundant in the lower part of the M. coranguinum Zone and banded flints higher up, so that the character of

the flint is of local value only.

Barrois (1878) had demonstrated that the lower part of the M. coranguinum Zone was characterised by Volviceramus involutus and the upper part by Micraster (Isomicraster) senonensis Lambert and Conulus albogalerus Leske, but no zonation based on these observations has been utilised in England. In France, however, Lambert (1878), reverting to Hébert's (1866) zonation, placed Barrois' 'Craie à I. involutus' within an 'Assise à M. cortestudinarium', renaming it the 'Zone à Holaster placenta' (H). Furthermore, he divided the 'Craie à Marsupites' of Barrois (1878) into four zones, characterised by: M. (Isomicraster) senonensis (I), Conulus albogalerus (J), M. coranguinum (K) and Marsupites testudinarius (Schlottheim) (L). He grouped these four zones into an 'Assise à M. coranguinum'.

The location of the M. decipiens/M. coranguinum Zone boundary has been discussed (see above). The top of the M. coranguinum Zone is characterised by common Conulus albogalerus, which forms a 'Conulus band' in east Kent (Rowe, 1900),

		BARROIS 1875b 1876	GRIFFITH AND BRYDONE 1911 BRYDONE 1912	RAWSON et al. 1978	THIS WORK
SENONIAN	Assise à Belemnitelles	Zone à Belemnitelles	— — — — — —	*Belemnitella mucronata* Zone	*Belemnitella langei* Zone
			Belemnitella mucronata Zone		*Belemnitella minor* Zone
					Belemnitella mucronata Zone
	Assise à Marsupites	Zone à Marsupites	*Actinocamax quadratus* Zone	*Gonioteuthis quadrata* Zone	*Gonioteuthis quadrata* Zone
			Offaster pilula Zone	*Offaster pilula* Zone	*Offaster pilula* Zone
			Marsupites testudinarius Zone	*Marsupites testudinarius* Zone	*Marsupites testudinarius* Zone
	Assise à Micrasters	Zone à *M. coranguinum*	*Micraster coranguinum* Zone	*Uintacrinus socialis* Zone	*Uintacrinus socialis* Zone
				Micraster coranguinum Zone	*Micraster coranguinum* Zone
		Zone à *M. cortestudinarium*	*Micraster cortestudinarium* Zone	*Micraster cortestudinarium* Zone	*Micraster decipiens* Zone
TURONIAN (pars)		Zone à *Holaster planus*	*Holaster planus* Zone	*Holaster planus* Zone	
		Zone à *T. gracilis*	*Terebratulina gracilis* Zone	*Terebratulina lata* Zone	

Fig. 1.3 Correlation of macrofaunal zonations of the the Coniacian - Campanian of southern England. Double line indicates the base of the Coniacian.

and the occurrence of Gonioteuthis westfalica (Schlüter). Actinocamax verus occurs at the summit of the zone (Peake in Hancock, 1972). For discussion of the upper limit of the zone, see below. The M. coranguinum Zone is, however, a partial range zone characterised by the absence of the index fossils of the under and overlying zones, and not only the presence of M. coranguinum.

1.5.3 Uintacrinus socialis Zone

Rowe (1900) used the term 'Uintacrinus band' and 'Marsupites band' for the lower and upper portions of his Marsupites testudinarius Zone in Kent. White (1909) proposed to elevate the 'Uintacrinus band' to subzonal status and in 1911, Griffith and Brydone established it as the uppermost subzone of an extended M. coranguinum Zone. This was not generally accepted (e.g. Gaster, 1937) because the faunal change at the base is more pronounced than at its top (Peake in Hancock, 1972). Wright and Wright (1942) accorded the subzone full zonal status, a suggestion made earlier for the Yorkshire succession (Rowe, 1908). Rowe's (1900) application of the 'Uintacrinus band' did not correspond to the range of the index fossil, but Peake (1958) suggested changing the boundary so that the base would approximate to the first occurrence of Uintacrinus socialis Grinnel (a suggestion followed by Peake and Hancock, 1961) and the top to the first appearance of Marsupites testudinarius. Occasionally, Uintacrinus and Marsupites coexist e.g. in Kent (Peake in Hancock, 1972) and Hampshire (Griffith and Brydone, 1911), but such examples are rare (and the Uintacrinus may be a different species), effectively making the U. socialis Zone a total range zone.

The zone is typified by 'high zonal' Micraster, flat-topped Echinocorys striata Lamarck, Actinocamax verus and Cretirhynchia plicatilis (J. Sowerby). Rare Gonioteuthis westfalicagranulata also occur at this level (Chapter 5).

1.5.4 Marsupites testudinarius Zone

Barrois (1875b) originally defined the M. testudinarius Zone at Margate, Kent, as the Chalk above the M. coranguinum Zone and below the 'Zone à Belemni-

telles'. He traced his 'Assise à Marsupites' (consisting of a single Zone of M. testudinarius) across Britain (1876). Included in his definition were the uppermost beds of Hébert's (1872a, b, 1875a) M. coranguinum Zone and a greater part of that authors 'Craie à Belemnitella quadrata', which Barrois did not immediately recognise in England. Later, Barrois (1878a, b) separated a B. quadrata Zone after having previously (1876 p.112) recognised it during his study of the M. testudinarius Zone; he then regarded the 'Craie à Marsupites' as the upper part of his 'Craie à M. coranguinum'. Thus, in all Barrois' applications of the M. testudinarius Zone, its range was always greater than that of the index fossil. After the removal of the 'B.' quadrata Zone from the M. testudinarius Zone (Barrois, 1878), the top of the zone was readily defined by the upper limit of the index fossil. At the type locality, however, Barrois took the base of the zone at the 'Barrois sponge-bed', this meant that the lower part of the zone (although containing a distinctive faunal assemblage) did not contain the zonal fossil. With the recognition of the 'Uintacrinus band' (Rowe, 1900) and the erection of the U. socialis Zone (Wright and Wright, 1942), the zone became a total range zone.

In most areas the top of the M. testudinarius Zone has been taken as the uppermost range of the index fossil. However, Osbourne-White (1909) included, near Basingstoke and elsewhere, 5 - 7 m of chalk with Gonioteuthis granulata (Blainville) within the zone. These beds, which do not contain the zonal fossil, he termed the 'granulatus beds'. Brydone (1915) describes a similar situation in Sussex, where he recognised 5 m of chalk with G. granulata and Uintacrinus anglicus Rasmussen, occurring above the range of M. testudinarius. Recently, Rawson et al. (1978) have defined the top of the M. testudinarius Zone as being located slightly above the upper limit of the index species, with the base of the overlying Offaster pilula Zone being taken at the base of the band of U. anglicus (Griffith and Brydone's, 1911 bed 5).

Despite the M. testudinarius Zone being erected by a French author, it was not established in France until later than in England (Barrois, 1878a, b). As in England, the 'Craie à Marsupites' was found to be too imprecise a term and Lambert (1878, 1879) divided it into four zones (see discussion in 1.5.2).

Lambert's (op cit.) Zone L was typified by Marsupites ornatus (both M. ornatus and M. milleri are junior synonyms of M. testudinarius; Sieverts, 1927; Rasmussen, 1961) and was presumably established as a range zone. Recent French authors (e.g. Bignot and Ebrahimzadeh-Assadian, 1969; Bignot and Aubry, 1973) still retain the zone sensu Lambert (1878).

The restricted range and widespread occurrence of M. testudinarius throughout the Anglo-Paris Basin makes a total range Zone of M. testudinarius a readily applicable biozone, and this is, therefore, the definition recognised here; this follows the usage of Griffith and Brydone (1911). The most characteristic fossil of the zone (other than the index species) is Echinocorys elevata Brydone, which is generally confined to it (Griffith and Brydone, 1911; Brydone, 1912; see however discussion of the biostratigraphy of Beauval quarry: 2.3.2). Other fossils which are typical of, but not restricted to, the zone are Actinocamax verus and nipple-shaped heads of Bourgueticrinus (Rowe, 1900; Griffith and Brydone, 1911). Gonioteuthis granulata is at its most abundant in the upper part of the zone (Rowe, 1900; Jukes-Browne and Hill, 1904; see Section 5.4).

1.5.5 Offaster pilula Zone

Lambert (1878) introduced the Zone of Offaster pilula (M) in the area of the type Senonian and designated the 'Craie de Sourcy' as the type. Rowe (1900) suggested the term to replace the 'Actinocamax' quadratus Zone, but did not adopt this in his work. Jukes-Browne (1912) also suggested the erection of an O. pilula Zone but gave no details concerning the limits of such a zone. A few months later, however, Brydone (1912) carefully defined a new Zone of O. pilula which he divided into two subzones, a lower one characterised by Echinocorys depressula Brydone, and an upper one of 'abundant O. pilula'. These subzones had been previously (Griffith and Brydone, 1911) regarded as being the lower part of the Gonioteuthis quadrata Zone.

The O. pilula Zone has its base above the upper range of M. testudinarius which disappears at the same time as E. elevata, Bourgueticrinus papilliformis Brydone and Terebratulina rowei Kitchin. The top is taken above a bed of abundant

large (25 mm) inflated Offaster pilula (Lamarck), which thereafter becomes extremely rare. Gaster (1924), working in Sussex, extended Brydone's (1912) Zone to include the immediately-overlying horizon characterised by Hagenowia rostrata Forbes. He considered that this horizon has at its top an upper band of Echinocorys cincta Brydone in association with E. depressula, and therefore proposed to replace Brydone's (1912) 'Subzone of abundant O. pilula' by an extended E. cincta Subzone. Brydone (1939), however, disputed Gaster's (op cit.) identifications of the Echinocorys and therefore the subsequent enlargement of the zone. Furthermore, Gaster's (1924) zonation has not been established beyond Sussex, and has therefore not been accepted widely by English geologists, although his H. rostrata horizon has been utilised as a local subdivision of the G. quadrata Zone (Hayward, 1940), of which it forms the base.

A more detailed macrofossil biostratigraphy is available for the O. pilula Zone than any other Coniacian to Campanian zone. The zonal subdivisions are based on echinoids, in particular O. pilula and various species of Echinocorys (Fig. 1.4). The divisions utilised here, and by most other workers in southern England, are essentially those of Griffith and Brydone (1911) and Brydone (1912). The zone is divided into two subzones. Although it is the index species, E. depressula is not always the dominant Echinocorys within the lower subzone; at the base there lies a belt of E. tectiformis Brydone, and at the summit there is a similar belt of E. truncata Brydone. E. depressula is, however, both restricted to, and characteristic of, the subzone, although other 'passage forms' of Echinocorys become common in Sussex. O. pilula occurs sporadically throughout the E. depressula Subzone, but is very rare towards the base. Ostrea wegmanniana d' Orbigny) and O. incurva Nilsson are abundant in the lower part. The 'abundant O. pilula' Subzone is divided into three belts (Fig. 1.4). A lower belt of abundant O. pilula, a middle belt in which E. cincta Brydone predominates, and an upper belt of abundant O. pilula. O. pilula occurs throughout all three belts but is commonest in the upper belt where it increases in size, particularly towards the summit. It is fairly common in the lower belt, but scarce in the E. cincta belt. The base of the lower belt lies within a belt of E. tectiformis which spans the junction between the two subzones. The top of the upper belt is

marked locally by the 'planoconvexus Bed' which contains abundant abnormally-large O. pilula. The abundant O. pilula Subzone is also typified by rare Gonioteuthis granulataquadrata (Stolley) and G. quadrata quadrata (Blainville), Bourgueticrinus elegans Brydone, B. fritillus Brydone (the dice-box form) and Gryphaeostrea canaliculata (J. Sowerby) var. striata Gaster.

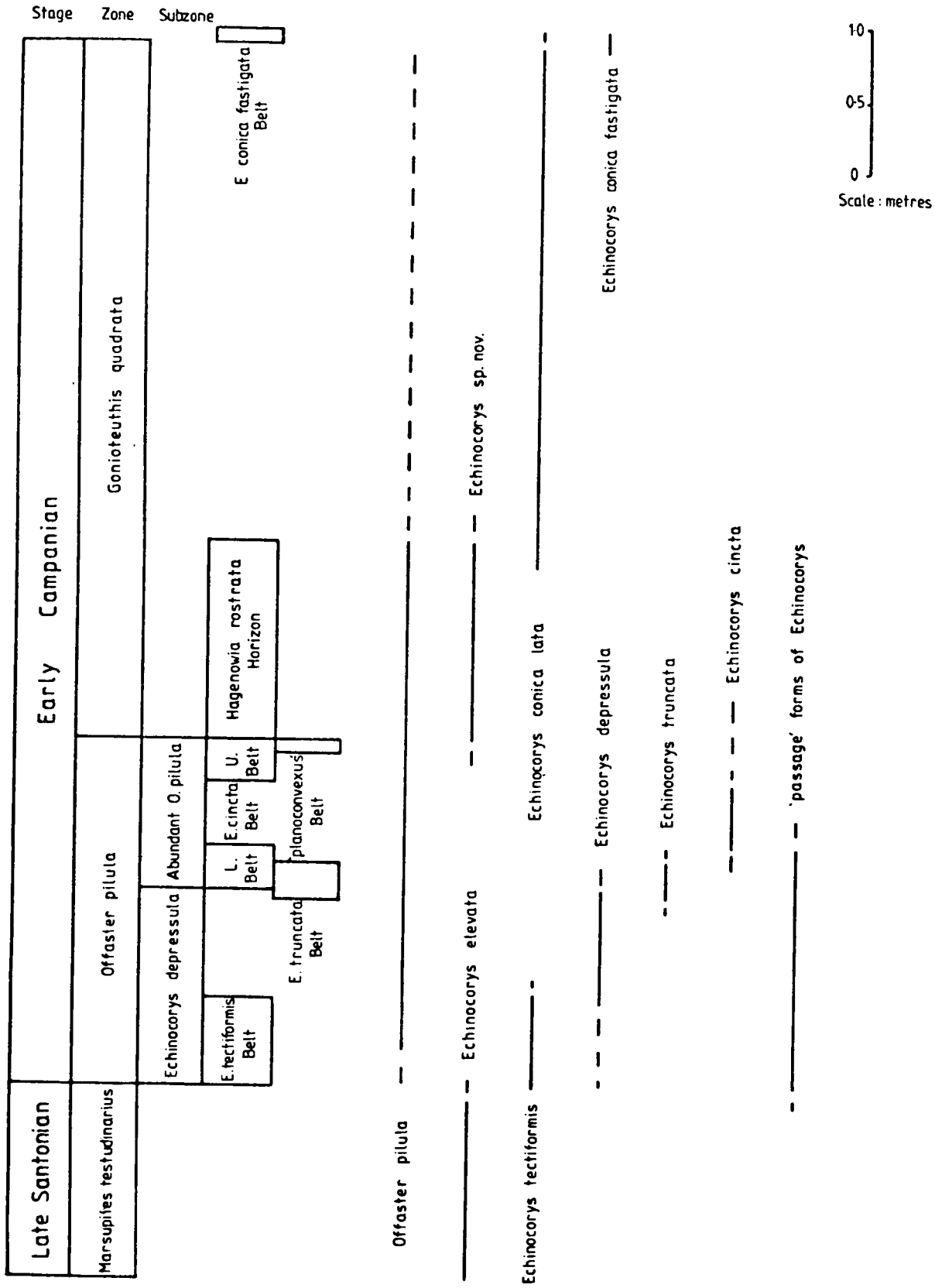

Fig. 1.4 Zonation of the late Santonian and early Campanian based on echinoderms and belemnites. The ranges of the major Echinocorys species are shown (Echinocorys from phosphatic chalks are figured in Appendix 3). The scale is based on an average succession in the Hampshire Basin. Data from Griffith and Brydone (1911), Brydone (1912), Smiser (1935), Willcox (1953c) and Peake (in Hancock, 1972).

1.5.6 Gonioteuthis quadrata Zone

The Gonioteuthis quadrata Zone was first recognised by Strombeck in Germany in about 1855 (Jukes-Browne and Hill, 1904) and was subsequently applied by Hébert (1863a, b) in France for the lower beds of the 'Craie de Meudon' sensu lato or the 'Craie blanche' of the same author. The zone has been utilised in France by Hébert (1866, 1872a, b, 1875a, b) and Barrois (1878a, b, c), while Lambert (1878) grouped together his Zones of Offaster pilula (M) and O. corculum (N) into an 'Assise à Belemnitella quadrata'. Barrois (1876) only distinguished two divisions above his M. coranguinum Zone in England, an upper 'Assise à Belemnitelles' and a lower 'Assise à Marsupites'. Later in the same work (1876 p.112) he introduced a 'Belemnitella' quadrata Zone as a lower division of his 'Assise à Belemnitelles'. He subsequently used a similar scheme in France (1878).

Rowe (op cit.) traced the G. quadrata Zone throughout England, but realised that the index fossil was restricted to the summit of the zone, its place being taken lower down in the succession by G. granulata (and prior to this G. granulataquadrata). He therefore suggested that Offaster pilula was a better zonal fossil for the lower part, but did not adopt his own suggestion. Brydone (1912) removed the lower portion of the old 'Actinocamax' quadratus Zone and assigned it to his new O. pilula Zone, leaving a restricted 'A.' quadratus Zone which approximated to the range of the index fossil. Attempts by Gaster (op cit.) to extend the O. pilula Zone into the 'A.' quadratus Zone sensu Brydone have not received wide acceptance (1.5.5), but his lower horizon of Hagenowia rostrata remains of local value in Sussex at the base of the G. quadrata Zone.

Wright and Wright (1951) referred the zonal fossil to the genus Gonioteuthis. In addition to G. quadrata the zone contains Saccoma cretacea Bather, Echinocorys conica lata Lambert and related narrow forms (Peake in Hancock, 1972). The top of the zone could be located at the uppermost limit of Gonioteuthis, which disappears after a short period of coexistence with Belemnitella mucronata Schlottheim. G. quadrata is, however, rare in white chalk facies and would not make a good zonal fossil if it were not for the relative abundance of B. mucronata in the overlying zone (Jukes-Browne and Hill, 1904). Consequently, I regard the

incoming of B. mucronata as a better limit to the G. quadrata Zone than the disappearance of Gonioteuthis. The boundary is marked locally (e.g. Portsmouth and the Isle of Wight) by a band of Echinocorys conica fastigata Lambert, which is taken to mark the base of the B. mucronata Zone (Griffith and Brydone, 1911).

1.5.7 Belemnitella mucronata Zone

Hébert (1863a, b) divided his 'Craie à Belemnitelles', the uppermost 'Craie de Meudon sensu lato' into two beds: an upper 'Assise à B. mucronata' or 'Craie de Meudon sensu stricto', and a lower 'Assise à B. quadrata' or 'Craie de Reims'. The zone was applied to the English succession by Barrois (1876) who initially used it for all the chalk overlying his M. testudinarius Zone, but later in the same work (1876 p.112), he assigned the lower portion of this chalk to the G. quadrata Zone.

The base of the zone is easily recognised by the influx of common B. mucronata, but, as noted above, this influx does not coincide with the disappearance of Gonioteuthis. The zone may be subdivided, therefore, into two subzones: a lower one of B. mucronata and G. quadrata gracilis (Stolley) (regarded as a zone by Ernst, 1963a and Christensen, 1975a p.17), and an upper subzone where B. mucronata occurs alone. In practise the lower of these subzones is rarely identifiable in the Anglo-Paris Basin, chiefly due to the scarcity of Gonioteuthis compared to Belemnitella in white chalks. This contrasts strikingly with the rich belemnite-bearing horizons of northern Germany and northern Poland (Christensen, 1975a), where the subzone was first recognised (Schmid, 1953). The presence of this lower concurrent range subzone has caused some difficulties with previous authors. Rowe (1908) noted the coexistence of the two genera and drew the base of the B. mucronata Zone below the first occurrence of B. mucronata. Brydone (1912 p.9), however, misguidedly attempted to use a lithological marker for his G. quadrata/B. mucronata Zone boundary, in the middle of what was clearly the B. mucronata-G. q. gracilis Subzone.

Previous French and English workers (Hébert, 1872a, b, 1875a; Lambert, 1873; Barrois, 1876; Rawson et al., 1978) have, in general, regarded the zone as

a range Zone of B. mucronata. German authors and others however (see Christensen, 1975a, 1976b), have subdivided the range zone into three belemnite zones, based on various species of Belemnitella. Since the lower two of these zones have been recognised in the Anglo-Paris Basin (see below), they will be utilised here. Consequently, the top of the B. mucronata Zone is defined as being immediately below the first appearance of Belemnitella minor Jeletzky, and is therefore a partial range zone.

The base of the B. mucronata Zone is marked in southern England by a band of Echinocorys conica fastigata and is characterised by E. conica (Agassiz), although later forms of Echinocorys, and Magas pumilus J. Sowerby occur towards the summit of the zone (Peake in Hancock, 1972). Lambert (1878, 1879, 1902) divided his 'Assise à B. mucronata' into two zones: a lower Zone of Micraster brongniarti Hébert, and an upper Zone of M. pumilus. Clearly, the B. mucronata Zone as defined here includes all of the lower zone and the lower portion of the upper (see below).

1.5.8 Belemnitella minor Zone

The B. minor Zone was originally applied in Germany (see Christensen, 1975a) but was first utilised in southern England by Peake and Hancock (1961) and Hancock (1975). Unfortunately, the latter authors did not define their zone, although their meaning was presumably similar to that of eastern European workers. Peake and Hancock (1961 p.332) considered that the highest chalk in southern England lies within the middle of the B. minor Zone. The distribution of the zone within the Anglo-Paris Basin remains uncertain, but the limited number of localities with B. mucronata Zone (sensu de Grossouvre, 1901) chalk in France, suggests that the poor preservation of the highest Cretaceous zones in southern England is similar in France. Certainly, post-B. mucronata Zone chalk is rarely exposed on land in the Anglo-Paris Basin (Marlière, 1954).

The base of the zone is here defined as being immediately below the first appearance of Belemnitella minor; the top is designated as being immediately below the first occurrence of B. langei Jeletzky, making the zone a concurrent

range zone. Guide fossils include Cretirhynchia lentiformis (S. Woodward), Echinocorys subglobosa (Goldfuss) (in the lower part), Micraster glyphus (Schlüter) and M. (Isomicraster) stolleyi Lambert (in the upper part). B. mucronata and Magas pumilus range throughout the zone.

1.5.9 Belemnitella langei Zone

The zone has a similar history of usage to that of the B. minor Zone (1.5.8). The B. langei Zone is here defined as being the total range Zone of Belemnitella langei. Guide fossils include Cretirhynchia arcuata Pettit, Cardiaster ananchystis (Leske), Galerites abbreviatus Desor, and, towards the top, Echinocorys pyramidata Portlock. Belemnitella mucronata, B. minor and Magas pumilus range throughout the zone and beyond. The M. pumilus Zone (Lambert, 1878) presumably encompasses both the B. minor and B. langei Zones.

1.6 Stage boundaries and the zonal scheme

1.6.1 Coniacian

As demonstrated previously (1.4.2), the base of the Craie de Villedieu is generally regared as being the base of the Senonian and therefore the Coniacian. Ammonites are rare in white chalk lithofacies of the Anglo-Paris Basin, so a direct correlation with the Craie de Villedieu must be based on other groups of fossils. Unfortunately, there has been no recent work on either the macro- or microfauna of this formation.

Micraster decipiens occurs in the lower part of the Craie de Villedieu (de Grossouvre, 1901), indicating that the M. decipiens Zone is, at least in part, of Coniacian age. The base of the stage is commonly taken at the base of the M. coranguinum Zone (Rawson et al., 1978), but the M. decipiens Zone contains common Micraster normanniae at its base (Stokes, 1975, 1977), a form regarded by French authors (Jodot, 1965) as being of Turonian age. De Grossouvre (1901) considered that M. decipiens ranges down into the Turonian and this is substant-

iated by the entire spatangoid fauna of the lowest M. decipiens Zone (Stokes, 1975), which has a Turonian aspect. Thus the lower portion of the M. decipiens Zone is probably within the Upper Turonian, but without ammonite evidence, the exact boundary must remain uncertain.

Rawson et al. (1978) argued that the recent discovery of Coniacian ammonites including Barroisiceras cf. haberfellneri within the German 'Schloenbachi Schichten' near Anrochte in West Germany suggests (since both this horizon and the upper part of the M. decipiens Zone yield Inoceramus schloenbachi Bohm) a B. haberfellneri Zone (early Coniacian) age for the upper portion of the M. decipiens Zone. De Grossouvre (1901 p.793) demonstrated that the reidentification of some of Bucaille's Micraster from near Chartres indicated the presence of M. coranguinum within an undoubtedly Coniacian section, but he was unable to determine a precise boundary. Thus the Coniacian must include the upper part of the M. decipiens Zone and since Rawson et al. (1978) record two Santonian texanitids from the high M. coranguinum Zone of Kent, only the lower portion of the M. coranguinum Zone.

1.6.2 Santonian

The upper part of the Craie de Villedieu (of undoubted Santonian age) has been correlated with beds yielding Marsupites testudinarius near Chartres (de Grossouvre, 1901 p.799). Furthermore, M. testudinarius occurs in Germany with Placenticeras syrtale, Gonioteuthis granulata and Belemnellocamax ex gr. grossouvrei (Janet), but is absent from the overlying chalk containing Diplacmoceras bidorsatum and Gonioteuthis granulataquadrata. The conclusion from these observations is that the top of the M. testudinarius Zone approximates to the top of the Santonian. The Santonian must, therefore, include the upper part of the M. coranguinum Zone, the U. socialis Zone and the M. testudinarius Zone.

1.6.3 Campanian

The base of the Campanian is generally regarded as approximating to the base

of the O. pilula Zone (see above), but the parastratotype provides no further data to enable a correlation of either the top or the bottom of the stage within the Anglo-Paris Basin. Unfortunately, the Maastrichtian stratotype falls entirely within the Upper Maastrictian Substage of current usage (Schmid, 1959a, b, 1967), so even this stratotype provides no indicator for the top of the Campanian. The Maastrichtian, however, is generally regarded as being coextensive with the range of Scaphites (Hoploscaphites) constrictus and its base is marked by the entry of Belemnitella lanceolata lanceolata (1.4.4). Consequently the Campanian includes the O. pilula, G. quadrata, B. mucronata, B. minor and B. langei Zones. On belemnite evidence alone, the Lower/Upper Campanian boundary is generally taken at the first appearance of Belemnitella minor, but there is evidence in some areas that this species appears below the boundary (Christensen, 1975a, 1976b) as generally accepted.

1.7 Foraminiferal biozones

Several authors, working on both sides of the Channel (e.g. Ebrahimzadeh-Assadian, 1968; Teherani, 1968; Barnard and Banner, 1953; Barr, 1962; Bailey, 1975) have studied the biostratigraphy of Upper Cretaceous foraminiferans. The only zonation that has been applied widely, however, is that developed by Monciardini during the recent geological remapping of France for the production of the new 1:50,000 sheets. Monciardini (e.g. in Devries et al., 1974; in Ménillet et al., 1974) has divided both the Turonian and Cenomanian into three biozones, and the Coniacian - Campanian into eleven biozones (designated by the letters a - k), based on both benthonic and planktonic foraminiferans (Fig. 1.5).

Little macrofaunal collecting has accompanied the development of Monciardini's scheme (Devries et al., 1974; Guèrin et al., 1977), so the correspondence between the macrofaunal zonation (in France after Lambert, 1878) and its microfaunal equivalent, has been based on the faunal records that accompany the 1:80,000 geological maps and other early literature. Clearly, such a correlation can, at best, only be an approximation. The only published information which enables a direct correlation between the two zonal schemes is the record of Gavelinella

cristata (Goel), G. clementiana costata (Marie) and Bolivinoides strigillatus (Chapman) at the summit of the M. testudinarius Zone of Seine-Maritime (Bignot and Ebrahimzadeh-Assadian, 1969). This association ranges from Biozone f to h, but the absence of such forms as Stensioina pommerana Brotzen and Bolivinoides decoratus Jones indicate a Biozone f age, while the presence of B. strigillatus suggests the upper part of that biozone (Fig. 1.5). The positioning of the stage

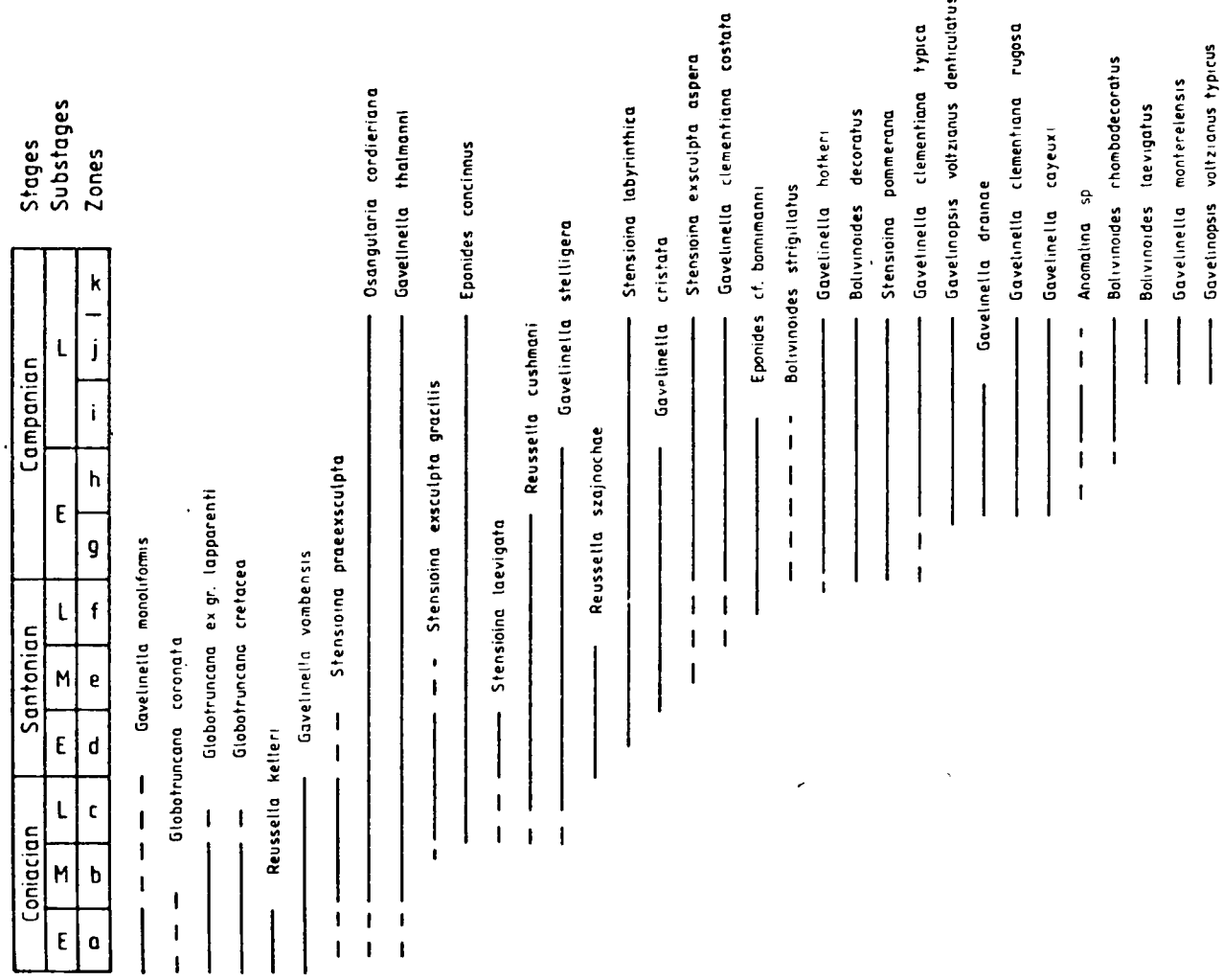

Fig. 1.5 Foraminiferal biozones of the Coniacian - Campanian of northern France. Ranges of the major guide species and their relationship to the zonation are shown. Based on Monciardini (in: Bouiller et al., 1971; Devries et al., 1974; Mathieu et al., 1975; Ménillet et al., 1974; Mennessier et al., 1974, 1976, 1978).

boundaries within the microfaunal scheme are similarly only approximate (Fig. 1.6).

A general trend which is apparent amongst the foraminiferans is the rapid reduction in planktonic species during the early Coniacian, after a peak abundance during Turonian times. The Turonian yields numerous short lived species of Praeglobotruncata and, later, Globotruncata. Following this rapid decline, the benthonic/planktonic ratio remains fairly constant throughout the Coniacian - Campanian (Monciardini in Guèrin, 1977), except in the phosphatic chalk lithofacies (Tabatabai", 1977) where the ratio of benthonic forms increases dramatically.

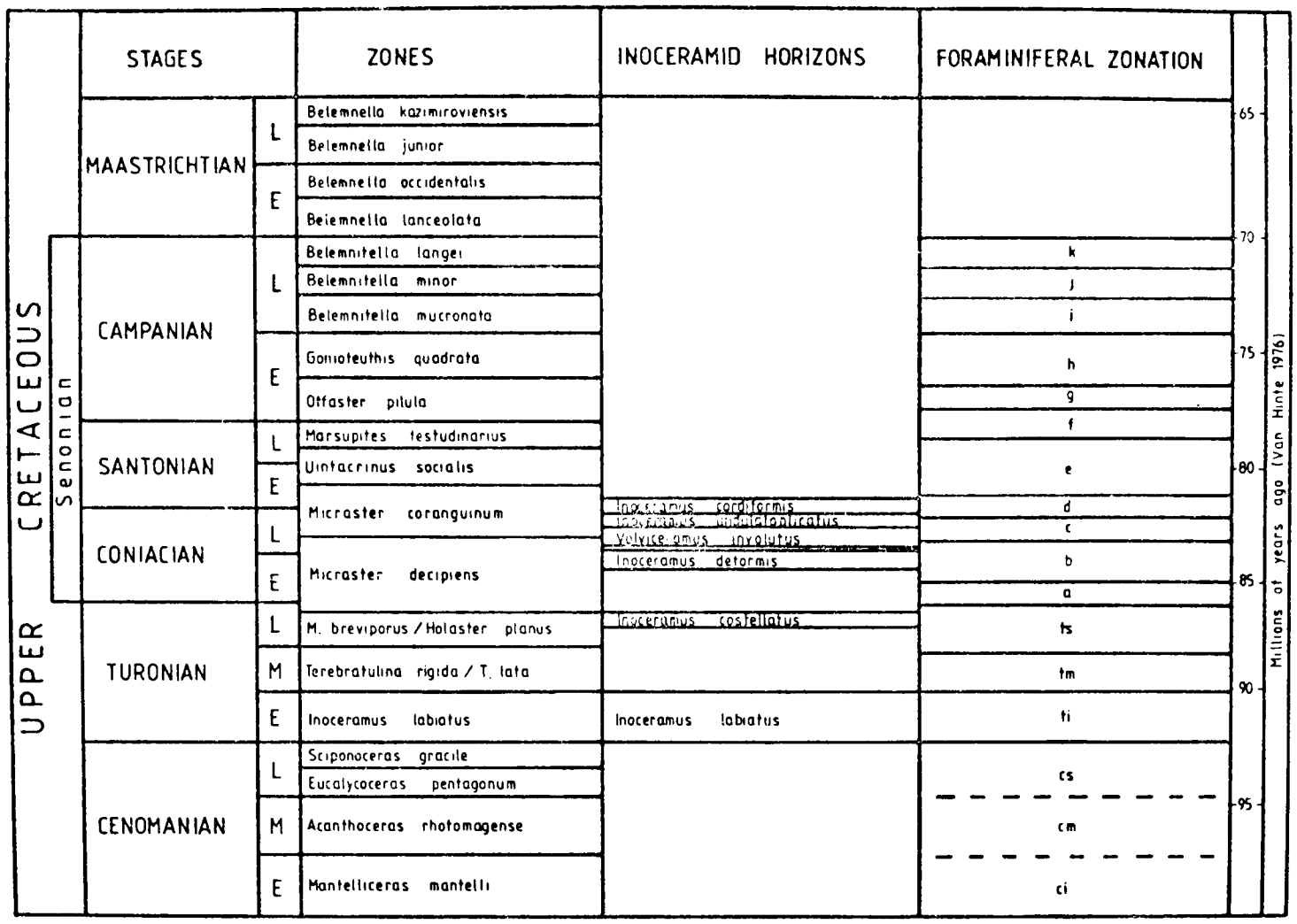

Fig. 1.6 Correlation diagram of Upper Cretaceous zonation schemes in the Anglo-Paris Basin. The zonation schemes are described in detail in the text. Inoceramid horizons provide a correlation with the German stratigraphy.

1.7.1 Coniacian

The base of the Coniacian is taken at the base of Biozone a, which is characterised by the appearance of occasional Stensioina praeexsculpta (Keller), Osangularia cordieriana (d'Orbigny) and Gavelinella thalmanni (Brotzen). Reusella kelleri Vassilenko and Gavelinella vombensis (Brotzen) originate in the Upper Turonian but do not evolve their main characteristics until the early Coniacian. Upper Turonian species of Globotruncana and Gavelinella monoliformis (Reuss) continue up into Biozone a and beyond (Fig. 1.5). Biozone b is assigned to the mid Coniacian and is characterised by the disappearance of R. kelleri at the base, and the presence of abundant G. vombensis, S. praeexsculpta, O. cordieriana and G. thalmanni. The subspecies Stensioina exsculpta gracilis Brotzen appears towards the top of the biozone. The base of Biozone c is marked by the appearance of occasional Stensioina laevigata Akimez, Reusella cushmani Brotzen and Gavelinella stelligera (Marie). Eponides concinnus Brotzen, S. exsculpta gracilis and species typical of Biozone b continue throughout, but remaining

Globotruncana spp. and Gavelinella monoliformis become extinct. The top of Biozone c approximates to the base of the Santonian.

1.7.2 Santonian

The base of Biozone d is designated by the occurrence of Reusella szajnochae Grzybowski and the disappearance of G. vombensis. Stensioina labyrinthica Cush and Dorsey replaces S. praeexsculpta towards the top of the biozone. Other species continue throughout. Gavelinella cristata Goel appears at the base of Biozone e, concurrent with the extinction of S. laevigata. S. exsculpta gracilis is replaced by S. exsculpta aspera Hofker within the biozone. Other species remain the same. Reusella szajnochae becomes extinct at the base of Biozone f but Eponides cf. bronnimanni Hofker and Gavelinella clementiana costata (Marie) appear at this time. S. exsculpta remains rare but Gavelinella hofkeri Goel and Bolivinoides strigillatus (Chapman) evolve towards the top of the biozone.

1.7.3 Campanian

The base of the Campanian approximates to the base of Biozone g, which is typified by common G. hofkeri, but also the first occurrence of Bolivinoides decoratus (Jones) and Stensioina pommerana Brotzen. Gavelinella drainae (Mjatluik) and two other species of Gavelinella appear at the base of Biozone h, R. cushmani, on the other hand, becomes extinct. Gavelinopsis voltzianus denticulatus (d'Orbigny) appears towards the top of the biozone and continues through Biozone h. The base of Biozone i is regarded as corresponding to the base of the Upper Campanian, and is marked by the disappearance of G. stelligera, G. cristata, E. cf. bronnimanni and B. strigillatus. Bolivinoides rhombodecoratus (Marie) and Anomalina sp. become abundant at this level. G. drainae disappears at the base of Biozone j but Bolivinoides laevigatus (Marie) and two species of Gavelinella appear at this level. I have been unable to obtain any information on the microfauna which characterises Biozone k, although the existence of the biozone is indicated by Monciardini (in Ménillet et al., 1974) without giving any details

This omission is of little importance to the present study, since the youngest phosphatic chalks have been dated as Biozone h (Tabatabai", 1977), furthermore, the extent of chalks of this age must be very limited within the Anglo-Paris Basin.

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2.1 Introduction

The phosphatic chalks of northern France have been described in a large volume of literature written by numerous French authors, particularly L. Cayeux, J. Gosselet, A. de Grossouvre, H. Lasne and M. Leriche, during the late nineteenth and early twentieth centuries. However, little description filtered into the English-language literature and consequently much of this rich and important work has been overlooked by contemporary geologists. The richest and most accessible deposits were mined out at the beginning of this century so that my conclusions are based on a combination of an extensive literature survey and field observation of the now sadly limited number of extant exposures of phosphatic chalk in the Anglo-Paris Basin (Fig. 2.1).

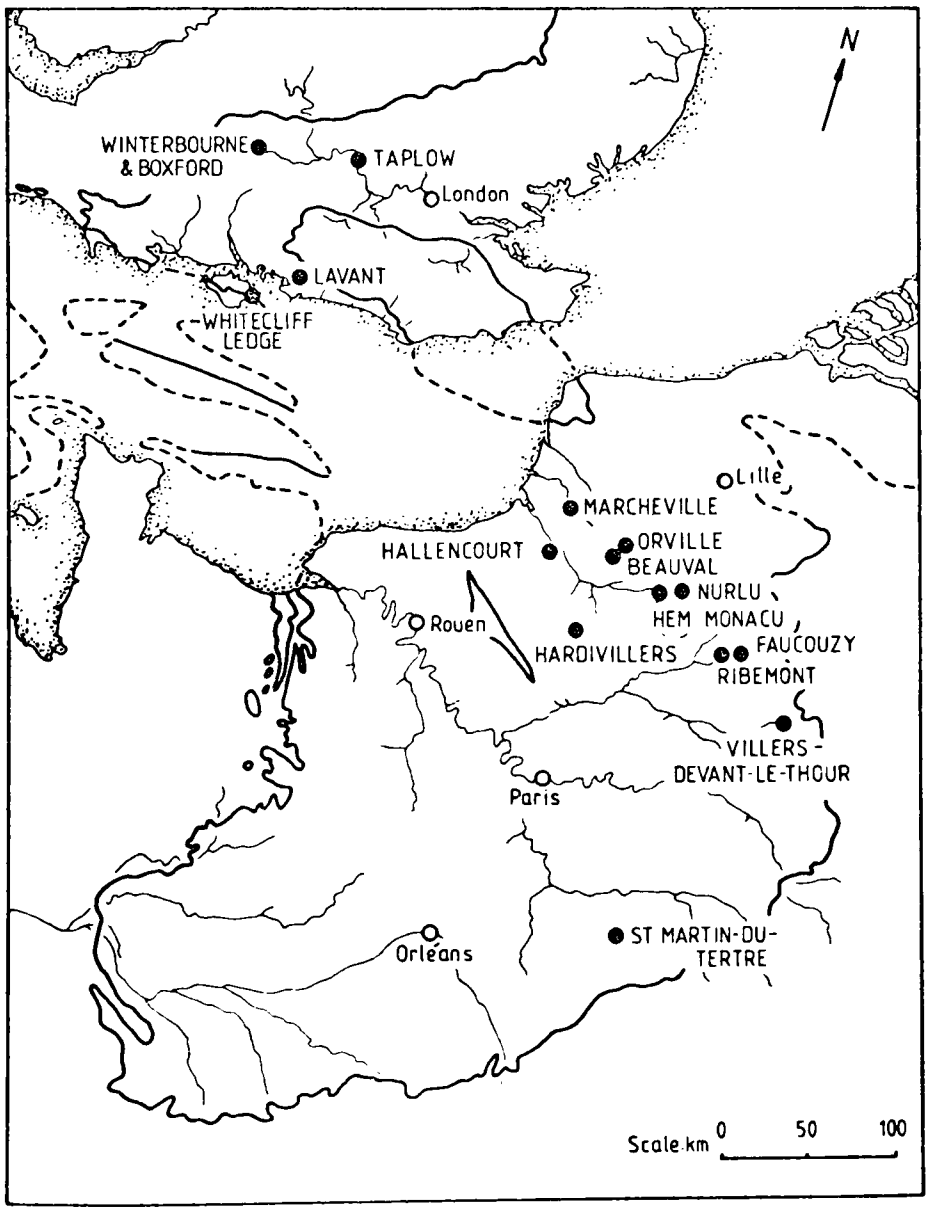


Fig. 2.1 Location map of extant phosphatic chalk localities in the Anglo-Paris Basin.
Solid circles = phosphatic chalk localities; open circles = major cities; the heavy solid and dashed lines mark the base of the Upper Cretaceous.

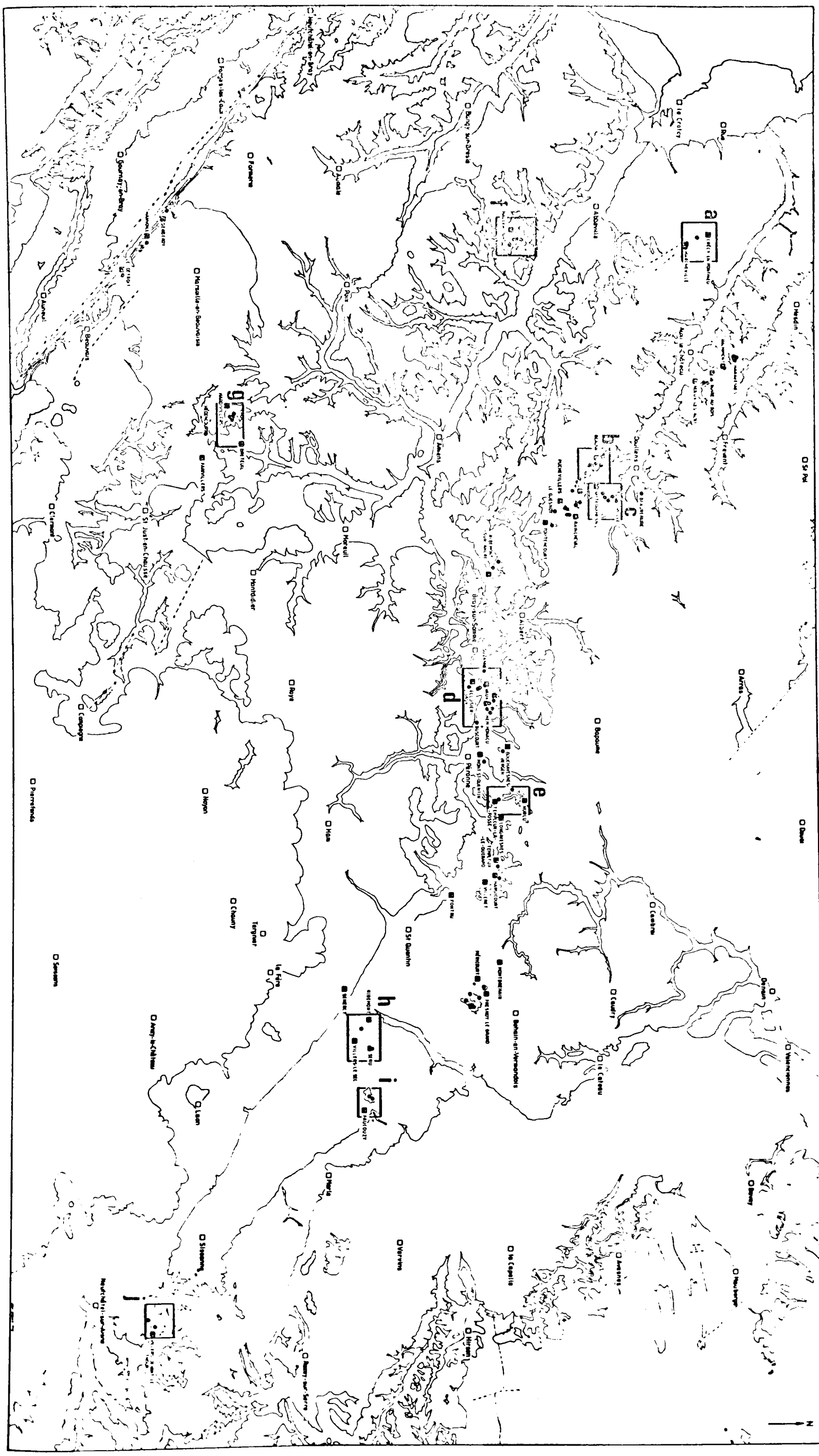
Phosphatic chalks provide the thickest and most concentrated reserves of economic phosphorite in NW Europe. The deposits usually occur in isolated troughs up to 1 km in length, 250 m wide and 30 m deep in soft white chalks of Santonian - early Campanian age of northern France and southern England. The troughs have been described as phosphatic chalk cuvettes by numerous authors (e.g. De Grossouvre, 1901 p.80) and the term is retained here.

The original distribution and extent of these deposits cannot now be determined since many occur as isolated erosional outliers of late Santonian - early Campanian age surrounded by older chalks, while much of the outcrop in the southern and central areas of the Paris Basin has a thick Tertiary cover. Nevertheless, the majority of sites have a very restricted distribution, lying in the valleys of the Rivers Authie and Somme within a 20 km wide belt running from Auxi-le-Chateau (Pas-de-Calais), SE to Albert (Somme) and then due east to Bohain-en-Vermandois (Aisne) (Fig. 2.2). The distribution of sites between Albert and Bohain-en-Vermandois is closely tied to the exposure of strata spaning the Santonian - Campanian boundary, whereas those NW of Albert are restricted to outliers of that age (Map 1). It is probable, therefore, that the original distribution of the facies north of the belt was of greater extent. To the south, however, there are considerable expanses of Chalk of similar age, yet phosphatic chalks are restricted to a small number of isolated occurrences, indicating that phosphorites were never abundant there. Similarly, in southern England, wide expanses of late Santonian - early Campanian chalk contain only rare horizons of phosphorite.

In 1849 Buteux described the occurrence of a bed of 'grey' chalk containing numerous grains of phosphate at Beauval, a small village south of Doullens (Somme). Between 1863 and 1887 De Mercey published descriptions of similar beds at Hardivillers (Oise) and Hallencourt (Somme). By 1886, the discovery of secondarily-enriched phosphate sands at Beauval, containing in excess of 35% P_2O_5, led to the realisation of the economic potential of these deposits as sources of agricultural phosphate. There followed a rapid expansion in the industry with the discovery and description of similar beds at Orville, Terramesnil, Beauquesne, Raincheval and Puchevillers in the department of Somme,

Fig. 2.2 Map showing the distribution of phosphatic chalk sites in Picardy, northern France. Major river valleys are picked out by the Upper Cretaceous stage boundaries (fine lines); see Map 1 for details. Villages giving their names to localities (filled squares) and their associated outcrops of phosphorite (filled circles) are indicated.
The location of larger-scale geological maps in the text are marked:

a. Fig. 2.3 Marcheville and Crecy-en-Ponthieu
b. Fig. 2.7 Beauval
c. Fig. 2.34 Orville
d. Fig. 2.39 Somme valley
e. Fig. 2.44 Nurlu
f. Fig. 2.60 Hallencourt
g. Fig. 2.68 Hardivillers
h. Fig. 2.84 Ribemont
i. Fig. 2.88 Faucouzy
j. Fig. 2.96 Villers-devant-le-Thour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Combles
Flers
Ginchy
Guillemont
Montauban
Mametz
Fricourt
Contalmaison
Pozières
Thiepval
Ovillers
La Boisselle
Beaucourt
Miraumont
Pys
Irles
Bihucourt
Bucquoy
Ablainzevelle
Achiet-le-Petit
Achiet-le-Grand
Bapaume
Le Transloy
Rocquigny
Equancourt
Beaumetz
Morchies
Doingt
Lieramont
Nurlu
Villers-Faucon
Epehy
Peronne
Haut-Allaines
Hardecourt-aux-Bois
Maricourt
Dompierre-Becquincourt
Herbécourt
Feuillaucourt
Frise
Suzanne
Curlu
Hem
Hardecourt
Cléry-sur-Somme
Bray-sur-Somme
Corbie
Amiens
Boves
Ailly-sur-Somme
Camon
Etinehem
Méricourt-sur-Somme
Proyart
Framerville-Rainecourt
Morcourt
Harbonnières
Vauvillers
Rosières-en-Santerre
Warfusée-Abancourt
Hangest-en-Santerre
Villers-Bretonneux
Fouilloy
Hamel
Le Hamel
Marcelcave
Cachy
Domart-en-Ponthieu
Gentelles
Villers-Tournelle
Longueau
Boves
Dury
Saleux
Ailly-le-Haut-Clocher
Pont-Noyelles
Berteaucourt-les-Dames
Flixecourt
Airaines
Hangest-sur-Somme
Picquigny
Ailly-sur-Noye
Moreuil
Montdidier
Roye
Chaulnes
Lihons
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followed by Toutencourt and Ribemont near Peronne and the deposits of the Somme valley at Curlu, Vaux, Vaux-Eclusier and Templeux-la-Fosse. It was soon realised that the rich phosphate sands which had originally led to the exploitation of these sites were Tertiary weathering phenomena, a decalcification product of the underlying phosphate-bearing chalks first described by Buteux (1849) at Beauval. These rich solution pockets ("les bonshommes") were resting on poorer phosphatic chalks containing 5 - 20% P_2O_5.

Between 1888 and 1896 the literature on phosphatic chalks reached its peak, a reflection of the rapid expansion in the industry, with J. Gosselet in particular producing a considerable volume of descriptive literature. Numerous new phosphorite deposits were discovered during this period including those near Auxi-le-Château in 1891 and Crécy-en-Ponthieu in 1893. After 1900 the number of new publications on the subject fell rapidly, and since 1914 only a handful of papers have been published, the most significant being Cayeux's review in his "Les phosphates de chaux sédimentaires de France" (1939 - 1950). The industry never recovered between the two wars or afterwards and today (1979) only two workings are exploiting phosphatic chalk - Nurlu (Somme) and Hallencourt (Somme). Exposures still remain at Beauval, Ribemont, Orville, Faucouzy, Hardivillers and St. Martin du Tertre. Less permanent exposures are present at Hallencourt quarry, Hem-Monacu, Villers-devant-le-Thour and Marcheville. An exposure of phosphorite identical to the French examples occurs in the south of England at Taplow (Bucks) but although this is potentially economic, it has never been exploited for phosphate. Phosphate-bearing horizons are exposed at Winterbourne, Boxford, Lavant, Whitecliff Ledge and Downend but none of these approach the richness of the Taplow phosphatic chalk.

A great deal of confusion is apparent in the literature as to the exact location and distribution of phosphatic chalk outcrops. Different authors have utilised different place names for the same site and have frequently failed to provide details of its location. Previous maps showing the distribution of phosphatic chalks (De Mercey, 1891 pl.19; Broquet, 1973 fig.4) are ambiguous and do not record all localities. My literature survey, however, has enabled the construction of more detailed maps (Fig. 2.2, Map 1) and rationalisation of the

site nomenclature. Each site was visited and the detailed lithostratigraphy of all contemporary exposures recorded, and any fauna accurately located. Representative block specimens of all major lithologies were taken back to the laboratory, cut and faced, and portions thin-sectioned. Analysis of this material and the field data provided a sound basis for a reexamination of the descriptions of phosphatic chalk in the literature, the majority of which were published in French geological journals (particularly the annals of the Société géologique du Nord) which are not readily available to non-French geologists. Many of these descriptions are of sufficient detail to enable reinterpretation of the section based on my knowledge of the facies. Consequently, all known deposits of phosphatic chalk are described in order to provide a detailed data base for an interpretation of the stratigraphy, sedimentology, palaeontology and origin of the lithofacies.

English sites are positioned to within ±50 m by reference to the national grid system of the Ordnance Survey and French localities are located to the same precision utilising the equivalent Lambert coordinate system which also provides the height (z) relative to sea-level. Unfortunately, older French maps are not supplied with a Lambert grid so the position of the sites is also recorded by reference to the Paris grid system which locates points relative (east or west) to a central meridian ($0^{g}.000$) passing through the centre of Paris, and a north-south coordinate.

2.2 Crécy-en-Ponthieu to Frévent

The historic town of Crécy-en-Ponthieu (Somme), scene of the famous defeat of the French cavalry by English longbowmen in 1346, lies 16 km NNE of the town of Abbeville and 62 km west of Arras, capital of the Département of Pas-de-Calais. The town of Frévent (Pas-de-Calais) is situated 37 km NE of Abbeville and 34 km west of Arras.

Most of the Cretaceous outcrop is obscured by 5 - 8 m of Pleistocene clay-rich sands. Consequently, the Cretaceous outcrops only in river valleys that have been incised into the Quaternary cover, and now expose ~130 m of early

Turonian - early Campanian chalk (Delattre, 1969; Destombes et al., 1971). The Campanian outcrop is restricted to a small number of outliers that invariably contain beds of phosphorite (Gosselet, 1909b; Delattre, 1969; Destombes et al., 1971). The outliers fall into two distinct groups. The first contains two outliers situated on a NW - SE line between Marcheville (Somme) and Crécy-en-Ponthieu, the second contains five similarly-oriented outliers between Quoeux (Pas-de-Calais) and Noeux-les-Auxi (Pas-de-Calais) and including the localities of Haravesnes, Bachimont and Buire-au-Bois.

2.2.1 Crécy-en-Ponthieu (Somme) x 568,26 y 281,69 z 80 ($0^{g}.494W$ $55^{g}.815$)

A 1000 x 500 m, NW-SE elongated Campanian outlier forms a small hill 2 km SSE of Crécy-en-Ponthieu and on the west side of "le Bois Guérard" (Fig. 2.3) and the D10. The outlier was the site of a complex of subterranean phosphorite

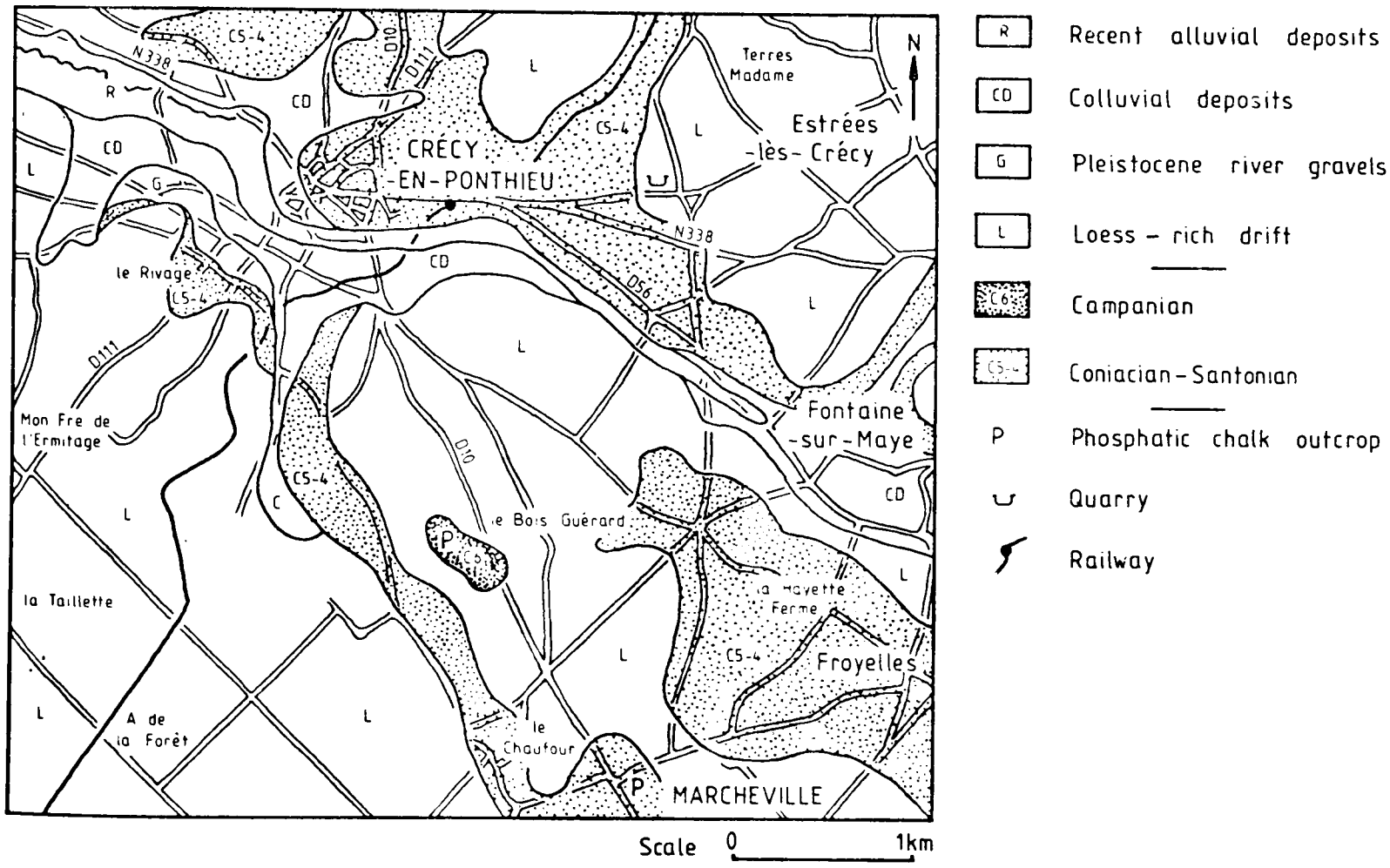


Fig. 2.3 Geological map of the area between Marcheville and Crécy-en-Ponthieu (Somme). Modified from Destombes et al. (1971).

workings that predominantly consisted of a N - S trending main gallery, which followed the axis of the phosphatic chalk cuvette (Gosselet, 1901b). The phosphorite was directly underlain by a hardground which was penetrated by a

phosphatic-chalk filled Thalassinoides system. At its thickest point, in the centre of the cuvette, the phosphatic chalk could be divided into three distinct beds (Gosselet, 1901b). The 1.40 m of phosphatic chalk immediately overlying the hardground contained 19% P_2O_5 but the following 2.50 m of phosphorite had a much higher pelletal phosphate content admixed with large numbers of small, angular to rounded white chalk intraclasts. The pelletal phosphate content of this bed was sufficient to yield P_2O_5 contents of 27 - 28%, values normally restricted to secondarily-enriched phosphorites. The 4.00 m thick, upper phosphatic chalk bed was less phosphatic (17% P_2O_5) and was in turn overlain by ~2 m of white chalk. The phosphatic chalk thinned northwards towards the entrance to the workings, where the lowest phosphatic chalk remained ~1.40 m thick but the intraclastic bed had been reduced to 40 cm and the overlying phosphatic chalk to <80 cm (Gosselet, 1901b fig.2). The succession was downfaulted by three small faults which, working southward, had throws to the south of 0.80, 1.50 and 1.50 m respectively. Gosselet's diagram (1901b fig.2) indicates that the faulting was penecontemporaneous since it did not affect the overlying white chalk although this may be the result of 'artistic license' by the draftsman. South of the last of these faults the phosphorite began to thin, suggesting that the centre of the cuvette was in the vicinity of the faults. Away from the axis of the cuvette the intraclastic bed contained progressively less pelletal phosphate and passed laterally into a white chalk breccia.

Patches of small (0.1 - 1.0 cm) white chalk pebble lags occur at other localities (e.g. Nurlu) but this is the only record of an extensive deposit of this type. The virtual absence of micrite within the bed suggests that during its deposition current activity was sufficient to remove, or at least keep in suspension, any component finer than sand grade. The concentration of white chalk intraclasts within the bed indicates that a white chalk has been reworked either in situ or has been derived laterally, the angular component favouring the former explanation. The eroded white chalk must have been sufficiently competent to allow reworking as discrete intraclasts rather than being winnowed as a carbonate ooze, but whether this competence was the result of seafloor lithification or burial diagenesis remains uncertain.

The phosphatic chalk at this locality has been mapped (Gosselet, 1909b; Destombes et al., 1971) as Campanian but, although a fauna has been recorded from the site (Leriche, 1911), no index species are known.

2.2.2 Marcheville (Somme) x 569,28 y 280,422 z 79 ($0^g.478$W $55^g.802$)

The village of Marcheville lies 3.5 km SSE of Crécy-en-Ponthieu on the D10. A 1000 x 500 m, NW - SE elongated, phosphorite-bearing outcrop, with its axis along the D10, has its centre in the village. The outcrop was originally mapped (Gosselet, 1909b) as Campanian but this has recently been revised (Destombes et al., 1971) to Coniacian - Santonian (Fig. 2.3).

Phosphorite was first recognised in the area in 1893 (Broquet, 1973) being one of the last sites to be discovered in Picardy, but by 1901 a number of workings had been initiated (Gosselet, 1901b). The phosphatic chalk outcrop was bisected by an 'anticline' of white chalk. The western portion lay underneath the village and had been exhausted by 1901, but the larger, eastern portion contained several workings at that time. The majority of these were restricted to the extraction of secondarily-enriched phosphorite in Tertiary solution pipes and only one, Patin's quarry, exposed a succession through primary phosphatic chalk (Fig. 2.4A, B). The quarry contained three exposures of a shiny, phosphate skin coated and bored basal hardground. The SW exposure had an apparent dip of 75° NE; the NE exposure 40° SW; and the third, in the centre of the quarry, displayed a fold with limbs dipping 46° SW and 80° NE respectively. The NE limb of this last exposure was truncated so that it passed directly into phosphatic chalk. These hardgrounds were underlain by soft white chalk in the SW and NE exposures, but the folded section had only 1.00 - 1.50 m of white chalk, below which lay an unknown thickness of poorly phosphatic chalk. The central exposure effectively divided the overlying phosphatic chalk sequences into two separate areas. To the SW the succession consisted of 4.00 m of rich phosphatic chalk, 1.20 m of burrowed-out white chalk, 1.50 m of rich phosphatic chalk containing small white chalk intraclasts, and finally 2.00 m of an upper white chalk. To the NE, however, the burrowed-out white chalk was absent, the hardground being over-

lain by ~6 m of phosphatic chalk followed by ~2 m of upper white chalk.

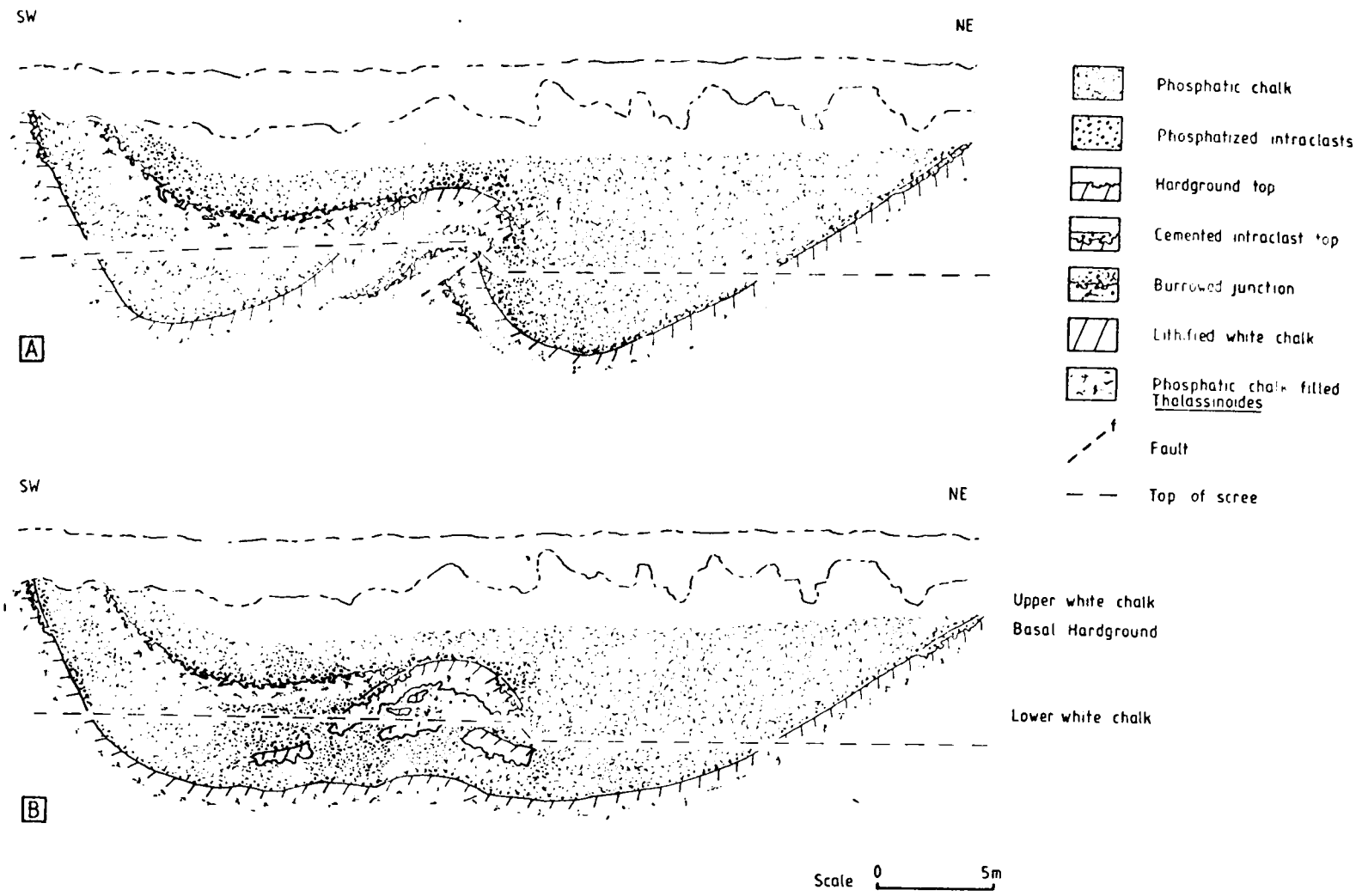


Fig. 2.4 Patin's quarry, Marcheville (Somme). A. Reconstruction of the obscured section after Gosselet (1901b). Essential features are a phosphatic chalk lenticle within the lower white chalk and a phase of folding and faulting of the basal hardground and underlying white chalk. B. An alternative reconstruction that does not include a pre-basal hardground period of phosphorite formation but requires more extensive dislocation and lateral displacement of the basal hardground.

Gosselet (1901b) considered that the three exposures of hardground were laterally continuous, and that the sharp NE termination of the central folded portion was the result of a small fault (Fig. 2.4A). His explanation requires, however, that the phosphatic chalk, which underlay the central fold, be a phosphorite lens below the basal hardground. I consider that a more plausible explanation is that the exposure of hardground in the centre of the quarry was a large ~3 - 4 m displaced block (Fig. 2.4B), as indicated by its truncated NE margin, which had been redeposited during the penecontemporaneous folding that commonly occurs in phosphatic chalk basal hardgrounds (3.7.1). The block itself appears to have been folded. The termination of the burrowed-out white chalk against the SW side of the block demonstrates that dislocation and emplacement took place prior to the deposition of that unit. The relationship between the phosphatic chalk and the upper white chalk differed from NE - SW; to the NE the

latter was horizontally bedded and discordant with the surface of the basal hardground, while to the SW they both dipped at 75° NE. An explanation for these observations may be that the NE dip on the hardground surface was primarily a sedimentological feature, the result of erosional incision prior to the deposition of the phosphorite that infilled the initial topography, while to the SW the slope was dominantly tectonic, an indication that some deformation post-dated the deposition of the upper white chalk. As such, the locality provides rare evidence for post-upper white chalk folding.

A small exposure of phosphatic chalk remains on the side of an abandoned phosphorite working, 200 m east of the D10 on the south side of the unclassified road that joins Marcheville and Froyelles. The section (Fig. 2.5) exposes

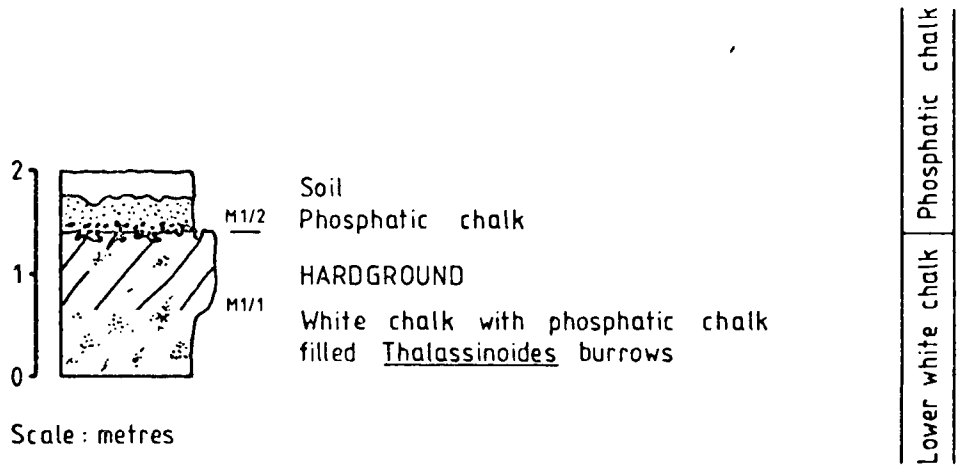


Fig. 2.5 Lithostratigraphy of the Marcheville farm pit section (Somme).

30 cm of phosphatic chalk resting on top of a strongly lithified, mineralized hardground which is coated with an iridescent phosphate patina and overlain by a phosphatized intraclast lag. The hardground top has been extensively bored by polychaete worms and is penetrated by narrow, stenomorphic (Bromley, 1975a), phosphatic-chalk filled Thalassinoides paradoxicus (Woodward) burrows which spread out in the soft white chalk below the 80 cm thick lithified chalk of the hardground. Both borings and the upper portions of the burrow systems are infilled by phosphatized intraclast/phosphate skin complexes that seal-off many of the upper passages of the Thalassinoides systems. The burrow walls have been phosphatized and weakly glauconitized, but more pervasive mineralization is provided by other iron minerals - goethite, lepidocrocite and limonite. Burrows within the hardground are lined with 0.1 - 1.0 mm thick goethite/lepidocrocite

crusts which have also developed along the junctions between successive generations of phosphatic chalk that infill the burrows. The body of the hardground has been stained a pale yellow by a complex limonitic mineralization in the form of 'liesegang rings', while manganese oxides have concentrated along late-stage fractures, both within the hardground and the overlying intraclasts.

The phosphatic chalk at Marcheville has been successively mapped as Campanian (Gosselet, 1909b) and Coniacian - Santonian (Destombes et al., 1971). Leriche (1908) records both Gonioteuthis granulata (Blainville) and Actinocamax verus Miller from the site, but there are no examples of Gonioteuthis ex gr. quadrata (Blainville) known. The fauna of the basal lag includes A. verus, Diblasus arborescens Parent, Platyceramus, Spondylus, Gryphaeostrea, Eutrephoceras , ventriculitid sponges, pycnodonteine oysters, fragments of Micraster test, cidarid spines and elasmobranch teeth. The total absence of G. ex gr. quadrata or other fauna characteristic of younger phosphatic chalks is indicative of a Santonian age for the deposit.

2.2.3 Haravesnes (Pas-de-Calais)

The village of Haravesnes lies on the D117, $6\frac{1}{2}$ km north of Auxi-le-Château, 11 km east of Frévent and 11 km SSE of Hesdin. Two phosphorite-bearing (400 x 100 m and 500 x 400 m) Campanian outliers are situated (Gosselet, 1909b; Destombes et al., 1971) 500 m north and 500 m east of the village : x 584,99 y 288,26 z 135 ($0^g.234$W $55^g.882$); x 585,65 y 287,77 z 130 ($0^g.223$W $55^g.877$).

The eastern quarry contained the largest working face (> 500 m), but the northern quarry is the one mapped as the main phosphate working in 1909 (Gosselet, 1909b). The major exploitations were situated in 1 - 50 m deep solution pipes, but Bernard's quarry exposed ~7 m of primary phosphatic chalk (Gosselet, 1898, 1900b, 1901b). The lowest 1.10 m of the section (Fig. 2.6) consisted of a soft white chalk with phosphatic-chalk filled Thalassinoides burrows in its upper half. A 15 cm thick, well-lithified basal hardground was only seen in one part of the quarry (Gosselet, 1898); elsewhere, the hardground top had been entirely broken up by burrowing and boring to form a 20 cm thick conglomerate of poorly-

rounded, lithified, phosphatized and phosphate-skin coated nodules. This conglomerate was overlain by 1.20 m of fossiliferous phosphatic chalk containing

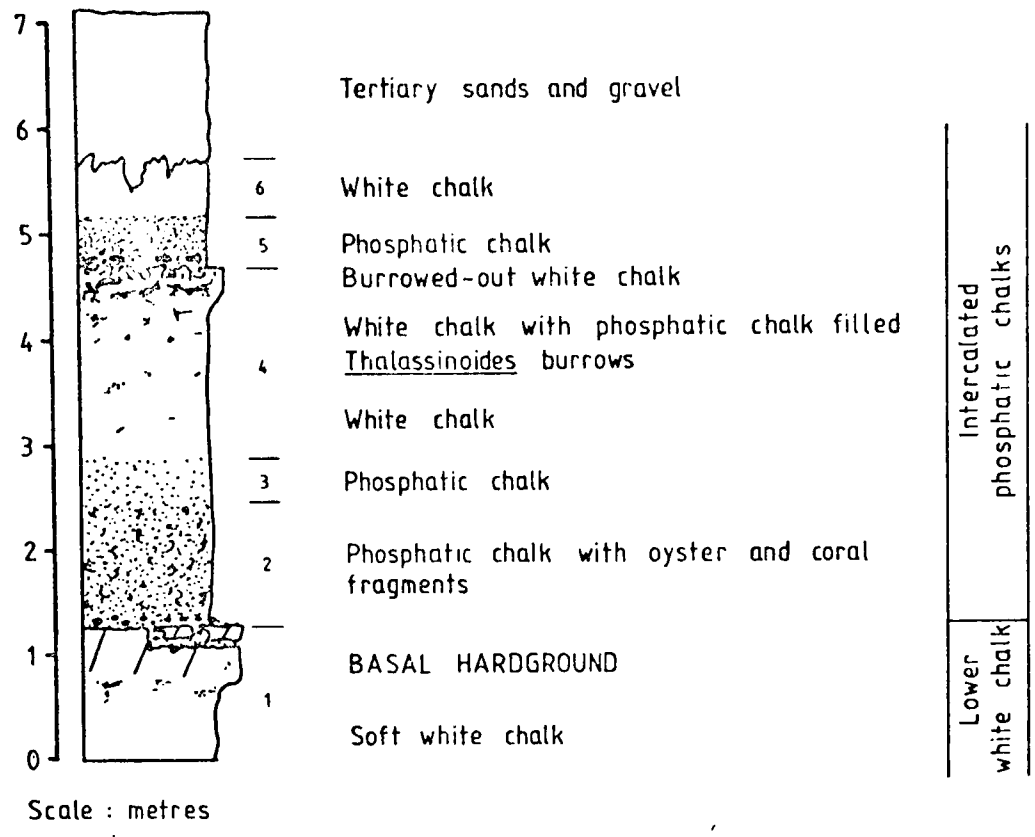


Fig. 2.6 Lithostratigraphy of Bernard's quarry, Haravesnes (Pas-de-Calais). After Gosselet (1898, 1900b, 1901b).

oyster and scleractinian coral debris, followed by 30 cm of phosphatic chalk passing up into 1.80 m of white chalk. The upper 80 cm of this latter bed contained a progressively increasing density of phosphatic-chalk filled Thalassinoides towards its top which originated from the overlying 50 cm of phosphatic chalk. A final 40 cm of white chalk unconformably overlain by 1.50 m of Tertiary sands completed the succession. Unfortunately, Gosselet (op cit) did not give any orientations for his sections but he recorded a dip of 25 - 35° for the basal hardground surface. It is noteworthy the the succeeding beds, prior to the Tertiary deposits, were concordant with the basal hardground.

The outliers have both been mapped as Campanian but Gonioteuthis ex gr. quadrata has been noted as being absent from the phosphorite (Gosselet, 1898,1901b). It is likely, therefore, that most (if not all) of the succession is of Santonian age.

2.2.4 Bachimont (Pas-de-Calais) x 586,66 y 286,10 z 132 (0^{g}.207W 55^{g}.860)

The village of Bachimont lies between Haravesnes and Buire-au-Bois on the

D117, 5 km NNE of Auxi-le-Château. A large (1100 x 400 m), NNW - SSE elongated, Campanian outlier caps the hill east of the village (Gosselet, 1909b; Destombes et al., 1971). The main phosphate quarry was situated 1000 m ESE of the village on the south side of the unclassified road that joins Bachimont and Rougefay, but a second smaller working is marked on the older (Gosselet, 1909b) map [x 586,16 y 286,63 z 132 ($0^g.216$W $55^g.866$)]. There is no exposure at the present day (1979) and no section details are known.

2.2.5 Buire-au-Bois (Pas-de-Calais) x 587,64 y 284,78 z 135 ($0^g.192$W $55^g.847$)

The village of Buire-au-Bois is situated at the intersection of the D117 and D102, $3\frac{1}{2}$ km NNW of Noeux-les-Auxi and $4\frac{1}{2}$ km NNE of Auxi-le-Château. A single NNW - SSE elongated, 900 x 400 m Campanian outlier is located on the eastern side of the town, north of "le Bois Wallon". An extensive complex of abandoned phosphorite workings occurs at the northern end of the outlier (Gosselet, 1909b; Delattre, 1969), but these were almost exclusively sited in secondary phosphorite-bearing solution pockets (Gosselet, 1893a, b, 1901b; Lasne, 1894), although 2 - 3 m of phosphatic chalk was exposed (Gosselet, 1893a) at the southern end (Lasne, 1894). Like other exposures in the region, no diagnostic fauna has been recorded from this site.

2.2.6 Noeux-les-Auxi (Pas-de-Calais)

The village of Noeux-les-Auxi lies $4\frac{1}{2}$ km east of Auxi-le-Château, on the D117. A large (1000 x 1250 m) Campanian outlier caps the hill 1500 m north of the village. An abandoned phosphatic chalk quarry is situated (Gosselet, 1909b; Delattre, 1969) on the north side of the N41, 250 m NE of the "Ferme de Mamur" [x 588,32 y 283,73 z 130 ($0^g.182$W $55^g.836$)]. A second site lies 350 m south of the N41 and the farm [x 588,27 y 283,162 z 135 ($0^g.183$W $55^g.831$)]. These sites are not described in the literature.

2.2.7 Oignies (Pas-de-Calais) x 646,25 y 307,10 z 27 ($0^g.723E$ $56^g.069$)

The town of Oignies lies NE of the area considered so far, 12 km NW of Douai and 19 km SSW of Lille. Although phosphatic chalk has never been worked in the area, borehole data (Mathieu, 1931; Bonte et al., 1964) indicates that a 2.20 m thick bed of phosphatic chalk containing 13% P_2O_5 lies at the base of the 18.75 m thick Campanian section at a site 1 km SW of the town. The phosphorite is underlain by 34 cm of burrowed-out white chalk which rests directly on top of a strongly-lithified basal hardground. A 10 cm solution seam of rich phosphorite occurs at the summit of the phosphatic chalk. Extensive borehole data for the area indicate that the deposit is extremely localised since the lithology is unknown outside this single boring.

The fauna recorded from the bed includes Gonioteuthis ex gr. quadrata, Inoceramus and Corax pristodontus Agassiz, indicating a late Santonian - early Campanian age for the phosphorite which is underlain by 38 m of Coniacian - Santonian soft white chalk with flints.

2.2.8 The age of the phosphatic chalk

The phosphatic chalk in the region has been repeatedly mapped (Gosselet, 1909b; Delattre, 1969; Destombes et al., 1971) as Campanian, despite the absence of Gonioteuthis ex gr. quadrata or other Campanian fauna (Gosselet, 1898, 1901b). If the phosphorite-bearing outliers are Campanian then the underlying Santonian sediment is only 20 - 30 m thick (Gosselet, 1898), contrary to the field data (Gosselet, 1893c, 1898) which indicate that the stage is 40 m thick in the area. There are several possible explanations for these apparent anomalies :

(a) Santonian chalks show primary attenuation within the vicinity of the outliers,

(b) erosion during the earliest Campanian has removed the uppermost Santonian sediment prior to phosphorite deposition,

(c) the phosphatic chalk is of late Santonian age.

The occurrence of Actinocamax verus and the absence of G. ex gr. quadrata

suggests that the third of these explanations is the significant one, although pre-phosphatic chalk erosion must be considered and does not preclude the bulk of the phosphorite being of Santonian age. The occurrence of G. ex gr. quadrata in the Oignies phosphorite clearly indicates an early Campanian age for that deposit.

2.3 Doullens to Albert

The towns of Doullens (Somme) and Albert (Somme) lie 29 km north and 27 km ESE of the city of Amiens (capital of the Département of Somme and the ancient region of Picardy),respectively. All of the phosphatic chalk outcrops are to the south, and within 8 km of, the N338, the road linking the two towns. The phosphatic chalks are associated with Campanian outliers (Delattre et al., 1974; Mennessier et al., 1976), which are surrounded by Coniacian - Santonian chalk. However, the bulk of the Cretaceous outcrop is obscured by drift so the true distribution may be wider. The majority of sites lie within 10 km of Doullens.

The largest outliers are in the vicinity of Beauval and in the area between Orville and Terramesnil, and the most extensive and best documented phosphorites lie within these areas. Other localities are situated between Terramesnil and Toutencourt and NE of Ribémont-sur-Ancre.

2.3.1 Beaurepaire (Somme) x 604,46 y 274,12 z 150 ($0^g.069$E $55^g.740$)

The hamlet of Beaurepaire lies 4 km east of Doullens on the south side of the N25. The hamlet is at the centre of a 1100 x 450 m E - W oriented Campanian outlier that contains a phosphatic chalk outcrop (Delattre et al., 1974) at its eastern end. The site has not been described in the literature and is not exposed at present (1979).

2.3.2 Beauval (Somme)

The village of Beauval is situated 6 km south of Doullens on the western

side of the N16. Two large Campanian outliers occur in the general area. The first lies NW of the village (Fig. 2.7) and has a rectangular (1300 x 500 m) morphology, elongated NW - SE. The outcrop was the site of six phosphatic chalk

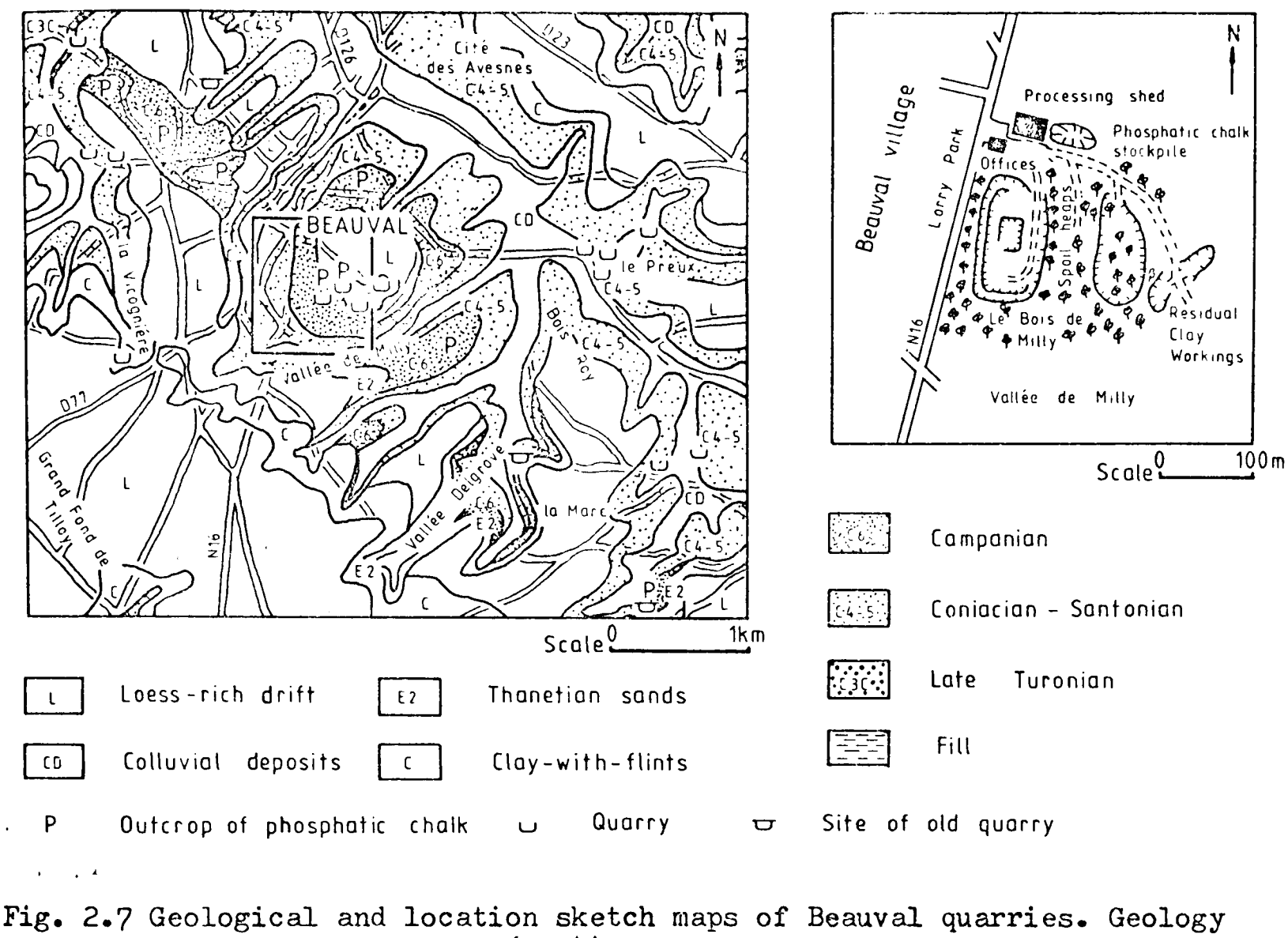


Fig. 2.7 Geological and location sketch maps of Beauval quarries. Geology modified from Delattre et al. (1974).

quarries (Gosselet et al., 1894) and shafts (Briquet, 1902b) : x 598,38 y 268,30 z 125 (0g.156W 55g.682); x 598,51 y 268,34 z 125 (0g.163W 55g.683); x 598,77 y 268,15 z 136 (0g.191W 55g.681); x 598,77 y 268,02 z 136 (0g.191W 55g.679); x 598,95 y 267,76 z 137 (0g.230W 55g.677); x 599,00 y 268,08 z 130 (0g.249W 55g.680), but there is no current exposure (1979).

The second outlier is 1 km across and has a circular form (Fig. 2.7). It is situated east of the village and the N16 and south of the unclassified road that joins Beauval and Beauquesne. Three phosphatic chalk quarries were situated in the northern portion of the outlier (Gosselet et al., 1894) : x 599,82 y 267,06 z 130 (0g.003W 55g.669); x 599,89 y 267,44 z 120 (0g.002W 55g.674); x 600,17 y 267,59 z 120 (0g.003E 55g.675). However, the only two quarries that expose phosphorite at the present time (1979) lie to the north of the "Bois de Milly" (Fig. 2.7) :

Beauval quarry x 599,89 y 266,80 z 130 (0g.002W 55g.667)

Beauval old quarry x 600,00 y 266,60 z 130 (0°.000 55°.666)

Beauval has acquired a unique position amongst phosphatic chalk localities. It was one of the first sites in France to be exploited and its discovery led to a degree of activity and speculation that was akin to a gold rush. The identification of the nature of the deposit has been attributed to Buteux in 1843, although details of the lithology were not presented until later editions of that authors' book (1849, 1864). The discovery pre-dated the general use of phosphate fertilizers in French agriculture, and therefore remained a geological curiosity until 1886, when MM. Merle and Poncin had some samples of phosphatic sand analysed. On receipt of the results, the owner of the site, M. Hordequin, refused to sell the extraction rights to MM. Merle and Poncin, and the resulting court battle led to the awarding of 25,000 francs compensation to the latter for breach of contract!

The workings attracted the attention of several geologists (De Mercey, 1887a, b, c; Meunier, 1888; Lasne, 1890, 1892) but, at this time, extraction was entirely restricted to "les bonshommes" or solution pockets of phosphate sand. By the turn of the century, however, two larger workings had been initiated in the eastern outlier. It had been discovered that the village cemetery was located on some of the richest phosphorite in the area (Gosselet, 1901b). Consequently, the dead were exhumed and buried elsewhere, and the site sold for 500,000 francs. The subsequent excavation was a sub-circular 'cuvette' with a diameter of 2-300 m (Briquet, 1902b) and displayed a section through the basal hardground and the overlying phosphatic chalk (Gosselet, 1901b), which contained a bed of white chalk 'nodules' in its upper portion (Briquet, 1902b).

A larger exploitation, Patin's quarry, was situated to the south of the previous exposure. This exposed a 20 m section for a distance of 120 m which included 15 m of phosphatic chalk resting on a burrowed junction and basal lag but with no evidence of hardground lithification (Gosselet, 1901b). A section near the centre of the quarry displayed a sequence that included three white chalk beds intercalated within the phosphorite. These intercalations pinched out towards the margins of the cuvette, where they were represented by white chalk 'nodule' beds within the phosphatic chalk (Briquet, 1902b). The decrease in

thickness of the phosphorite at the margins of the cuvette was due to attenuation, and finally the disappearance, of the lower beds (Fig. 2.8), and particularly the intercalated white chalks.

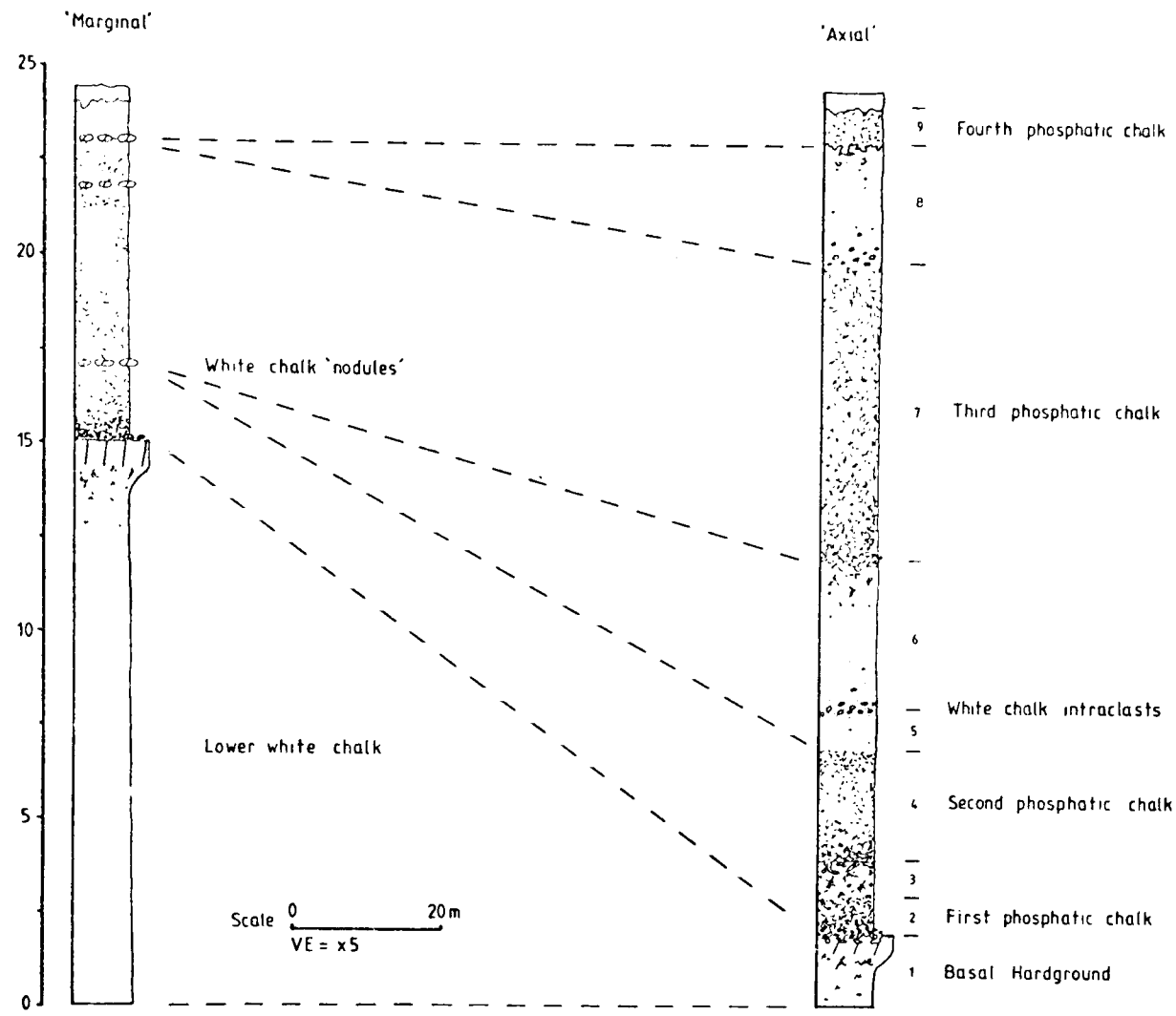


Fig. 2.8 Facies relationship between cuvette 'axial' and 'marginal' sections in Patin's quarry, Beauval (Somme) 1902. The 'axial' section is reconstructed from details in Briquet (1902b); the 'marginal' section is hypothetical but based on the observations of the same author. The yellow-stained white chalk 'nodules' in the 'marginal' succession are probably thin, discontinuous hardgrounds, similar to those seen in the upper phosphatic chalk at Beauval at the present day.

The current exposures (Beauval quarry and Beauval old quarry), owned by the "Compagnie Française de Phosphates", are adjacent to the villa once owned by M. Hordequin, the pharmacist who was the proprietor of the first phosphate exploitation. The locality, which was worked by the same company in 1912, exposed 28 m of phosphatic chalk at that time, although the lowest 5 m consisted of a burrowed-out white chalk, and was not economic (Negre, 1912a, 1963). At the present time (1979), phosphate extraction at Beauval quarry has ceased, and the company is beginning to work the underlying soft white chalk for agricultural lime and the basal hardground for hard-core. The old quarry has not been worked for some time. Permission for entry may be obtained at the works office.

Beauval quarry displays the most complete and laterally extensive exposure

of phosphatic chalk remaining in Europe. The quarry contains a 150 m long section with a total thickness of ~43 m; unfortunately, exposure is both laterally and vertically discontinuous and the lithostratigraphical interpretation is greatly complicated by the presence of a penecontemporaneous overfold in the SE portion of the quarry (Fig. 2.9).

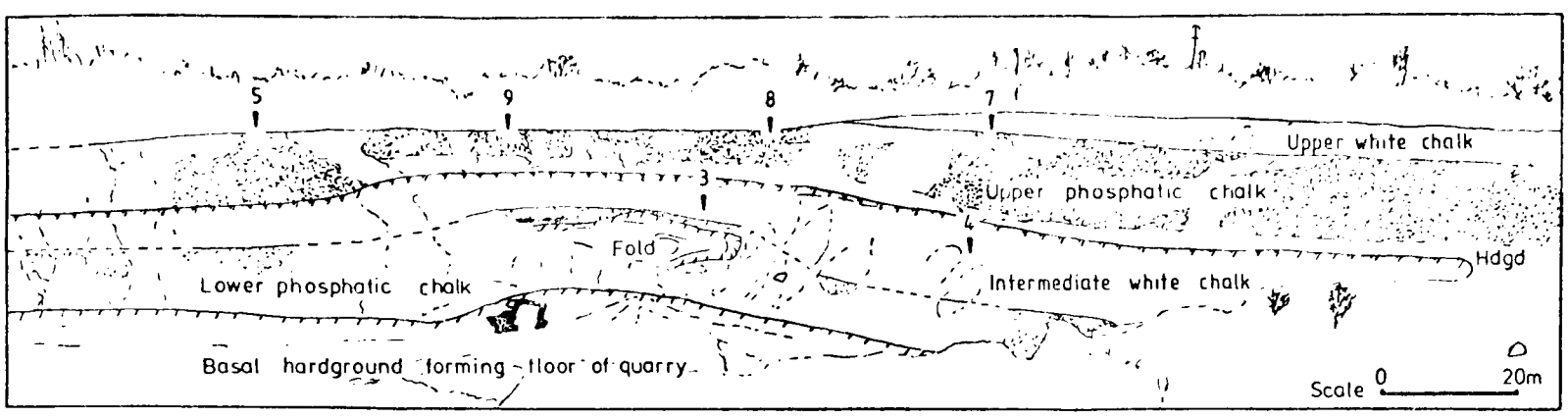


Fig. 2.9 General view, looking SSW, of the main face of the "Compagnie Française de Phosphates" quarry, Beauval (Somme) 1977. The numerals indicate the positions of measured sections refered to in the text.

The succession may be conveniently divided into five units : lower white chalk, lower phosphatic chalk, intermediate white chalk, upper phosphatic chalk and upper white chalk (Fig. 2.9). The location of the units relative to the phosphorites does not imply any bio- or chrono-stratigraphical uniformity of facies boundaries.

The lower white chalk is exposed in the portion of the quarry currently (1979) being excavated, in the centre of the old phosphate quarry. The base of the section (Section 1; Fig. 2.10) is $10\frac{1}{2}$ m below the surface of the basal hardground (the strongly-lithified, heavily-mineralized hardground that occurs at the base of the lower phosphatic chalk; see below), but this is being actively extended and deepened. The top of the lower white chalk is taken at the uppermost surface of the basal hardground and does not include the overlying poorly phosphatic chalk which is also lithified in some exposures. Although precise measurement is impossible, the beds dip at a few degrees ENE.

The lowest bed (B1/1) consists of 1.50 m of soft white chalk with abundant comminuted Platyceramus and thin-shelled oyster fragments. Two limonitic horizons and dispersed limonite-preserved sponge debris are present in the bed, the top of which is taken at the base of a thin marl seam. The marl, designated

the Beauval Lower White Chalk Marl, maintains a constant level along the section and, although it shows some associated flasering (sensu Garrison and Kennedy, 1977), it is regarded as a primary feature. The overlying 1.80 m of white chalk

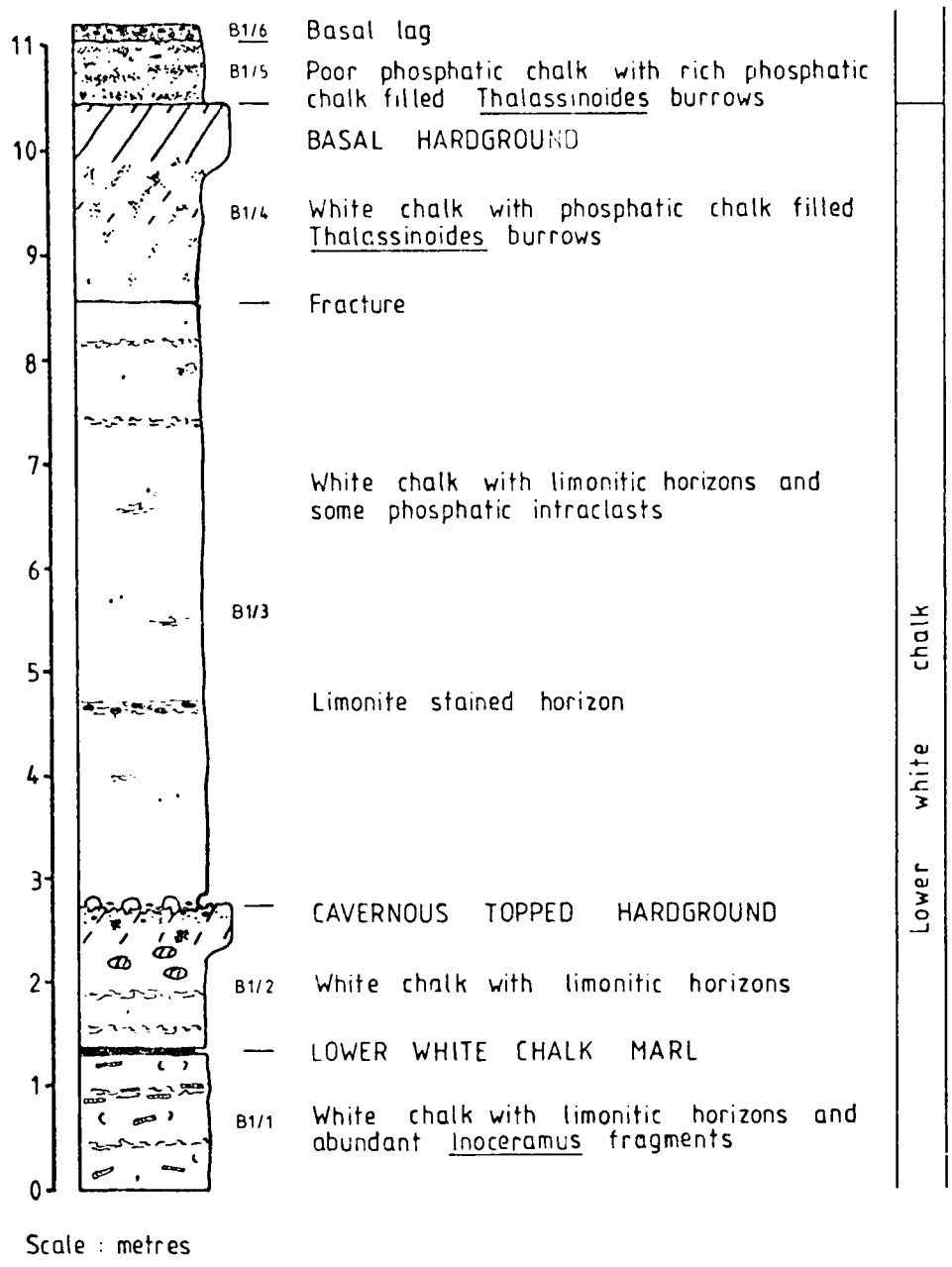


Fig. 2.10 Lithostratigraphy of the new soft white chalk workings in the centre of Beauval quarry (Section 1).

(bed B1/2) contains occasional inoceramid debris and two limonitic horizons; the top of the bed is taken at the surface of the Beauval Cavernous Topped Hardground. The 35 cm thick, weakly-lithified portion of this hardground is limonite stained, and contains phosphatized and glauconitized intraclasts and scattered 0.5 cm goethitic nodules. Large (2 cm) light-brown, soft, phosphatized (?)intraclasts occur below the lithified portion of the hardground, the surface of which is weakly phosphatized and glauconitized, and is overlain by numerous 10 cm, sub-spherical, rust-brown, clay-filled caverns (Fig. 2.11). These limonitic clays, which are probably the product of the breakdown of large pyrite nodules, are commonly removed by weathering to produce the characteristic cavernous appearance of the horizon. The remaining 6 m of bed B1/3 consists of soft

white chalk with occasional soft, phosphatic intraclasts. A prominent, laterally-



Fig. 2.11 Lower white chalk section exposed in the new soft white chalk quarry, Beauval. The Beauval Lower White Chalk Marl (A), Beauval Cavernous Topped Hardground (B) and the Beauval Basal Hardground (C) are clearly visible. The scale is 1.75 m high.

extensive limonitic horizon occurs 1.90 m above the Beauval Cavernous Topped Hardground. This horizon has a well-defined planar top, and contains scattered phosphatized intraclasts. Two less-visible limonitic (?)sponge horizons occur towards the top of bed B1/3, which is taken at a conspicuous fracture, 1.90 m below the basal hardground. This fracture is not apparently the result of any sedimentological variation although it approximates to the limit of distinct, phosphatic-chalk filled Thalassinoides originating from above the basal hard-ground.

This hardground, the Beauval Basal Hardground, includes an upper, strongly-lithified 50 cm, although demonstrable hardening occurs up to 90 cm below the surface. Lithification is apparently a surface-downward process since there is no evidence of nodule or burrow-wall cementation. The surface of the basal hard-ground is coated with a shiny phosphate veneer that also lines the upper (45 cm) portions of the Thalassinoides systems. Burrows in the upper part of the hard-ground commonly display a number of infill/reexcavation events (Fig. 2.12), the most prominent of which is invariably the final-stage phosphatic chalk infill

originating from the bed above that which immediately overlies the hardground surface (see below). The upper portion of the basal hardground is heavily mineralized by phosphate, glauconite, goethite, lepidocrocite, limonite and 'pyrolusite' (Fig. 2.13). The phosphate occurs as shiny phosphate skins, phosphatized intra-



Fig. 2.12 The Beauval Basal Hardground penetrated by a large idiomorphic Thalassinoides burrow with mineralized walls which has been infilled with poorly-phosphatic chalk. This fill has been subsequently reexcavated by a stenomorphic Thalassinoides system with a shiny phosphate lining which has been later infilled with the rich phosphorite of the basal lag. The coin has a diameter of 2.5 cm.

clasts, and as an impregnation of the lithified carbonate, extending downwards from the hardground surface and outwards from boring and burrow walls. Glauconite is present as sand-grade particles within the lithified sediment, as mineralized intraclasts and as an impregnation, particularly outwards from the roofs of large Thalassinoides burrows, where it is associated with goethitic crusts. Limonite staining occurs in patches throughout the upper part of the hardground, and as mineralization 'fronts' associated with burrow walls. 'Pyrolusite' and coarse (1 mm) calcite spar are concentrated in the late-stage fractures which occur in the most strongly-indurated portions of the hardground.

The nature of the hardground surface varies considerably laterally. In some areas it consists of a single sub-planar surface coated with a complex sequence of iridescent phosphate skins. The planarity of this variety of top is partly





Fig. 2.13 Beauval Basal Hardground : mineralized top. A. General view of a large block. The hardground surface (arrowed) is largely planar but exhibits minor convolutions and depressions. The surface is overlain by a poorly phosphatic chalk that is penetrated by a phosphorite-filled Thalassinoides system. The hammer head is 15 cm long. B. Closeup of the hardground top showing the bored, convolute surface. Mineralization includes phosphate (chocolate-brown), glauconite (green), limonite (rust-brown) and 'pyrolusite' (black dendrites). The coin is 2.5 cm in diameter.

secondary since cross-sections reveal that it has been extensively bored by bivalves and polychaete worms but that these borings (some of which have been truncated) have been infilled by small (1 - 10 mm) phosphatized and/or glauconitized intraclasts cemented within a phosphate skin complex (Fig. 2.14).

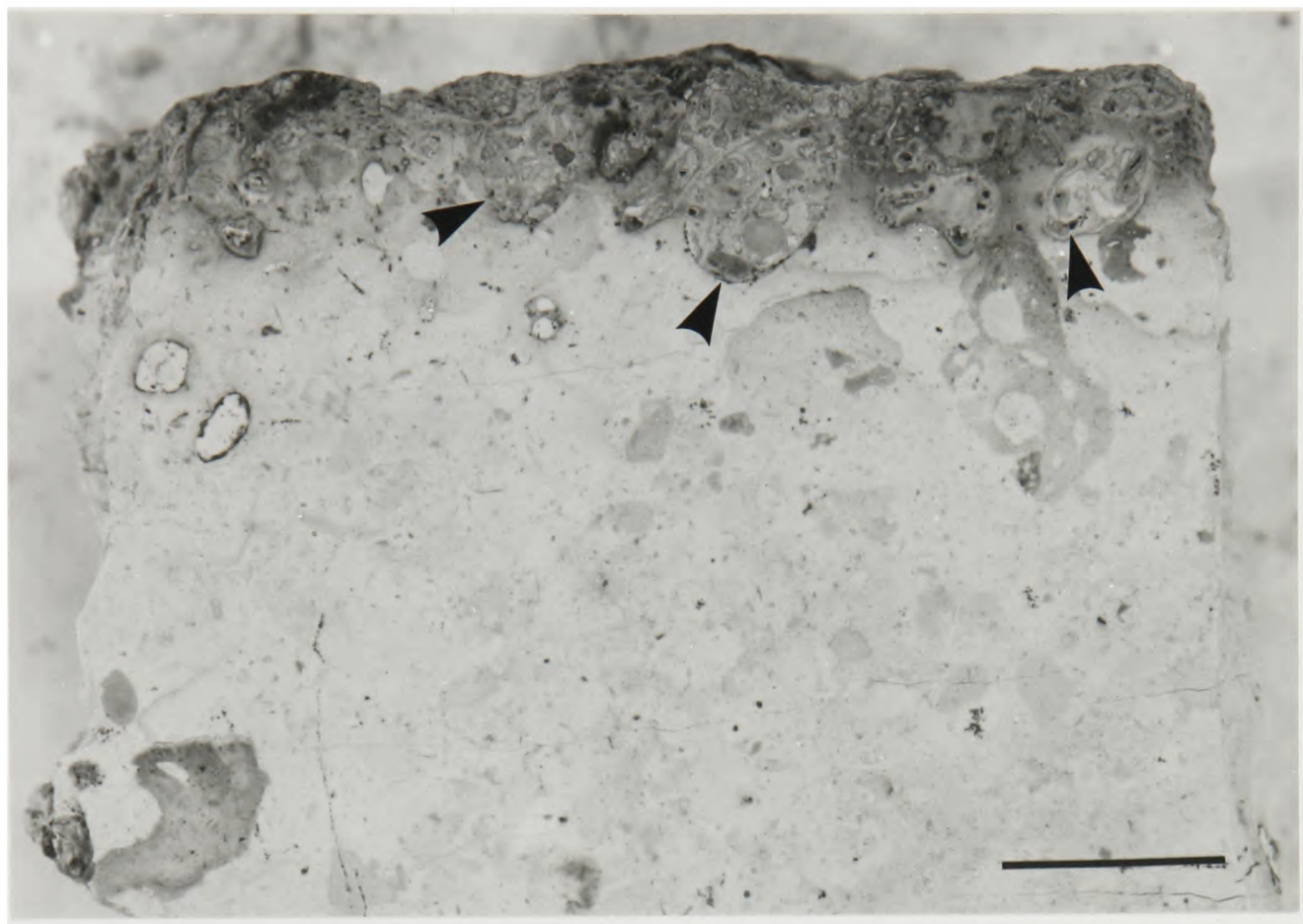


Fig. 2.14 Beauval Basal Hardground : faced block. The hardground sediment contains a high proportion of recognizable mineralized and unmineralized white chalk intraclasts. The surface has been phosphatized and contains truncated pholadid bivalve borings (arrowed). The borings have been subsequently infilled by a complex of intraclasts and phosphate skins. Truncation is indicative of significant erosion during the final stages of hardground formation. Scale bar = 2 cm.

Laterally, in depressions below the level of the planar surface, the top is more convolute and less well-defined, and commonly a number of hardground surfaces may be distinguished. A small exploration pit in the centre of the quarry displayed some of the lateral variation seen on a larger scale in the basal hardground (Fig. 2.15). The thickness of the strongly-lithified portion of the basal hardground increases from 50 cm in the SE to 130 cm in the NE corner of the pit, where three separate hardground surfaces may be discerned. These surfaces converge and become superimposed towards the south, with the grey lithified chalk of the NE section going through an intermediate stage of large, recemented intraclasts before its final superimposition. The terminal hardground surface is typically bored by bivalves, the other surfaces being dominated by the activities of other boring organisms. The uppermost surface is

overlain by a poor phosphatic chalk which is penetrated by rich phosphatic chalk

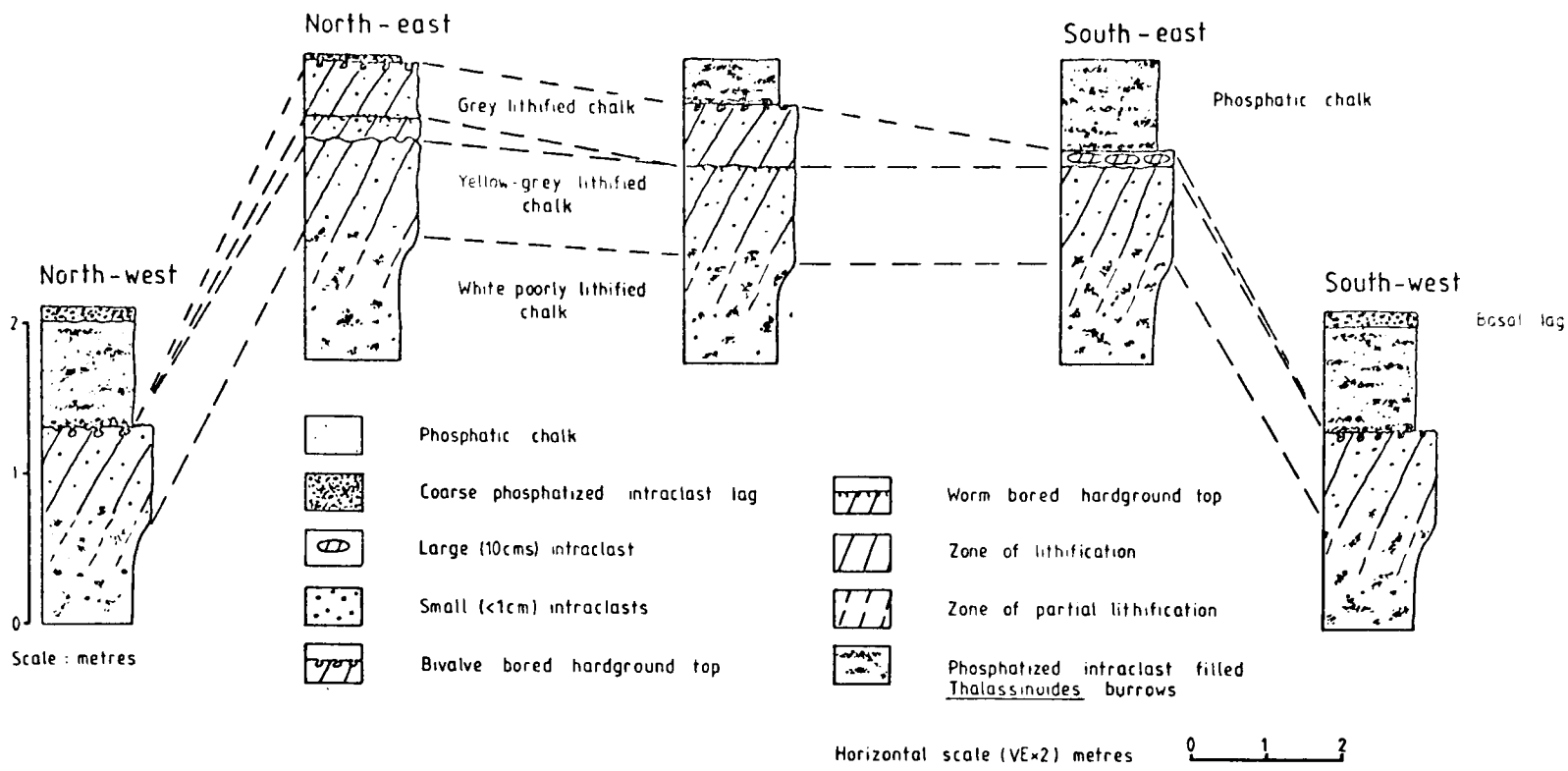


Fig. 2.15 Lateral variation in the basal hardground, Beauval quarry.

filled Thalassinoides burrows that spread horizontally on reaching the hardground surface. This imposed horizontality leads to a high, secondary concentration of rich phosphatic chalk on top of the hardground, through which the burrows penetrate by the reexcavation of preexisting Thalassinoides systems (Fig. 2.12). Although these later-generation burrows are stenomorphic (restricted) within the basal hardground, they return to an idiomorphic morphology below the lithified zone, where they again spread horizontally and vertically. The top of the poor phosphatic chalk was only seen in two of the sections (Fig. 2.15). These observations demonstrate that even in sections where the basal hardground sequence is relatively simple, its formation was not a single event, but the result of the superimposition of several hardgrounds, each with its own particular style of boring, encrustation and mineralization.

Although further accessible sections through the basal hardground are lacking, the hardground surface itself is (1979) exposed over most of the old phosphate quarry floor. The hardground displays topography on a variety of scales from a few centimetres (Fig. 2.16A) to several metres (Fig. 2.16B). Where the relationship between the hardground surface and the bedding of the underlying white chalk is visible, they are clearly discordant. The poor phosphorite



Fig. 2.16 Beauval Basal Hardground : surface topography. A. Surface hummocks exposed in a rainwater channel. The coin is 2.5 cm in diameter. B. View of the quarry floor in the NW corner. The appreciable dip of the basal hardground, which forms the floor, is clearly visible.



(Fig. 2.17A) which is intercalated between the uppermost surface of the basal hardground and the rich phosphorite of the basal lag pinches out laterally, but in the NE of the quarry is represented by a 0 - 10 cm thick coral bed (Fig. 2.17B). The Beauval Coral Bed consists predominantly of silicified and phosphatized branches of the ahermatypic scleractinian coral Diblasus arborescens Parent. The matrix of the bed, a lithified, poorly-phosphatic chalk with scattered phosphatized intraclasts, bioclasts and faecal pellets, is penetrated by a stenomorphic Thalassinoides system [Thalassinoides paradoxicus (Woodward)] lined by a complex of shiny phosphate skins. The top of the Coral Bed is itself a hardground surface coated with an iridescent phosphate patina and overlain by the rich phosphorite of the basal lag. The high concentration of virtually intact coral branches within the bed suggests that the coral patch reef (or thicket) is in situ.

The final phosphate skin of the basal hardground sequence (excluding the Coral Bed and the poor phosphatic chalk) is taken as the boundary between the lower white chalk and the lower phosphatic chalk. Apart from the exceptions already described, the lowest horizon of the lower phosphatic chalk is a basal lag of coarse, sandy gravel composed of phosphate-skin coated, phosphatized intraclasts, and phosphatized and silicified bioclasts. Approximately 20% of the basal lag components are of undoubted biological origin and much of the remainder may be similarly organically derived. Bioclasts are dominated by oysters including Lopha semiplana (J. Sowerby), Pycnodonte vesicularis (Lamarck) and Gryphaeostrea sp., but inoceramid, asteroid, cidarid, Micraster, cirripede, ventriculitid sponge debris, internal moulds of aragonitic bivalves and gastropods, elasmobranch teeth, teleost otoliths and vertebrae, terebratulid brachiopods, serpulids, 'Terebella' phosphatica tubes and scleractinian coral fragments (particularly Diblasus arborescens) are all abundant. The sand-grade component is dominated by intraclasts, bioclasts, faecal pellets, bryozoa and benthonic foraminiferans embedded in a micritic matrix. All varieties of clast commonly exhibit boring, Entobia-like sponge varieties predominating, the high frequency of such boring being masked by the layers of phosphate skin that coated all components subsequent to boring. Intraclasts and faecal pellets are completely phosphatized, while much of the bioclastic material, particularly the oyster and

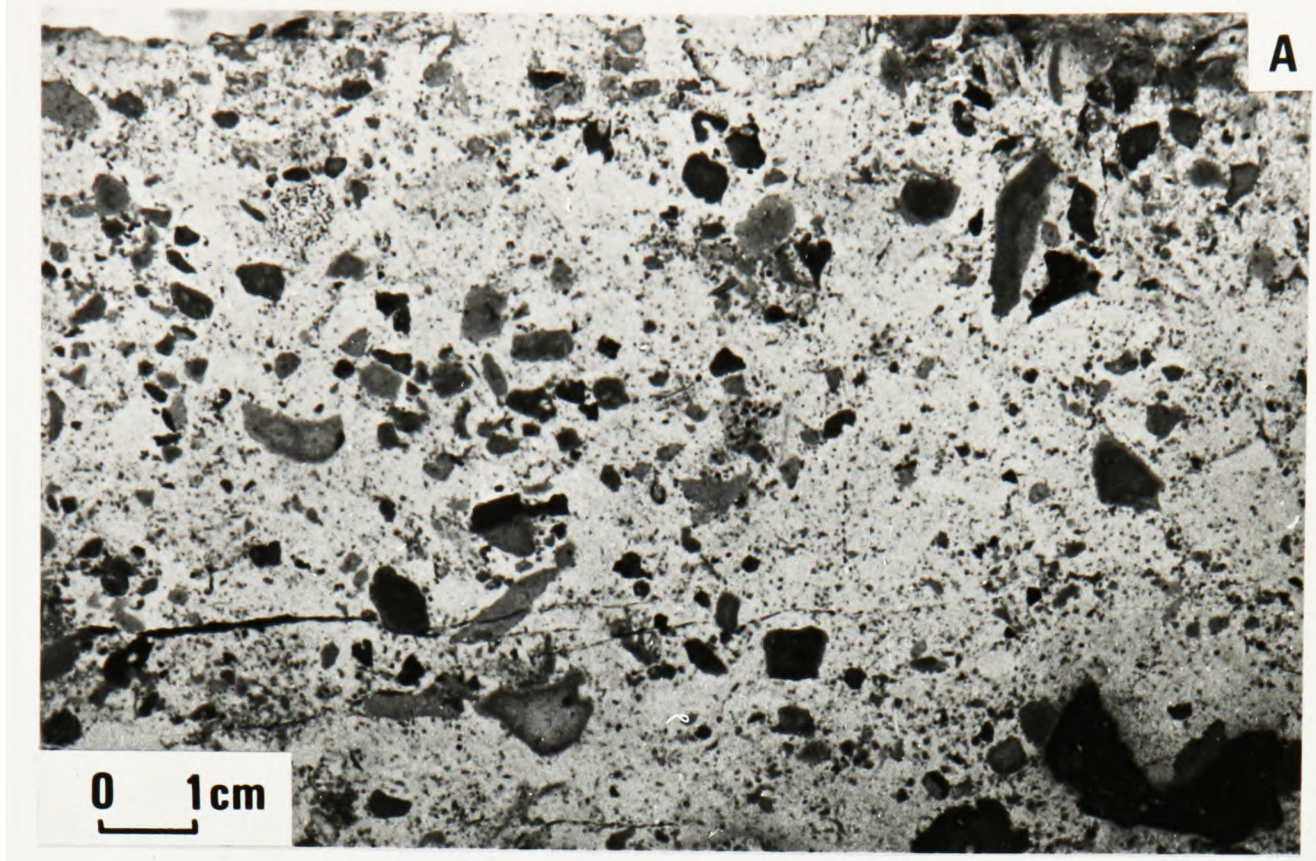


Fig. 2.17 Base of the lower phosphatic chalk, Beauval quarry. A. The phosphatized-intraclast rich, poor phosphatic chalk intercalated between the upper surface of the basal hardground and the basal lag. B. The Beauval Coral Bed. The lateral equivalent of A., the bed contains abundant calcitized (c), silicified (s) and phosphatized (p) fragments of scleractinian coral, predominantly Diblasus arborescens. Silicified comminuted Platyceramus, bored, glauconitized(g) and phosphatized intraclasts and sand-grade phosphate are also abundant. The matrix is a weakly-lithified micrite.

inoceramid component, is only superficially mineralized, the preserved calcite being masked by a complex of phosphate skins. Glauconitization is subordinate to phosphatization in the lag.

The basal lag is overlain by up to 4 m of deep-brown phosphatic chalk, but no complete section was available through this unit. A section in the NW corner of the second level of the quarry provided the most complete sequence (Section 2; Fig. 2.18), and displays the boundary between the lower phosphatic chalk and the

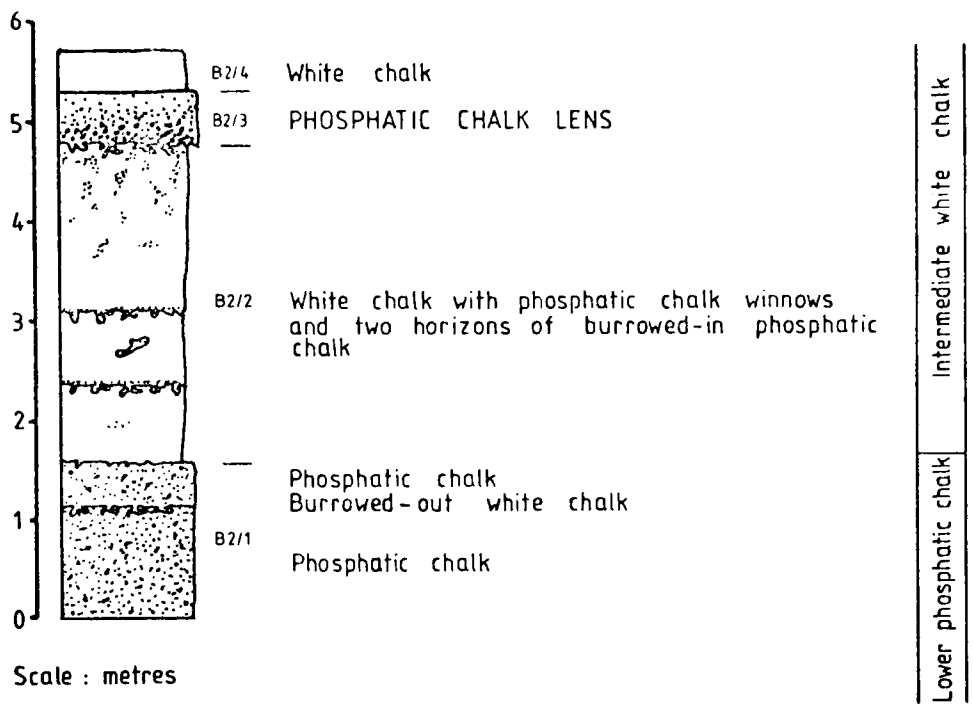


Fig. 2.18 Lithostratigraphy of the northern end of the west face, tunnel section, Beauval quarry (Section 2).

intermediate white chalk. The 1.85 m of phosphatic chalk exposed (B2/1) contains a burrowed-out white chalk 70 cm from its top (Fig. 2.19A). The junction between the white chalk and the phosphatic chalk is relatively sharp, and is taken at a phosphatic-sand filled fracture. The overlying 10 cm of sediment consists of a strongly bioturbated zone with white chalk being piped-down into, and intermixed with, the uppermost phosphatic chalk by a variety of indistinct burrow styles. A number of well-defined subcylindrical burrows have piped-up phosphatic chalk into the white chalk overlying the bioturbated zone. A conspicuous feature of these burrows is that those nearest the white chalk/bioturbated chalk junction have been streaked-out (Fig. 2.19B), presumably by differential movement along the boundary between the two sediment types and accompanying the penecontemporaneous folding present at this locality (see below).

The overlying white chalk (B2/2) contains local concentrations of phosphatic



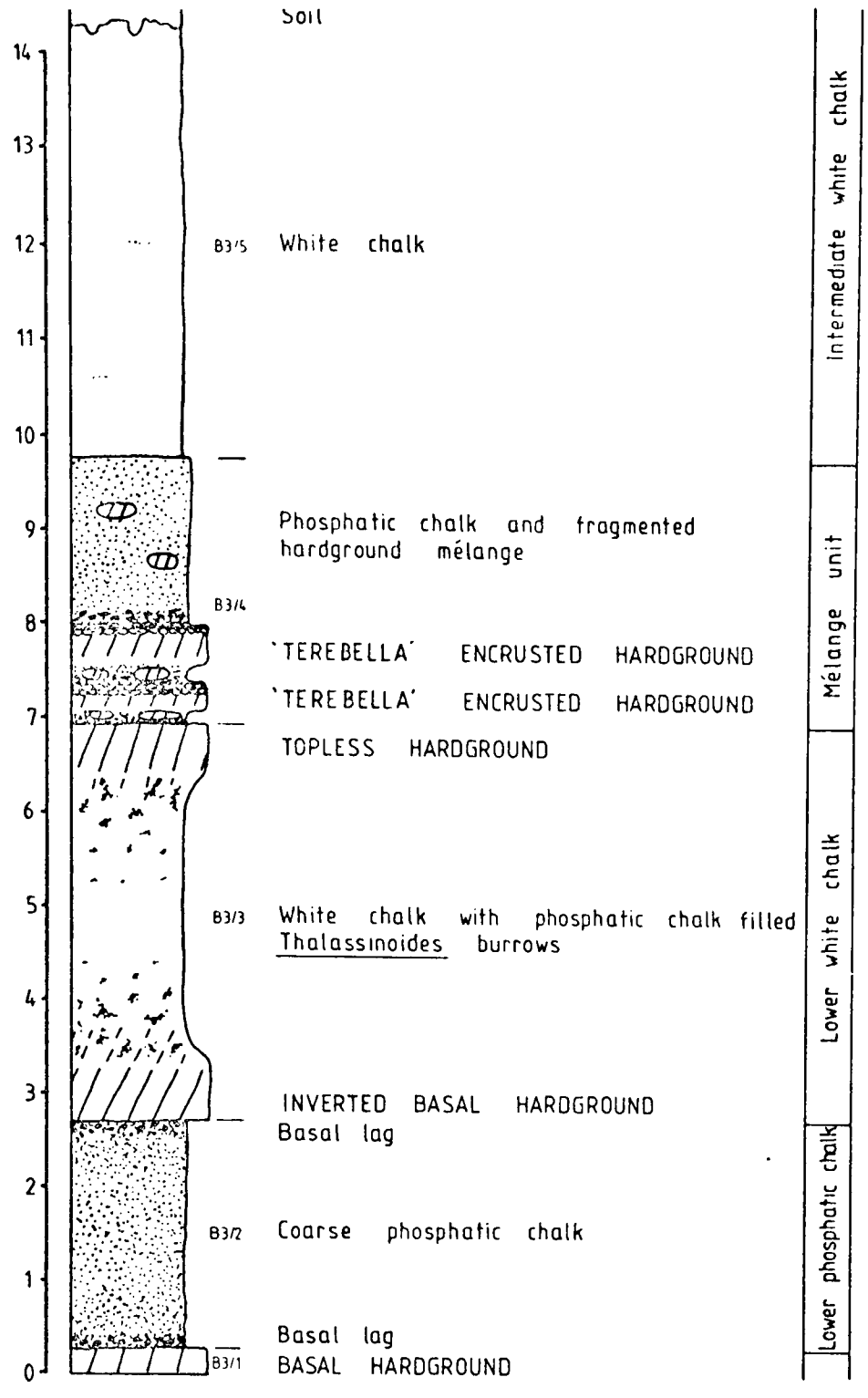
Fig. 2.19 Summit of the lower phosphatic chalk, Beauval quarry.
A. Northern end of the west face showing the burrowed-out white chalk (a) and the planar top (b) of the unit. The hammer shaft is 30 cm long. B. Close-up of the lower phosphatic chalk/ intermediate white chalk junction. Note the streaked-out, phosphatic-chalk filled Thalassinoides burrows.



chalk throughout, in burrow fills and as small lenticular winnows. Two more prominent burrowed-in phosphatic chalk horizons are also present. Phosphatic-chalk filled Thalassinoides burrows become progressively more common towards the top of the white chalk which is marked by a burrowed junction with the overlying 50 cm of phosphatic chalk (B2/3). The phosphorite is comprised of a lower 20 cm of intraclastic lag with large (5 cm), light-brown phosphatized intraclasts with goethitic cores, which has been piped down into the upper 20 cm of the underlying Thalassinoides system; and 30 cm of phosphatic chalk which becomes less phosphatic towards its top. Thin-shelled oysters are the dominant fauna within the unit, which thins out both northwards and southwards to give a 15 m wide, lenticular cross-section. The lens is overlain by 40 cm of white chalk.

A section in the SW corner of the quarry also exposes a sequence through the lower phosphatic chalk and up into the intermediate white chalk (Section 3; Fig. 2.20), but here the sedimentological data has been considerably complicated by the penecontemporaneous folding that affects this part of the quarry (Figs. 2.21, 2.22). The section given in Fig. 2.20 has been taken through the SW side of the structure (Figs.2.9, 2.22C). The basal hardground (B3/1) has been folded up from the bottom of the quarry and arches over so that the basal lag and the overlying phosphatic chalk are caught in a pocket surrounded successively by horizontal, vertical and inverted hardground. The hinge of phosphatic chalk pitches down at 10° and disappears below the quarry floor to the east; it is clearly the hinge of a large recumbent fold. The highly fractured white chalk (B3/3) that overlies the inverted basal hardground is therefore a repetition of the lower white chalk in the core of the fold, and the top of that bed a third repetition of the basal hard-ground. The top is poorly defined because the surface of the hardground has been sheared-off tectonically. Thus, although phosphatic-chalk filled Thalassinoides burrows increase in size and density towards the top of the white chalk bed (B3/3), the burrowed hardground sediment passes into a hardened mélange of displaced blocks of hardground top and heavily mineralized intraclasts of up to cobble grade. The matrix is a poor phosphatic chalk.

The section has been taken at a point where two large, 2 - 3 m x 30 cm blocks of 'Terebella' phosphatica Leriche encrusted hardground surface have been thrust one



Scale : metres

Fig. 2.20 Lithostratigraphy of the fold section, west corner, south face, Beauval quarry (Section 3).

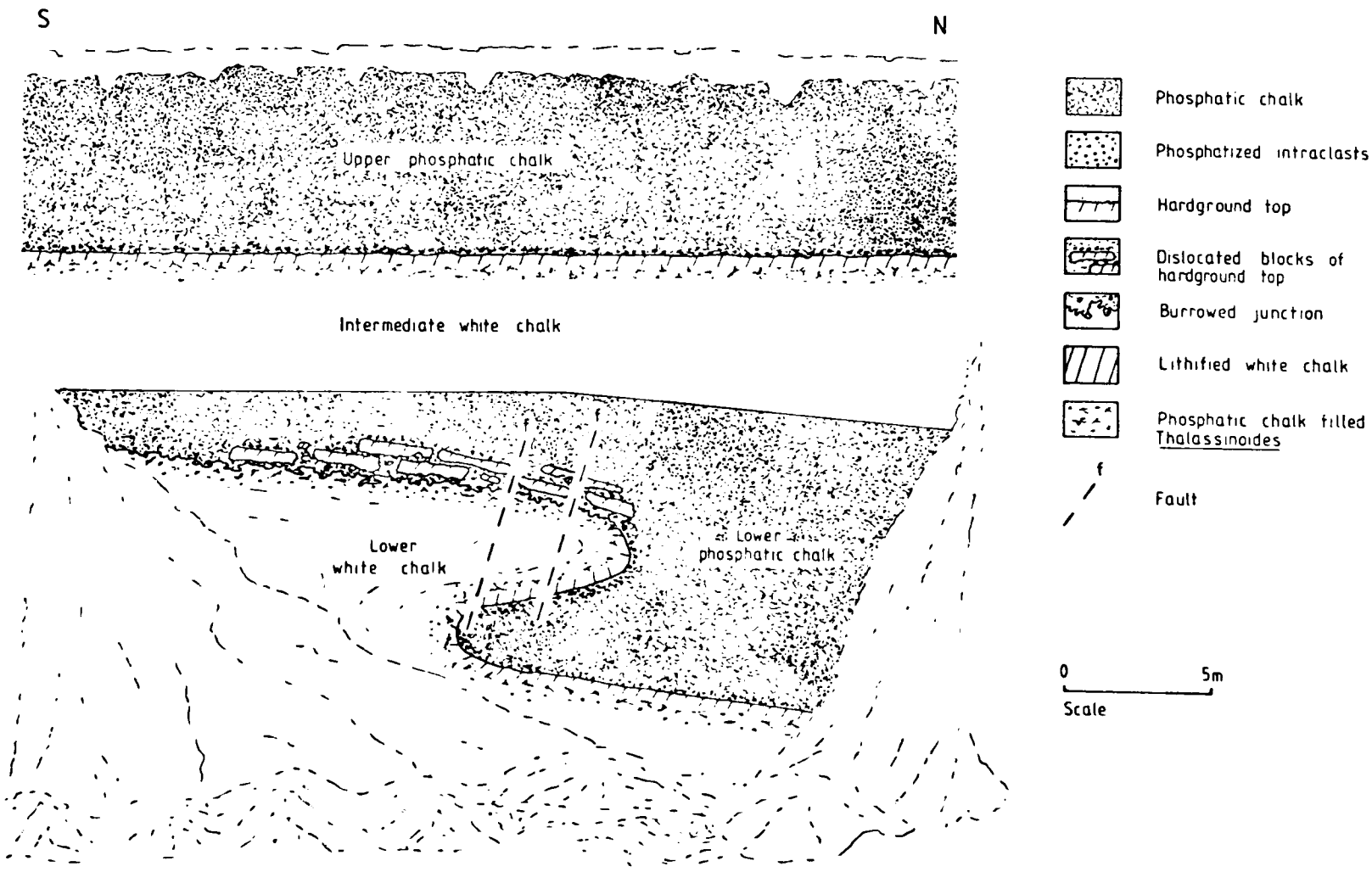
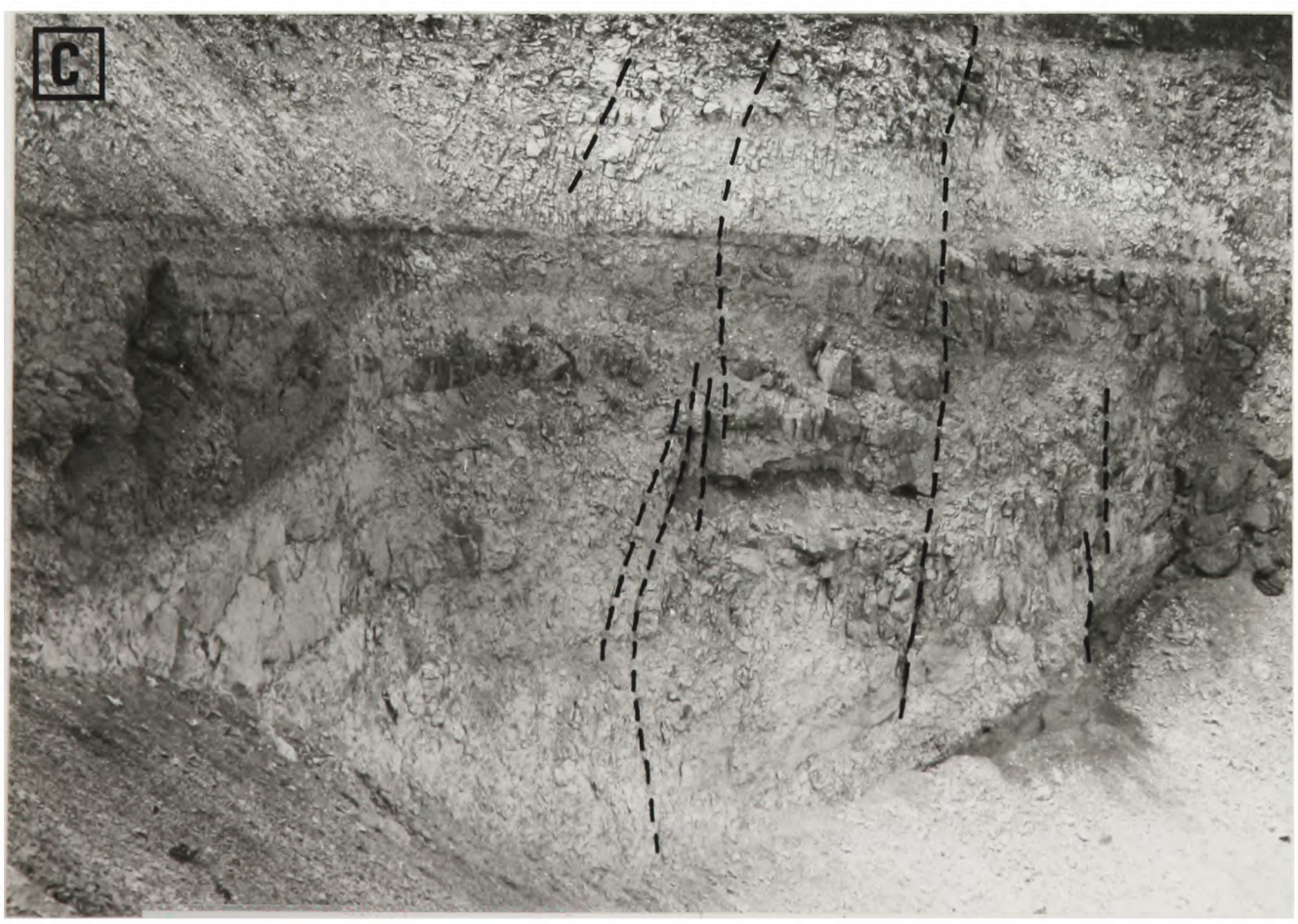


Fig. 2.21 Simplified N - S cross-section through the basal hardground overfold, SW corner, Beauval quarry.



Fig. 2.22 The overfold, Beauval quarry.
A. General view of the south face.
B. Close-up of the hinge of the fold indicated in (A). The hammer shaft is 30 cm long.
C. South-west view of the structure showing the high-angle faulting that cuts the overfold.





on top of the other. These larger fragments are floating in, and are overlain by, a mélange of fragmented hardground, basal lag intraclasts and phosphatic chalk. The larger blocks (>25 cm) have fractured, but distinct, bases and lateral margins and well-preserved, phosphate-skin coated tops that demonstrate that they have not been inverted. The cobble- and pebble-grade component, however, although recognizably of basal hardground origin, is more rounded and has been mineralized and phosphate-skin coated over its entire surface. Examples commonly show an oncolite-like internal structure of numerous shiny phosphate skins coating a polychaete-worm bored intraclast core (Fig. 2.23).

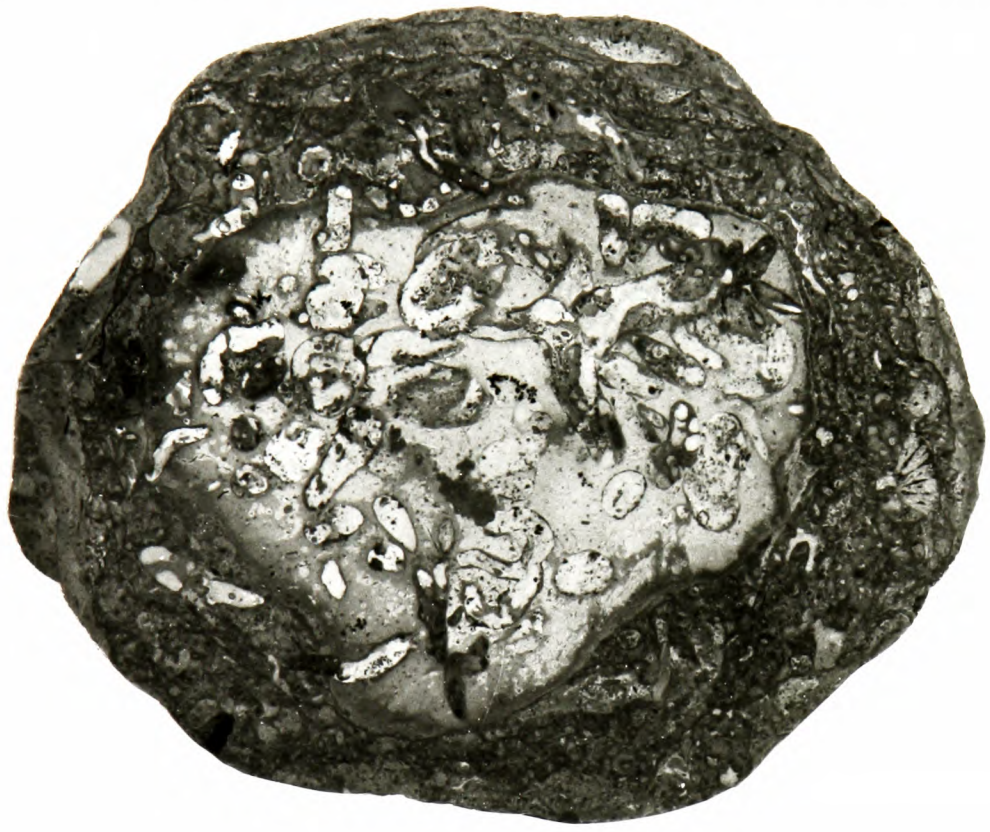


Fig. 2.23 Oncolite-like pebble from the mélange unit of the overfold, SW corner, Beauval quarry. The core is bored by a (?)spionid worm. Scale-bar = 1 cm.

Geopetals within the hardground blocks are of two generations, one parallel to the hardground surface, the other to the present-day land surface. The uppermost large block in the section is overlain by 180 cm of hard, shattered phosphatic chalk with numerous hardground fragments and basal lag derived intraclasts and bioclasts (which include large Lopha semiplana and Actinocamax verus). The top of the bed has a sharp, planar junction with the overlying 4.50 m of soft white chalk (B3/5). The chalk immediately below this junction is yellow stained and has an abnormally high pelletal phosphate content, presumably the result of preferential solution by weathering along the lithological boundary. The uppermost white chalk does not display any distinct horizons, but the exposure is mainly inaccessible. The lateral relationships of the various beds may be seen in Fig. 2.21. The folded top of the lower phosphatic chalk has been planed-off prior to the resumption of white chalk sedimentation, indicating that basal hard-

ground tectonism occurred during, or shortly after, the deposition of the lower phosphatic chalk.

A number of steeply-dipping faults cut both the fold and the overlying white chalk but their throw, which is minimal, is impossible to determine. A large fault in the centre of the overfold has a dip of 85° and a strike of 316°. The presence of a second fault direction parallel to the exposed face is indicated by the chalk/phosphorite fault breccia which is plastered on the exposed face.

The displaced hardground blocks which occur at the top of the folded sequence are not restricted to the fold exposure. The northern side of the southern-most bluff on the west face contains a large, 300 x 90 cm, isolated block of hardground surrounded by phosphatic chalk. The hardground is an intensely-lithified white chalk penetrated by a dense system of phosphatic-chalk filled Thalassinoides burrows. Its top is a 10 cm bed of bored and phosphatized 1 mm - 5 cm intraclasts and phosphatized and silicified bioclasts, that have been cemented early diagenetically onto the hardground surface (Fig. 2.24). This cemented intraclast bed is in turn overlain by a 0 - 5 cm complex of phosphate-cemented sand-grade phosphorite and phosphate skins, the top surface of which is encrusted by pycnodonteine oysters and 'Terebella' phosphatica. Towards the margins of the block the sandy substrate thins and disappears so that the final phosphate skin coats a progressively decreasing thickness of cemented intraclasts. The early diagenetic nature of the lithification is demonstrated by the existence of void spaces within the bed which have resulted from the dissolution of bivalve, gastropod and coral aragonite. There is, however, no preservation of inoceramid aragonite, although superficially-phosphatized and heavily-silicified inoceramid prismatic calcite is common. This suggests that the inoceramid component was included in the bed subsequent to reworking.

The occurrence of brecciated fragments of the phosphatic calcarenite within the phosphatic chalk surrounding the block demonstrates that the cemented units were deposited prior to fracturing and displacement of the hardground. However, the 'T.' phosphatica patch reef that encrusts the upper surface continues up into the overlying unlithified phosphorite suggesting that encrustation took place after dislocation.





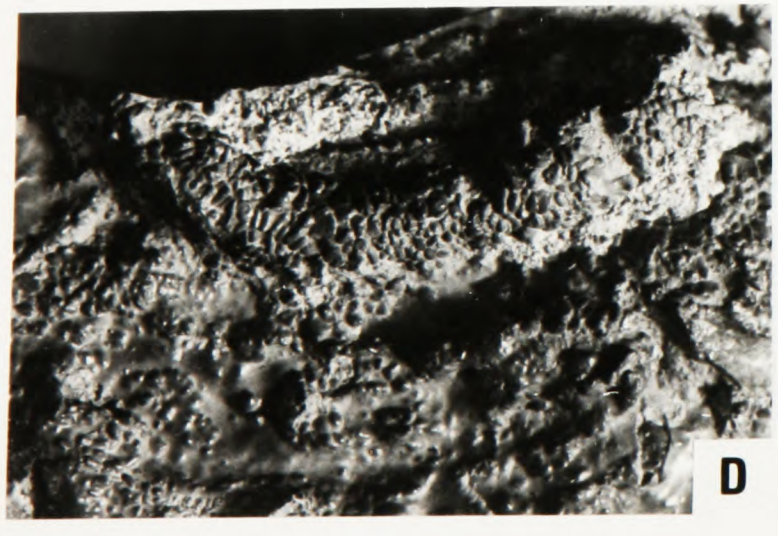




Fig. 2.24 Dislocated block of hardground within the lower phosphatic chalk, west face, Beauval quarry.
A. General view showing the block surrounded by phosphatic chalk. The hammer shaft is 30 cm long.
B. The cemented and phosphatized calcarenite/calcirudite top of the hardground. Polished cross-section.
C. Plan view of the 'Terebella' phosphatica Leriche encrusted surface of the hardground.
D. Close up of a 'T' phosphatica tube indicated in C., consisting of agglutinated ovoid faecal pellets cemented by phosphate.

An exposure on the north side of the quarry displays further evidence of synsedimentary hardground break-up (Fig. 2. 25). Unfortunately the face had to be excavated, so textural differences, which would be revealed by weathering, were not visible. The exposure shows evidence for two periods of hardground

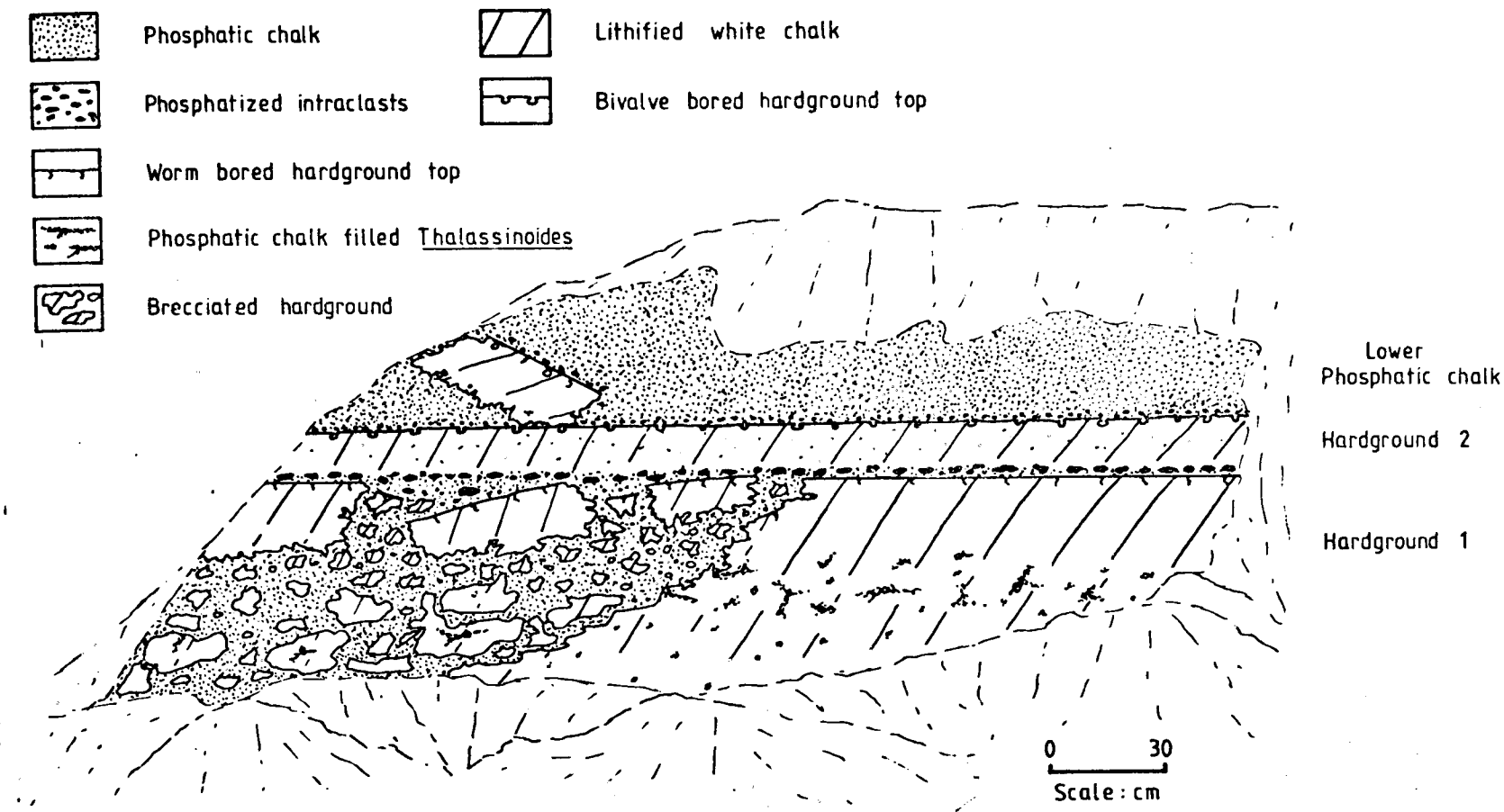


Fig. 2.25 Broken-up basal hardground, north face, Beauval quarry.

displacement. The upper surface of the lower hardground has been undermined and broken up into slabs, so that it rests on a hardground breccia floating in a matrix of phosphatic chalk. Dislocation has, in this case, involved little or no lateral movement of the blocks so a purely sedimentological origin may be envisaged. The change in disintegration styles between the upper, massive strongly-lithified top (which maintains its integrity) and the poorly-lithified, inhomogenous, Thalassinoides burrowed base (which produces the 1 - 10 cm breccia), is to be expected from the differences in the physical properties of the two lithologies. The penecontemporaneous nature of the brecciation and displacement is demonstrated by the planed-off top with its overlying basal lag and 20 cm of horizontally bedded hardground chalk. The second hardground has been bored by bivalves and polychaetes, strongly glauconitized, and overlain by a coarse intraclastic (?)basal lag and 45 cm of phosphatic chalk. Large displaced blocks are also present in the upper unit of phosphatic chalk, but these

occur as isolated fragments resting on top of the final hardground surface and were therefore probably derived laterally and redeposited during the formation of the overfold.

The most complete section through the intermediate white chalk (Section 4; Fig. 2.26) is situated in the middle of the west face, and shows 10 m of soft white chalk resting on ~1 m of phosphatic chalk. Two laterally impersistent

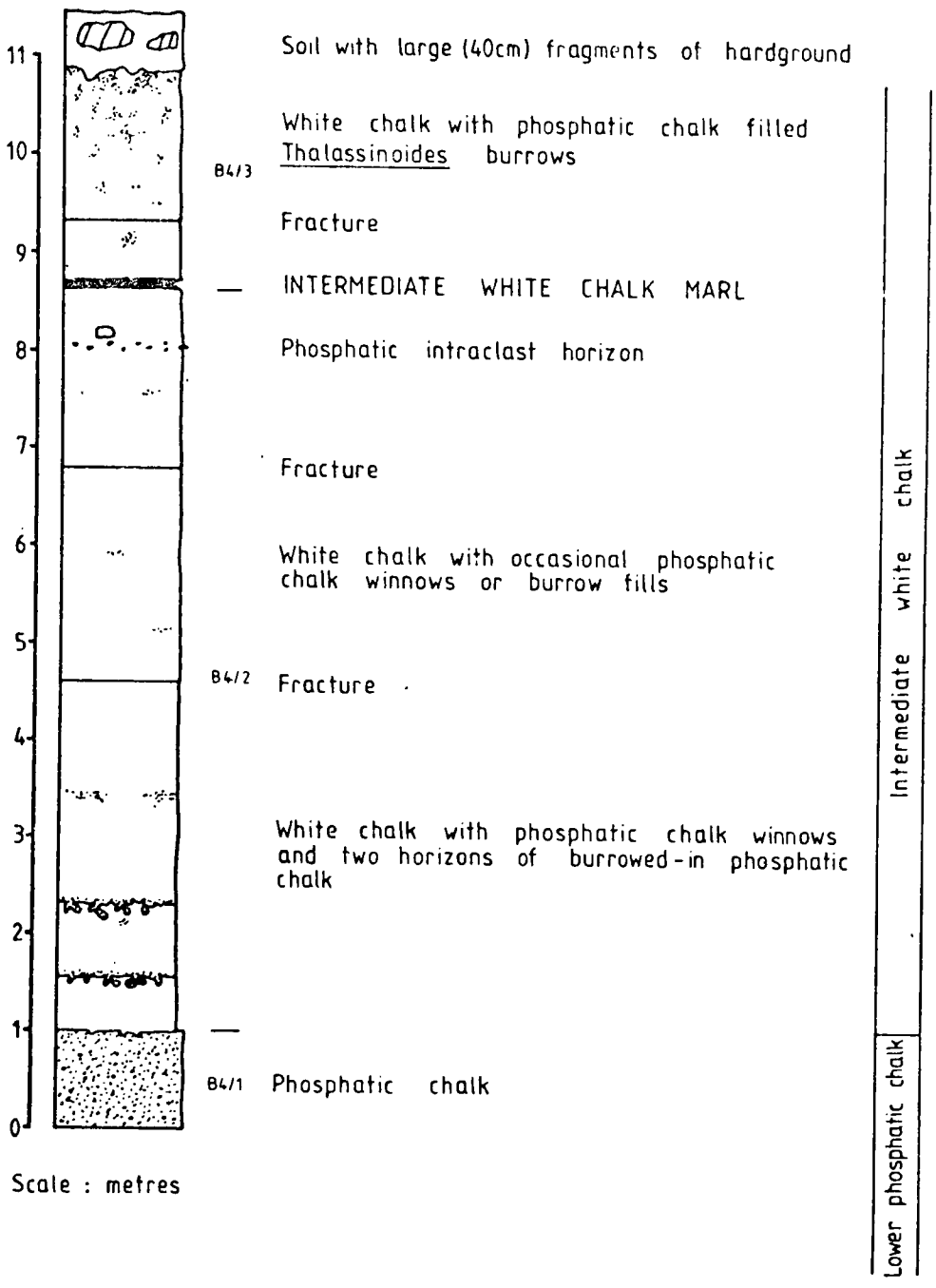


Fig. 2.26 Lithostratigraphy of the middle of the west face, Beauval quarry (Section 4).

horizons of burrowed-in phosphatic chalk occur at the bottom of the section, a phosphatic intraclast horizon and a 10 cm marl (the Beauval Intermediate White Chalk Marl) towards the top. The base of the marl seam marks the top of the first bed (B4/2) of the intermediate white chalk. The seam is penetrated by a few phosphatic-chalk filled burrows. These have undergone less compaction than the surrounding clay-rich sediment and therefore cause the marl to 'bulge' around them. The overlying 2.10 m of white chalk (B4/3) contains progressively greater numbers of phosphatic-chalk filled Thalassinoides burrows towards its top, where the overlying soil incorporates a substantial number of large (40 cm)

fragments of hardground.

A section in the middle of the south face, east of the fold (Section 5; Fig. 2.27), displays the junction between the intermediate white chalk and the upper phosphatic chalk. The top of the first bed of the intermediate white chalk (B5/1)

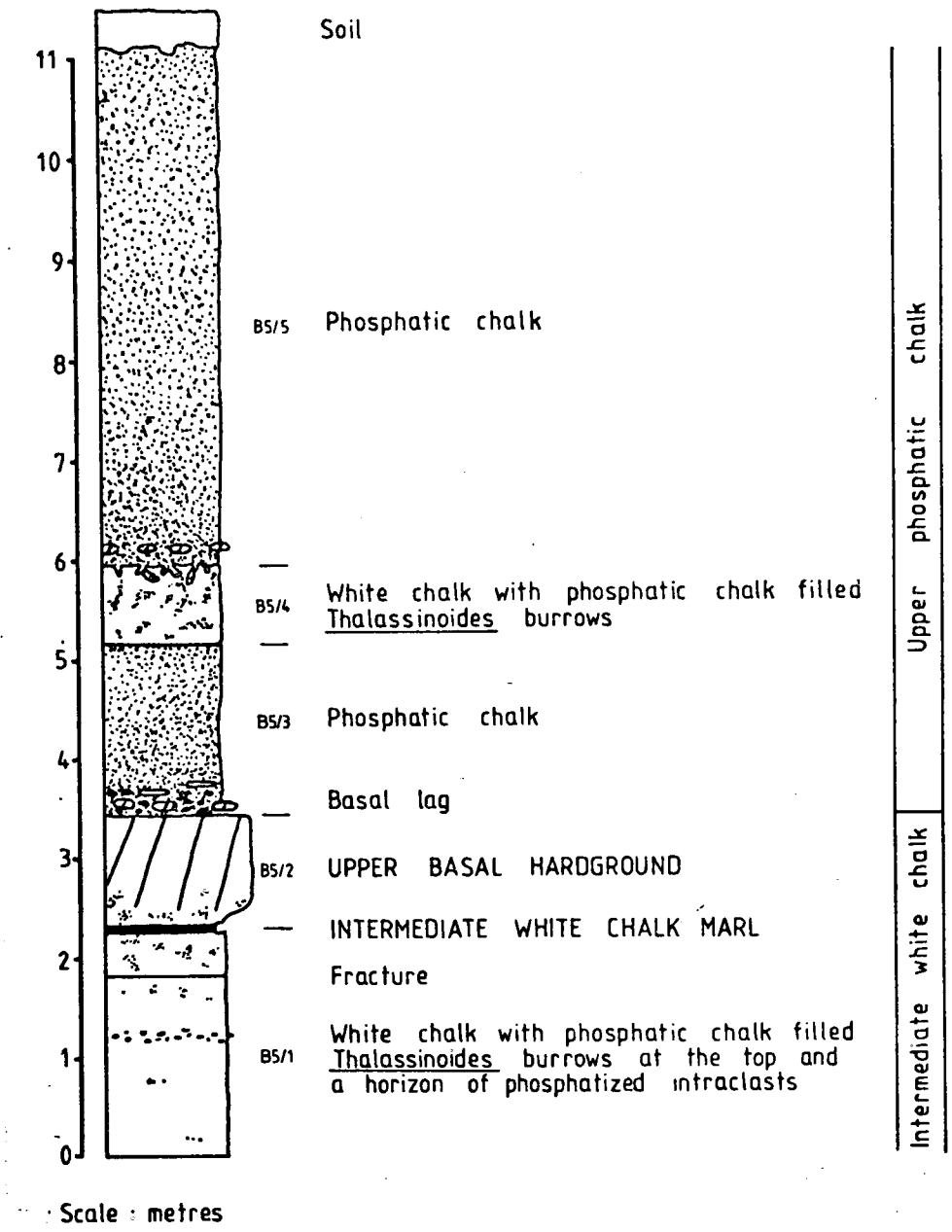


Fig. 2.27 Lithostratigraphy, middle of the south-face east of the fold, Beauval quarry (Section 5).

is taken at the base of a 4 cm marl seam (the Beauval Intermediate White Chalk Marl) which is penetrated by numerous phosphatic-chalk filled Thalassinoides burrows. The overlying bed (B5/2) is comprised of a lower 20 cm of soft white chalk, and 90 cm of hardground chalk becoming more indurated towards its top (Fig. 2.28). The surface of this bed (the Beauval Upper Basal Hardground) is phosphatized, glauconitized, limonite stained and coated with a series of shiny phosphate veneers that penetrate down into the upper portions of the Thalassinoides systems, and are encrusted by unmineralized pycnodonteine oysters. The hardground surface beneath the skin contains a number of narrow (1 mm) worm borings and is encrusted by phosphatized oysters. The surface, which marks the

base of the upper phosphatic chalk is overlain by a coarse intraclastic lag containing 1 - 10 cm oyster-encrusted intraclasts, inoceramid fragments, phosphatized ventriculitid sponges and Gonioteuthis guards. The virtual absence of material intermediate in size between the sand-grade component of the phosphatic chalk matrix and the large intraclasts, strongly contrasts with the composition of the basal lag associated with the Beauval Basal Hardground. The



Fig. 2.28 The Beauval Upper Basal Hardground, exposed in the middle of the south face, Beauval quarry. The hammer shaft is 30 cm long.

Upper Basal Lag is at the bottom of 1.70 m of very rich phosphatic chalk (B5/3) which has a planar top overlain by 80 cm of hard white chalk. This latter bed has a burrowed junction with the overlying phosphatic chalk and contains phosphatic-chalk filled Thalassinoides burrows throughout. There is no evidence for a hardground surface at the top of the bed. In this case lithification is probably a weathering effect since its lateral equivalent (see below) is not hardened. The white chalk is overlain by 5 m of largely-inaccessible phosphatic chalk which includes a line of yellow-stained intraclasts 15 cm from its base.

The thickest section (Section 6; Fig. 2.29) in the upper phosphatic chalk is situated in the NW corner of the quarry, where 14 m of phosphatic chalk rest

on 2 m of soft white chalk penetrated by phosphorite filled Thalassinoides (B6/1).

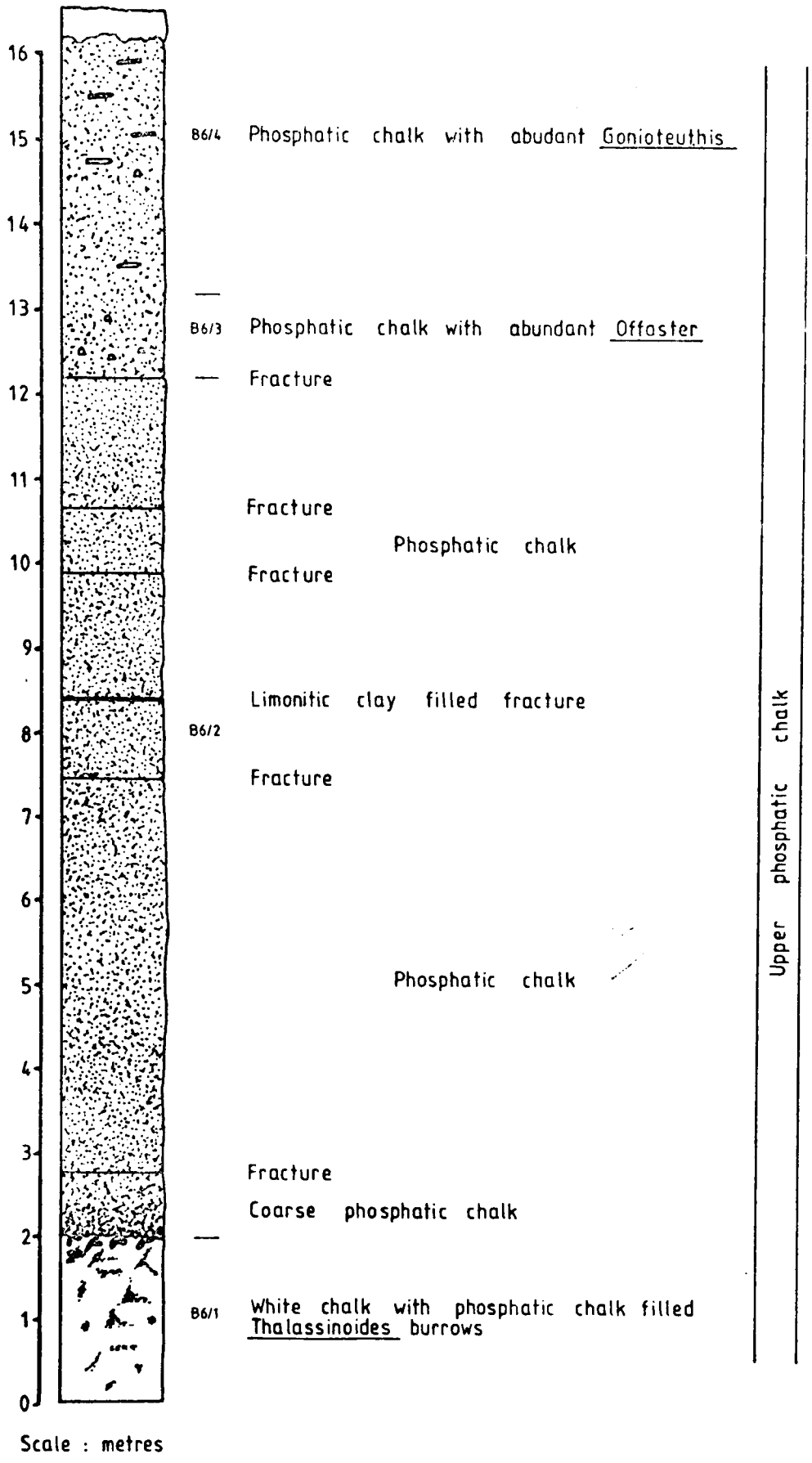


Fig. 2.29 Lithostratigraphy of the NW corner, top level, Beauval quarry (Section 6).

The lower 10 m of the phosphatic chalk (B6/2) is a monotonous sequence of blocky, brown phosphorite containing numerous thin-shelled oysters and occasional Gonioteuthis and comminuted inoceramid. Weathering has broken the phosphorite into 1 m blocks and produced a series of horizontal, laterally discontinuous fractures, a style that is typical of all phosphatic chalks. The pelletal phosphate content of the bed is fairly constant throughout. The top is taken for convenience at a fracture which marks a change in weathering style. Above

this level the phosphatic chalk becomes lighter brown, weathers into smaller (20 - 30 cm) blocks and is more calcarenitic, containing less pelletal phosphate. Offaster pilula (Lamarck) is particularly abundant at the base of these less phosphatic chalks, the lower 1 m of which is hence termed the Beauval Offaster Bed (B6/3). The remainder of the section also contains occasional O. pilula, but Gonioteuthis ex gr. quadrata becomes more prominent towards the top, which is separated off as the Beauval Gonioteuthis Bed. Although the boundaries of these two faunal horizons, unlike many purely sedimentological features, are indistinct and gradational, they provide an excellent marker level throughout the quarry and beyond.

The white chalk that occurs at the top of the quarry is generally obscured by drift and vegetation, but a section in the middle of the west face exposes the upper boundary of the upper phosphatic chalk. The sequence (Section 7; Fig. 2.30) contains 5 m of phosphatic chalk above the limonitic pelletal-phosphate

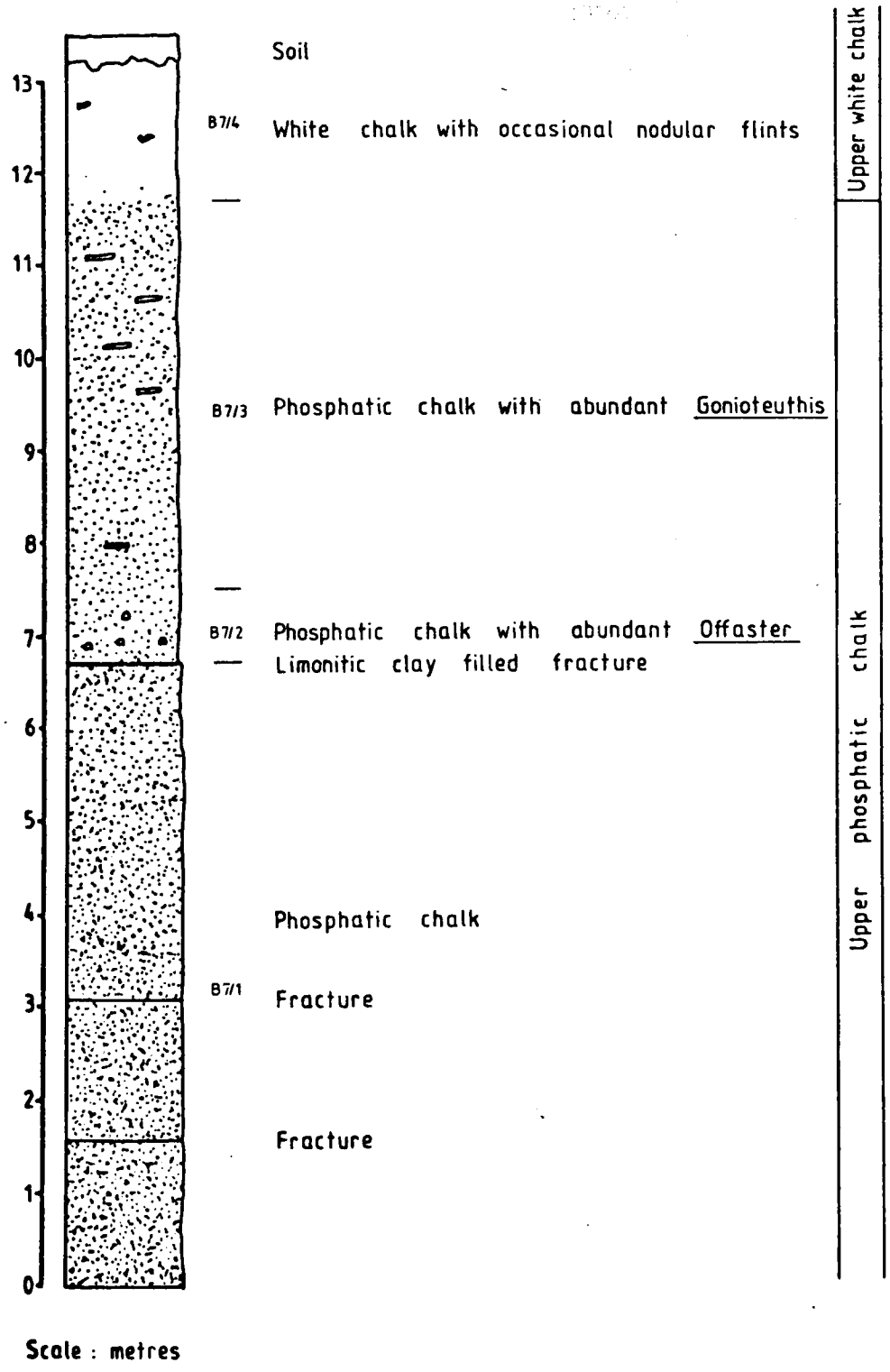


Fig. 2.30 Lithostratigraphy, middle of the west face, top level, Beauval quarry (Section 7).

filled fracture that marks the base of the Offaster bed (B7/2). G. ex gr. quadrata is particularly abundant in the upper portion of the unit (B7/3). The boundary between the upper phosphatic chalk and the upper white chalk is poorly exposed, but is apparently rapidly transitional over a thickness of 20 cm, a result of bioturbation. The overlying 1.40 m of white chalk (B7/4) contains scattered nodular flints but has not yielded any diagnostic fauna.

Two sections (8,9) in the south face expose the upper part of the upper phosphatic chalk below the Offaster bed. Both display a number of sedimentological features which are not apparent in the other exposures. A thin, limonite-stained hardground typified by the occurrence of Echinocorys truncata Brydone (termed the Beauval Echinocorys Hardground) occurs near the base. The hardground is immediately overlain by 60 - 95 cm of phosphatic chalk but above this a yellow-stained, 5 cm thick level of intraclasts marks the base of 95 cm of phosphatized-intraclast rich phosphorite. The top of the intraclast bed is marked by a pelletal phosphate-sand filled fracture in the western section (Section 8; Fig. 2.31A), above which is the Offaster bed. The upper 65 cm of the eastern section (Section 9; Fig. 2.31B) is badly obscured so that the presence of the Offaster bed at the same level cannot be confirmed. The presence of such laterally impersistent features indicates that significant lateral variations in sediment régime occurred during the deposition of the upper phosphatic chalk.

Beauval old quarry is situated 50 m east of the extant workings (Fig. 2.7). The bottom of the quarry has been partly filled by tipping, and much of the remaining section is obscured by soil and vegetation. Three 5 m sections were measured (Section 10; Fig. 2.32) but it is impossible to accurately correlate the logs because of the absence of marker horizons. The bulk of the sequence consists of monotonous, blocky-weathering phosphorite (B10/1), identical to the upper phosphatic chalk in the working quarry. A level of undiagnostic Echinocorys (B10/2) and a bed of coarse phosphatized intraclasts (10/3) occur towards the top of the section. Neither the Offaster bed nor the Gonioteuthis bed are exposed.

Lithostratigraphical correlation of the sections enables the construction of a composite lithostratigraphical column (Fig. 2.33) which, although it does

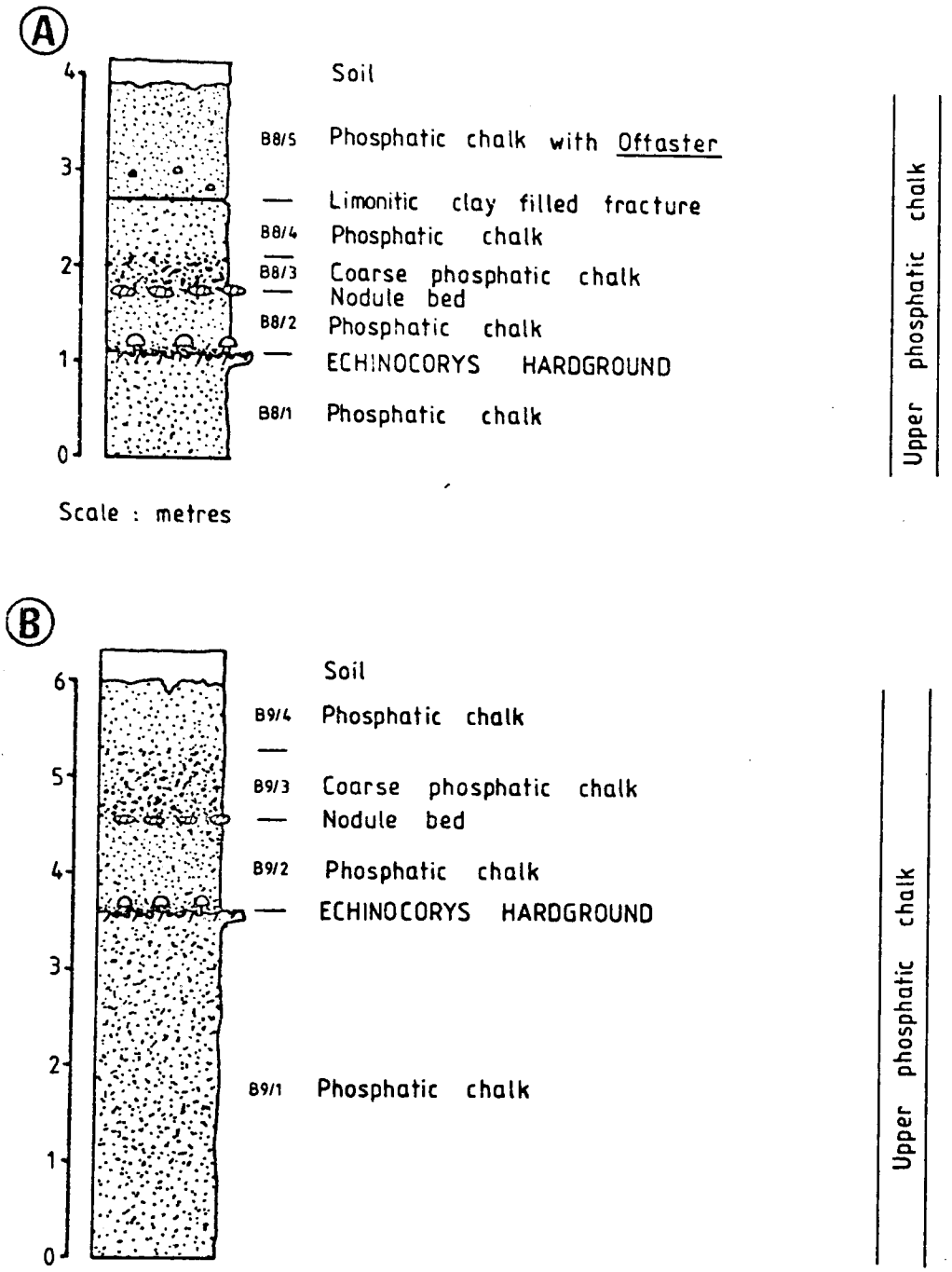
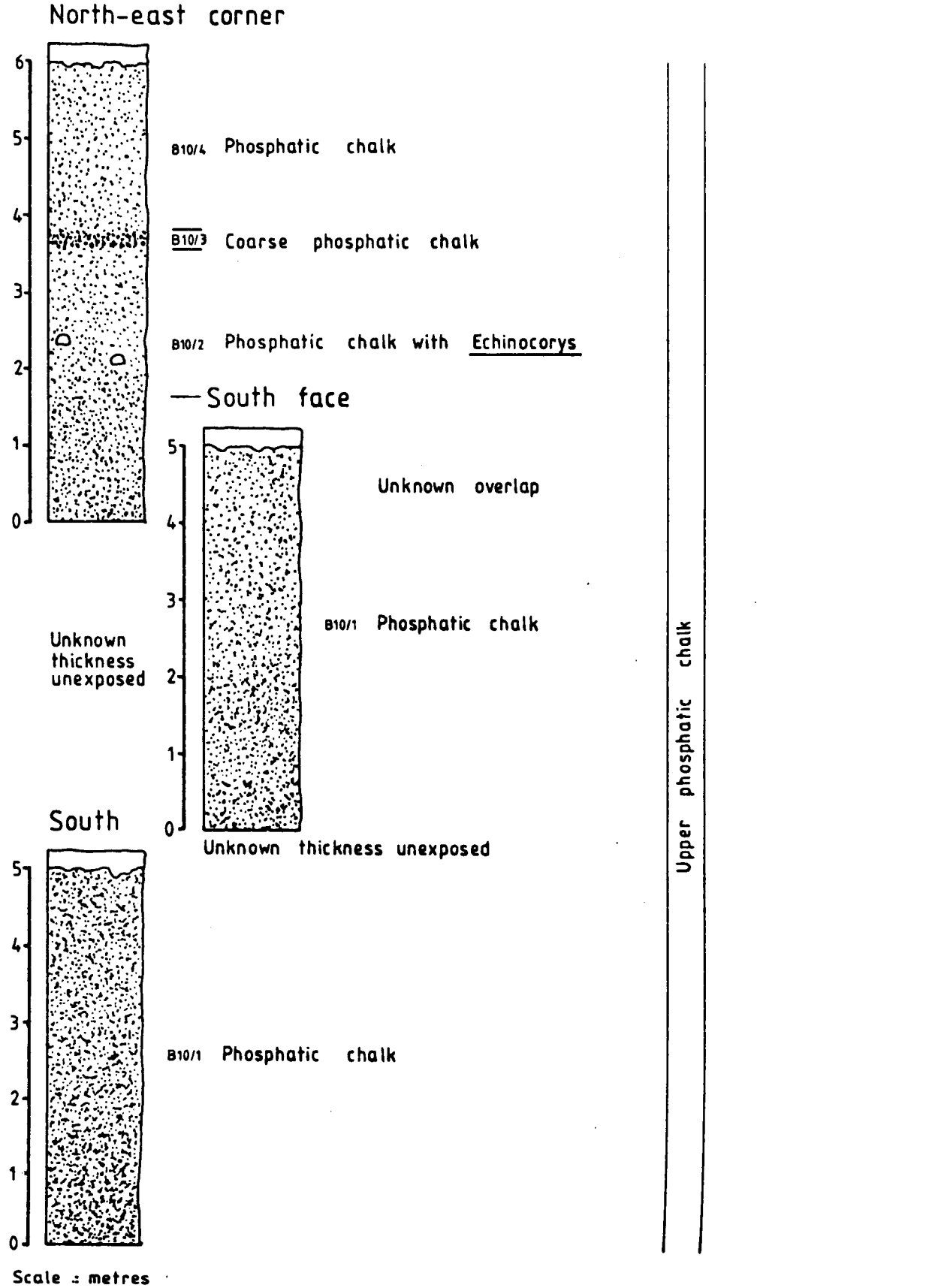


Fig. 2.31 Lithostratigraphy of the upper level, Beauval quarry. A. SW corner (Section 8). B. Middle of the south face (Section 9).

Fig. 2.32 Lithostratigraphy of Beauval old quarry (Section 10).



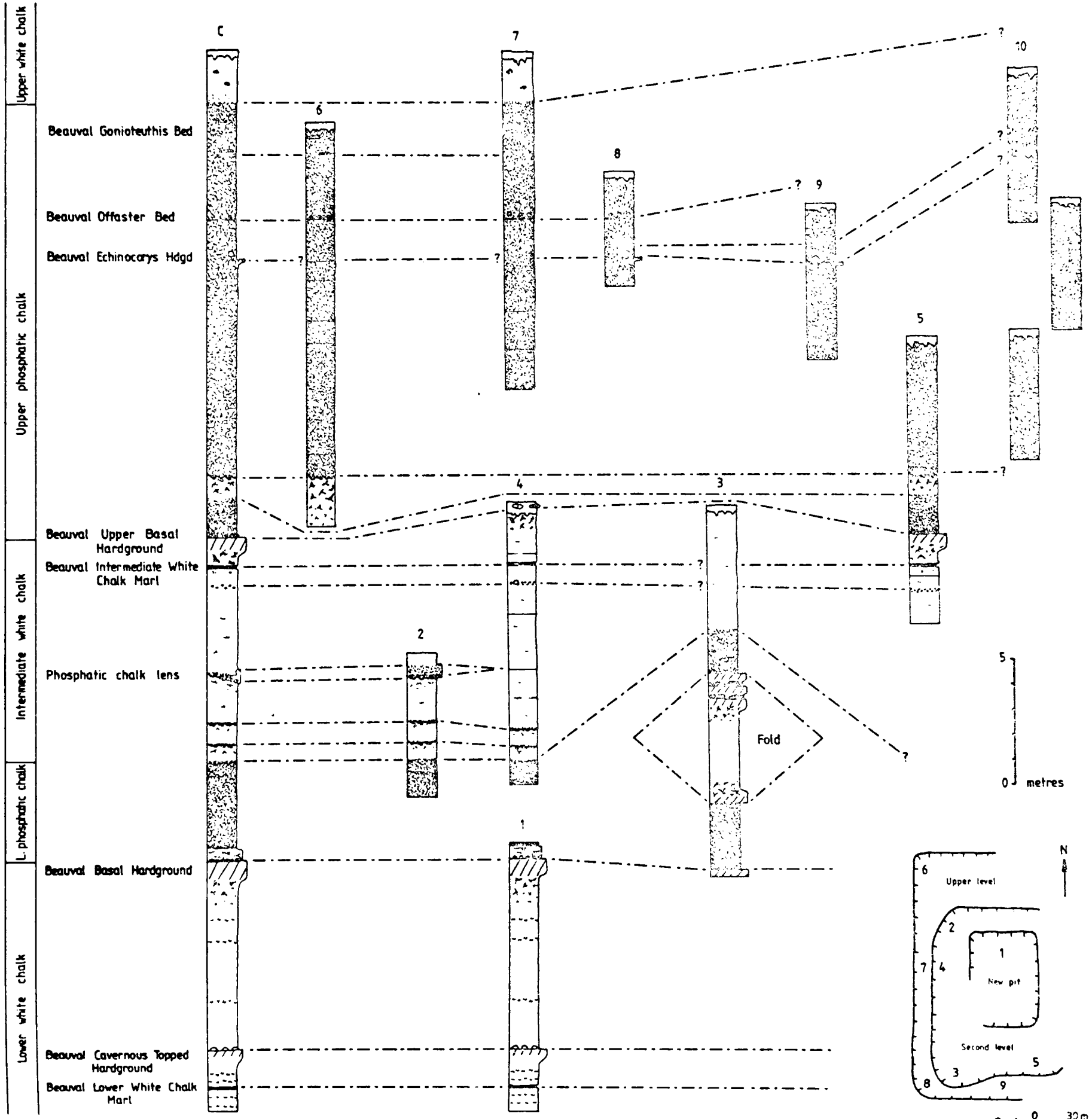


Fig. 2.33 Lithostratigraphical correlation diagram and composite section (C) of Beauval quarry and Beauval old quarry. The numerals correspond to the numbers of measured sections described in the text.

not represent any single point in either quarry, may be used when considering the biostratigraphy and correlation with other localities.

The first faunal records from Beauval were made by Buteux (1864) who lists Micraster coranguinum (Leske), elasmobranch teeth (including Lamna and Oxyrina), belemnites and oysters as being typical of the phosphatic chalk. Merle and Poncin (In: De Mercey, 1887a) proposed a Danian age for the phosphorite but De Mercey (1887a) considered that the phosphatic chalk should be assigned to the Senonian 'Belemnitella' quadrata Zone (see Chapter 1 for a discussion of the early zonation) and the underlying white chalk to the Micraster coranguinum Zone. De Grossouvre (1894a) considered that Actinocamax verus and M. coranguinum were typical of the lower white chalk and the oldest phosphatic chalk and Gonioteuthis ex gr. quadrata and Offaster pilula the youngest, but he did not recognise his uppermost phosphatic chalk division (containing G. ex gr. quadrata and 'Belemnitella mucronata') at Beauval.

Tabatabaï's (1977) work on the microfaunal succession indicates that the lower white chalk and the lower phosphatic chalk may be assigned to Biozone d, the intermediate white chalk to Biozone e and the upper phosphatic chalk to Biozones f - h. This zonation places the lower phosphatic chalk in the middle - late Santonian, the intermediate white chalk in the late Santonian and the Santonian - Campanian boundary within the upper phosphatic chalk. Tabatabaï (1977) does not zone the underlying or overlying white chalks.

My own biostratigraphy has been based entirely on the macrofaunal zonation, an aspect recently neglected by French authors. Comminuted Platyceramus are the only common fossil in the lower white chalk although a single specimen of M. coranguinum, of a form indicative of the middle - high M. coranguinum Zone, was recovered from just below the basal hardground. The basal lag and coral bed yielded phosphatized M. cf. coranguinum and Conulus but little else of diagnostic value. The mélange bed, however (which presumably contains the same fauna as the lower phosphatic chalk), contained Actinocamax verus, Gonioteuthis granulata and an unmineralized M. coranguinum of high M. coranguinum Zone form. The intermediate white chalk just above the phosphatic chalk lens yielded Uintacrinus socialis Grinnel although the lenticle itself contains Echinocorys cf. elevata

Brydone, a form presumed to be restricted to the Marsupites testudinarius Zone (Griffith and Brydone, 1911; Brydone, 1912). However, early forms of E. cf. elevata are found alongside U. socialis in southern England (A.S. Gale pers. comm.), so it must be concluded that the intermediate white chalk is, at least in part, referable to the U. socialis Zone. Micraster coranguinum cf. simpsoni Stokes, a form found in the M. testudinarius and Offaster pilula Zones (Stokes, 1977), was collected from the uppermost intermediate white chalk, suggesting a M. testudinarius Zone age for that level. The upper basal lag contained Gonioteuthis (?)granulataquadrata and a specimen of M. coranguinum cf. rostratus (Mantell) was recovered from the lowest upper phosphatic chalk, indicating the M. testudinarius Zone. Echinocorys depressula Brydone (the guide fossil of the E. depressula Subzone of the Offaster pilula Zone) occurred above this level, indicating that the M. testudinarius/O. pilula Zone boundary is within the lower portion of the upper phosphatic chalk. Occasional Gonioteuthis occur throughout the upper phosphatic chalk. The presence of Echinocorys truncata on top of the Echinocorys hardground provides a correlation with the E. truncata belt (Griffith and Brydone, 1911) of southern England, a horizon situated at the boundary between the E. depressula and abundant O. pilula Subzones of the O. pilula Zone. The high concentration of O. pilula in the Offaster bed suggests a correspondence with the lower belt of abundant O. pilula in southern England (Brydone, 1914). The Offaster bed also yielded Laevaptychus leptophyllus (Sharpe) a form that ranges from the M. testudinarius Zone to the Belemnitella mucronata Zone (Jukes-Browne and Hill, 1904). The top of the upper phosphatic chalk is marked by the Gonioteuthis bed containing Gonioteuthis quadrata quadrata (Blainville). No characteristic fauna was recovered from the upper white chalk.

The micro- and macro-faunal zonations are in close agreement, except for the total absence of M. testudinarius. It is possible that sediment of M. testudinarius Zone age was removed by erosion prior to the formation of the upper basal hardground, but this is not confirmed by the micro-faunal evidence. Furthermore, the presence of M. testudinarius Zone Micraster varieties suggeststhat the absence of the zonal fossil is due to a geographical or facies restriction, rather than the absence of sediment of that age. The presence of M. testudinarius in the

phosphatic chalks of Taplow and Winterbourne (see Sections 2.11.1, 2.11.2) indicates that the former explanation is more probable.

2.3.3 Orville (Pas-de-Calais)

The village of Orville lies 6 km ESE of Doullens on the D24. Two large (2.5 x 0.5 km), north - south elongated, Campanian outliers lie to the south of the village (Fig. 2.34) on the west side of the unclassified road that links Orville and Beauquesne. The northern outlier (which is undoubtedly joined to its southern

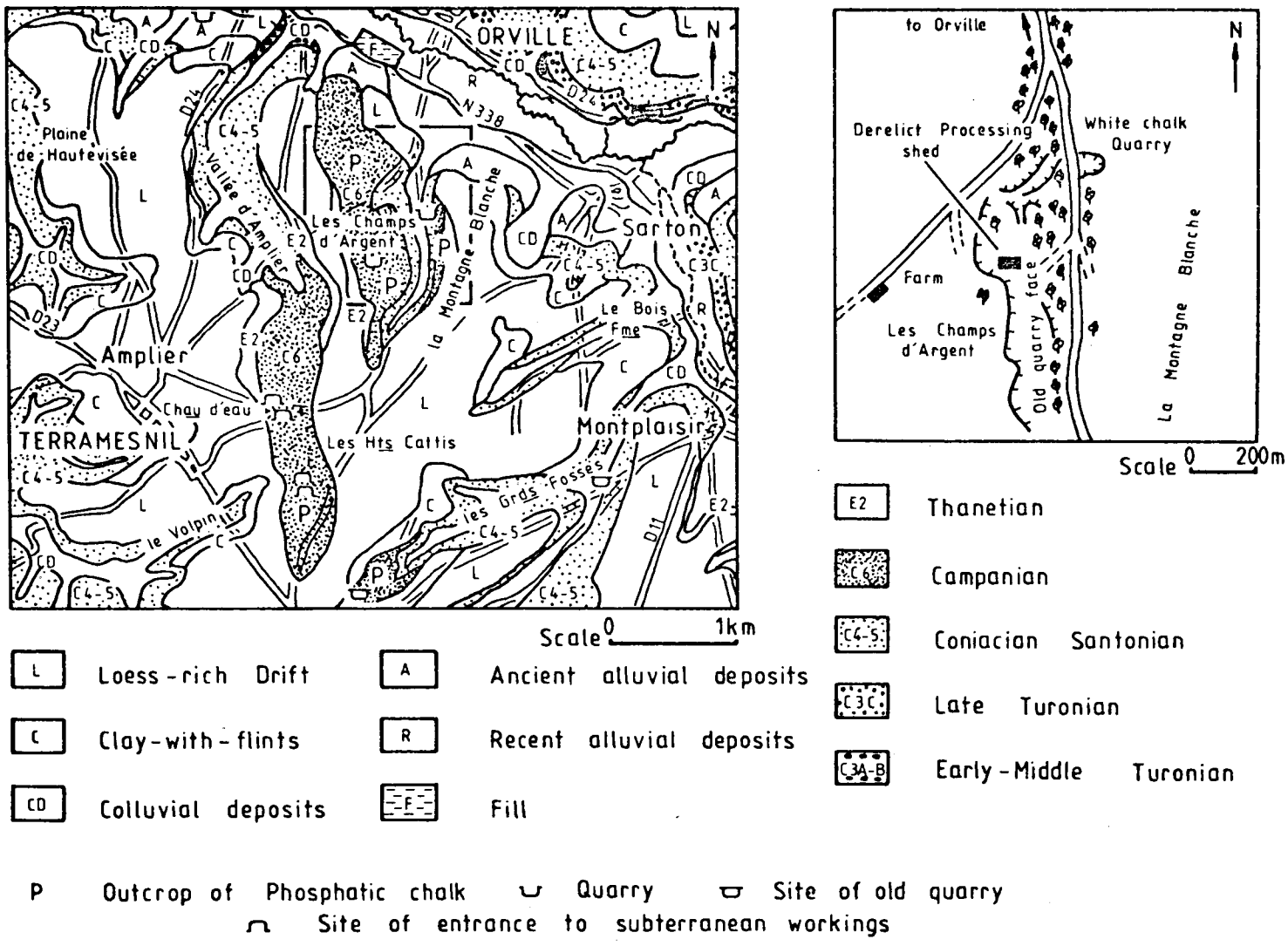


Fig. 2.34 Geological and location sketch maps of "les Champs d'Argent" quarry, Orville (Pas-de-Calais). The geological boundaries are after Delattre et al. (1974).

neighbour in subcrop), site of the Orville exposures of the literature, contained seven phosphatic chalk sites (Gosselet et al., 1894). Two of these are only known from the nineteenth century mapping of the area (Gosselet et al., 1894) : x 604,99 y 269,36 z 110 ($0^g.077$E $55^g.693$); x 604,59 y 269,85 z 107 ($0^g.071$E $55^g.698$). Four of the remainder are recognisable as overgrown quarries but contain no extant exposure : x 604,90 y 269,05 z 120 ($0^g.076$E $55^g.689$); x 604,84 y 268,39 z 135 ($0^g.075$E $55^g.683$); x 604,73 y 268,84 z 135 ($0^g.073$E $55^g.688$); x 604,52 y 269,45

z 130 ($0^g.067$E $55^g.694$), the remaining quarry in "les Champs d'Argent", retains a limited amount of exposure (Fig. 2.34) : x 604,86 y 268,65 z 135 ($0^g.075$E $55^g.686$). This quarry lies 1.75 km SSE of Orville, 400 m west of the Orville - Beauquesne road and may be reached by the farm track which leaves the main road within a small wood 1 km south of Orville.

A further site is located on the hillside east of the Orville - Beauquesne road, 1.5 km south of Orville (Lasne, 1890; Gosselet et al., 1894) : x 605,38 y 269,85 z 110 ($0^g.083$E $55^g.698$).

The Orville deposits were originally worked for the pelletal phosphate sands which overlay the primary deposits, but by 1890, 25 m of phosphorite-bearing strata were exposed in "les Champs d'Argent" quarry (Lasne, 1890) and by the First World War over 3×10^6 tonnes of phosphatic chalk had been extracted (Negre, 1912a). At the turn of the century three quarries were being exploited in the general area (Gosselet, 1901b; Briquet, 1902a). The thickest section was located at Desailly's quarry which exposed 20 m of strata that included two basal hardground - phosphatic chalk sequences (Fig. 2.35A). The quarry of the "Compagnie de St Gobain", which was located to the west of the previous exposure, exposed an intraclastic horizon with abundant Gonioteuthis ex gr. quadrata above the level of the previously described section, possibly indicating a third phosphorite in the area (Gosselet, 1901b). The third site, Drouet's quarry, is only mentioned by Briquet (1902a) who concludes that all three localities were situated in a single circular phosphatic chalk cuvette 300 m in diameter. 'Marginal' sections within the cuvette contrasted strongly with the 'axial' exploited areas, and only exposed a few centimetres of phosphorite (Fig. 2.35B). The quarries were cut by two main fault systems, one striking east - west, the other NW - SE, both sets having throws of ~2 m (Briquet, 1902a).

The present (1979) exposure in "les Champs d'Argent" quarry is restricted to a series of east-facing bluffs that outcrop in the upper part of the hillside surrounding the old phosphate workings (Figs. 2.36, 2.37). However, excavation of the quarry floor exposed a strongly-lithified hardground with two well-defined surfaces. The lower surface is sub-planar to convolute, phosphatized, weakly-glauconitized, limonite-stained and bears occasional goethitic crusts

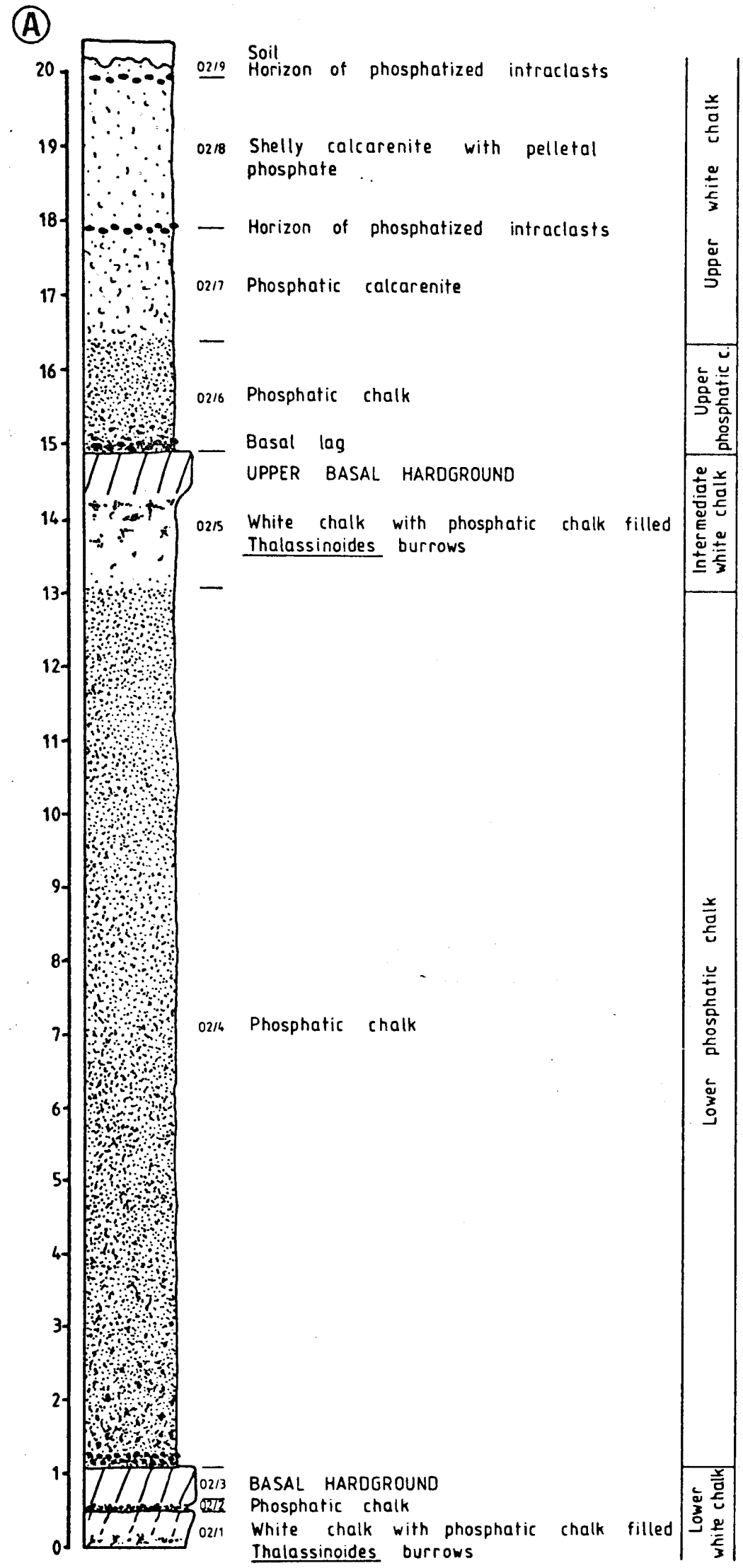


Fig. 2.35 "Les Champs d'Argent" quarries, Orville.
A. Lithostratigraphy of Desailly's quarry, 1902.
B. Lithostratigraphy of a 'marginal' section in the Orville cuvette. (Both sections from data in Briquet, 1902a).

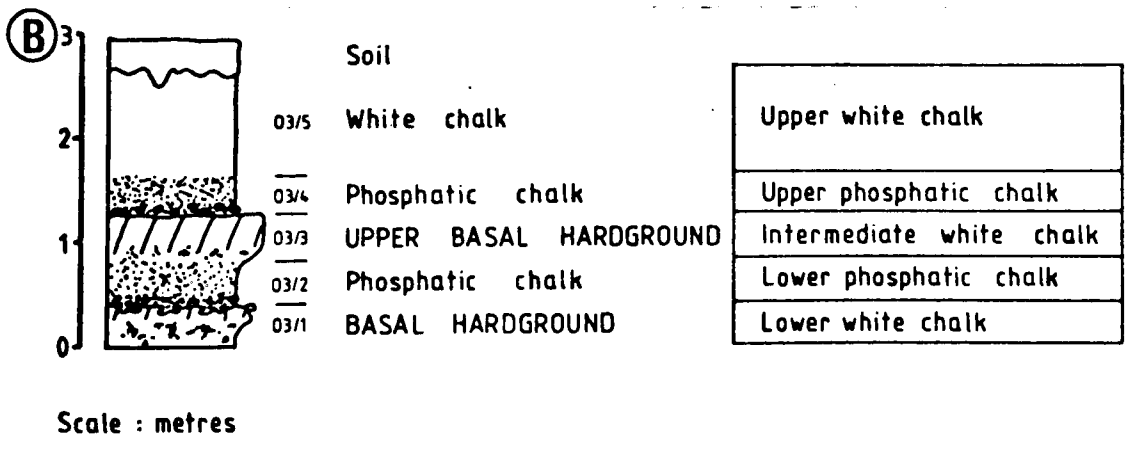




Fig. 2.36 General view of "les Champs d'Argent" quarry Orville, showing the typical form of an abandoned phosphate working.

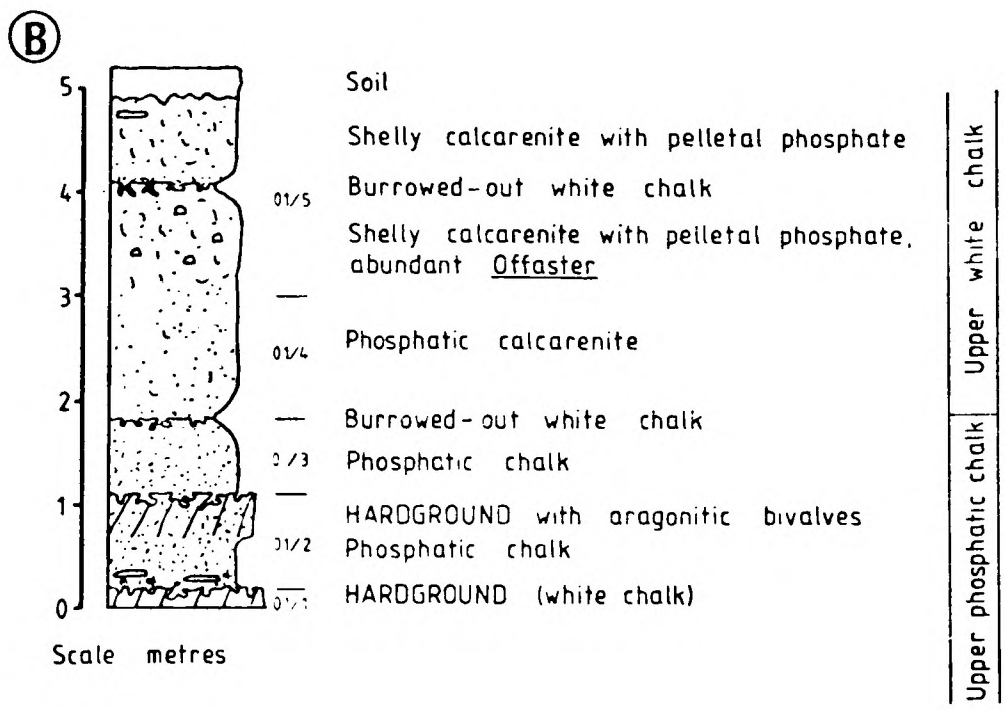
and a discontinuous, shiny phosphate skin. The lithified sediment is a bioturbated chalk with a high pelletal phosphate content and numerous 0.1 - 1.0 cm subangular, phosphatized intraclasts. Burrow morphologies are generally indistinct, but a phosphatic-chalk filled Thalassinoides system penetrates the lithified upper 60 cm and spreads out in the underlying soft white chalk. The second surface occurs on top of 6 cm of intraclast-rich phosphorite which has been cemented on the lower surface as a result of early diagenesis. The upper surface is coated by patches of iridescent phosphate, and is encrusted by scattered pycnodonteine oysters. The cemented lag contains 0.5 - 10.0 cm phosphatized, phosphate-veneer coated, worm-bored intraclasts which directly overlie the lower surface. The intraclasts are surrounded and overlain by a cemented phosphatic chalk containing a high proportion of bioclasts (particularly fragments of the scleractinian coral Diblasus arboresens), limonitic and phosphatized sponges, silicified inoceramid and echinoderm fragments. The unit has a high concentration of 'pyrolusite', is limonite stained and contains 0.5 cm calcite-spar filled voids. The hardground surface is overlain by an intraclast-rich basal lag of 2 - 5 cm intraclasts, cidarid spines, teeth, asteroid ossicles and numerous small Gryphaeostrea canaliculata (J. Sowerby).

There is no current exposure between the (?)basal hardground and the bluff

sections so no data are available on the intervening 10 - 15 m of sediment. Approximately 5 m of section can be reconstructed from the bluff exposures (Fig. 2.37). The lowest bed (01/1) consists of a yellow-stained hardground in a lithified white chalk, the surface of which has been weakly glauconitized and phosphatized and is coated by a shiny phosphate patina. The presence of numerous Gonioteuthis ex gr. (?)quadrata guards in the sediment immediately overlying the hardground indicates that it is in the upper portion of the phosphatic chalk



Fig. 2.37 The bluff section, "les Champs d' Argent" quarry Orville. A. Close-up of the exposure. The prominent notches coincide with levels of burrowed-out white chalk. B. Lithostratigraphical log.



sequence. This overlying sediment (01/2) consists of 90 cm of strongly-bioturbated phosphatic chalk containing numerous recognisable Thalassinoides systems. The uppermost 45 cm of the bed has been lithified at an early stage of diagenesis and contains large numbers of composite moulds of aragonitic bivalves. It is limonite stained throughout, and bears a shiny phosphate skin on its convolute surface. The hardground is overlain by 70 cm of blocky-weathering, coarse phosphatic chalk (01/3) which decreases in phosphatic chalk content upwards. The top is marked by a deeply weathered notch, which coincides with a burrowed-out white chalk horizon and a level of cavernous weathering, probably the result of pyrite decay. Above this level the pelletal phosphate content decreases, and the sediment becomes progressively more coarsely calcarenitic (01/4). The dominant components of these 2.30 m of calcarenites are echinoid debris, particularly fragments of Offaster tests, and calcisponge spicules. Partly crushed and complete Offaster pilula are abundant throughout the unit, but are commonest in the upper 110 cm. The calcarenite is intensely bioturbated, burrows commonly being filled with oriented fragments of thin-shelled echinoid test. The top of the bed is marked by a burrowed-out white chalk which is overlain by a lag concentration of pelletal phosphate and phosphatized intraclasts that include phosphatized O. pilula tests. The top of the section (01/5) consists of 80 cm of calcarenite with scattered Gonioteuthis ex gr. quadrata and O. pilula.

The Offaster-bearing spiculites are the most prominent feature of the quarry because they recrystallize and harden during weathering to form massive blocks, rather than breaking down into their individual components like the underlying phosphorite. Consequently, large 5 m blocks of slumped calcarenite are exposed on the quarry floor and provide excellent surfaces for collecting the macrofauna. The slumping is probably due to these poorly-phosphatic beds being avoided during the final stages of phosphorite extraction which resulted in them being undermined and left in an unstable condition.

The suggested correlation between the extant exposures and the two sections described in detail by Briquet (1902a) is shown in Fig. 2.38. A close correpondence between the bluff section and the upper part of the Desailly's quarry section is immediately apparent, while the correlation between that section

and the cuvette 'marginal' example indicates a considerable slope on the Orville Basal Hardground and, to a lesser extent, on the upper basal hardground. The upper portion of the calcarenitic sequence has been termed the Orville Offaster Bed, and probably correlates with similarly named beds elsewhere.

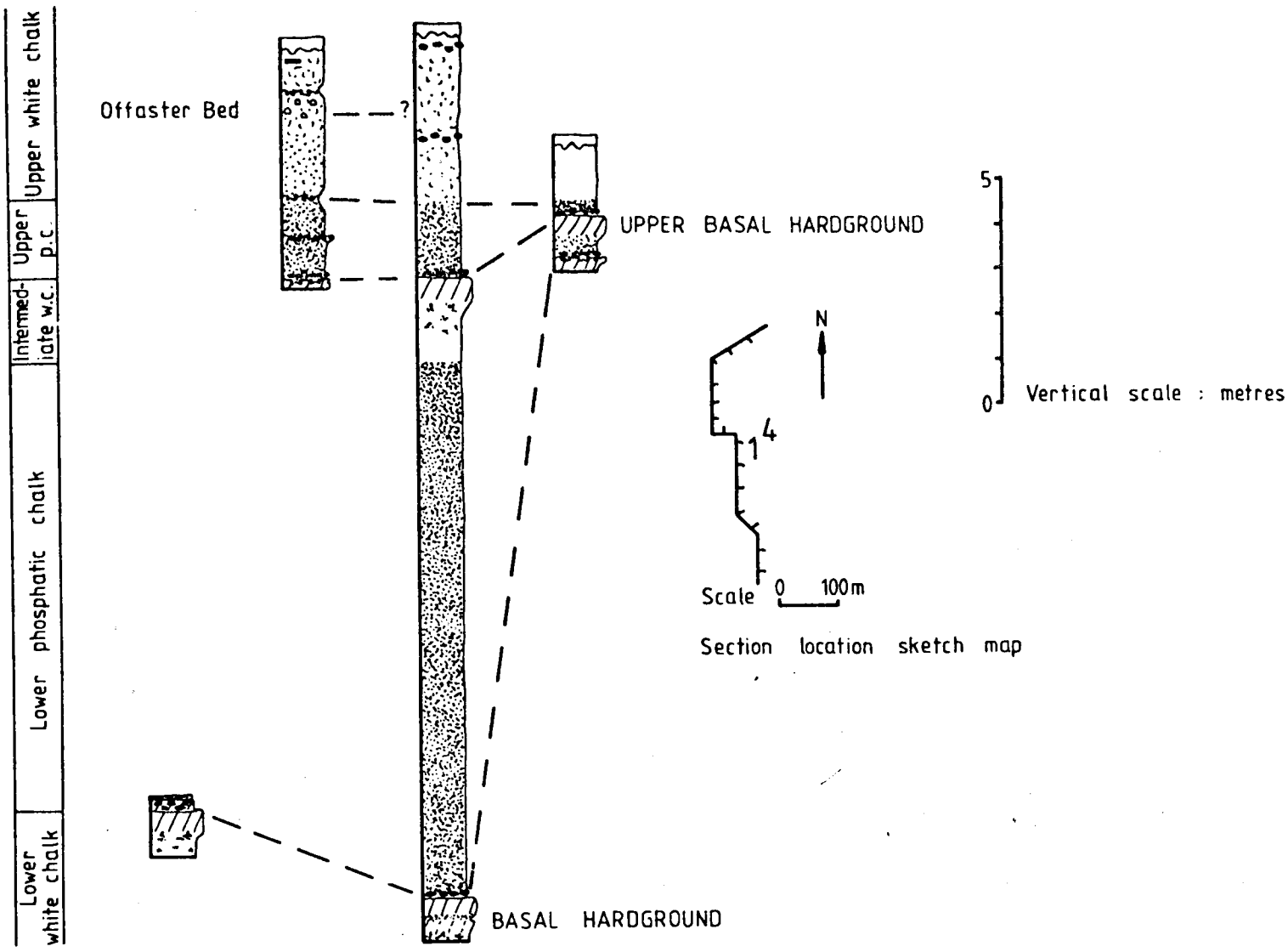


Fig. 2.38 Lithostratigraphical correlation diagram of the Orville cuvette section.

No diagnostic fauna was collected from the (?)basal hardground exposure although Actinocamax verus has been recorded from the lowest phosphatic chalk at the site (Lasne, 1902). The occurrence of G. ex gr. quadrata (Leriche, 1908; see above) and O. pilula towards the top of the sequence is indicative of the early Campanian abundant O. pilula Subzone of the O. pilula Zone. Leriche (1908) also records 'Pachydiscus' leptophylus Sharpe, Echinocorys 'scutata' and E. striata Lamarck from this locality.

2.3.4 Terramesnil (Somme)

The village of Terramesnil lies along the sides of the D23, 6 km SSE of Doullens and 3 km east of Beauval. The more southerly of the two Campanian out-

liers that are situated to the south of Orville, lies 750 m due east of Terramesnil. The northern portion of the outlier is transected by the "Vallée d' Orville", the site (Gosselet et al., 1894) of three phosphorite quarries : x 604,34 y 268,50 z 125 ($0^g.067$E $55^g.684$); x 604,33 y 268,07 z 140 ($0^g.067$E $55^g.680$); x 604,33 y 267,82 z 140 ($0^g.067$E $55^g.677$). Two entrances to subterranean workings were located (Gosselet et al., 1894; Delattre et al., 1974) on either side of the unclassified road that links Terramesnil and Orville, 750 m east of the SE extremity of Terramesnil village : x 604,08 y 267,55 z 147 ($0^g.063$E $55^g.675$); x 604,11 y 267,45 z 147 ($0^g.064$E $55^g.674$). Two further mine entrances were located at the southern end of the outlier, 600 m south of the preceding locations, NW of "les Bosquets" : x 604,33 y 266,84 z 138 ($0^g.067$E $55^g.668$); x 604,33 y 266,94 z 138 ($0^g.067$E $55^g.669$).

The only location described in the literature is "la Solette" quarry which was originally worked for secondarily enriched phosphorite (Lasne, 1890) but later (Negre, 1912a) exposed five (0.40 - 2.80 m) horizons of phosphatic chalk alternating with white chalk. A strongly-lithified, phosphate-skin veneered basal hardground overlain by a basal lag occurred at the base of the succession. Although they were not described, the "Vallée d'Orville" exposures were considered (Lasne, 1892) to fall in a NNW - SSE elongated cuvette. Leriche (1908) recorded a substantial proportion of his species of elasmobranch from Terramesnil.

2.3.5 Beauquesne (Somme)

The village of Beauquesne is situated 9 km SSE of Doullens, at the intersection of the D31 and D23. Eight small (< 1 km long) phosphorite-bearing Campanian outliers are located within a 2 km radius of the town, of which four contained (Delattre et al., 1974) phosphatic chalk quarries : x 602,14 y 264,56 z 128 ($0^g.033$E $55^g.633$); x 604,76 y 266,13 z 135 ($0^g.074$E $55^g.642$); x 605,39 y 263,91 z 125 ($0^g.084$E $55^g.645$); x 605,52 y 264,64 z 124 ($0^g.096$E $55^g.646$). The remaining four sites have been mapped (Delattre et al., 1974) as phosphatic chalk outcrops : x 602,55 y 264,26 z 143 ($0^g.040$E $55^g.637$); x 603,11 y 263,75 z 135 ($0^g.048$E $55^g.639$); x 603,15 y 264,11 z 120 ($0^g.095$E $55^g.661$). Although recorded as a phosphorite

locality (Lasne, 1890), no details of any of these sites are recorded in the literature.

2.3.6 Raincheval (Somme)

The village of Raincheval lies 11½ km SE of Doullens on the south side of the D31, 1 km east of the D11. A small (600 x 250 m), N - S elongated Campanian outlier is situated 750 m south of the village on the NW side of the "Champs de Varennes". This was the site (Gosselet et al., 1894; Delattre et al., 1974) of two phosphatic chalk exploitations : x 607,21 y 262,86 z 133 ($0^g.112$E $55^g.628$); x 607,26 y 262,62 z 133 ($0^g.112$E $55^g.626$). No further information is available.

2.3.7 Puchevillers (Somme)

The village of Puchevillers is situated 12½ km SSE of Doullens, at the intersection of the D23 and D11. A 1000 x 50 m Campanian outlier lies on the north side of the "Vallée Porion", 1 km NE of the village. This was (Gosselet et al., 1894; Delattre et al., 1974) the site of two phosphatic chalk quarries : x 606,30 y 262,37 z 112 ($0^g.09$E $55^g.623$); x 606,49 y 262,62 z 112 ($0^g.101$E $55^g.626$).

2.3.8 Le Quesnoy (Somme) x 607,03 y 260,94 z 125 ($0^g.109$E $55^g.609$)

The hamlet of le Quesnoy is located 14 km SSE of Doullens on the D23, 1¾ km ESE of Puchevillers. A phosphatic chalk quarry was situated (Delattre et al., 1974) within the 350 x 150 m, crescent-shaped Campanian outlier which lies 200 m SE of the hamlet.

2.3.9 Toutencourt (Somme) x 608,85 y 260,47 z 115 ($0^g.137$E $55^g.604$)

The village of Toutencourt lies 16 km SSE of Doullens, 14 km WNW of Albert, at the intersection of the D23, D114 and D124. A phosphorite quarry was located in the SE portion of the 500 x 450 m, crescent-shaped Campanian outlier which

is situated 1 km north of the village, on the south side of "le Haut des Bois", half-way between the D124 and D114.

2.3.10 Ribémont-sur-Ancre (Somme)

The village of Ribémont-sur-Ancre is situated 27 km SSE of Doullens, 8 km SW of Albert, on the north bank of the river Ancre. Two Campanian outliers are located on the north and south side of a NW - SE trending valley which is crossed by the N29, 2 km NW of the village. The larger (1750 x 150 m) outlier, which lies on the south side of the valley, was the site of two phosphorite workings (Gosselet et al., 1894). One lies at the SE end of the outlier on the northern side of the "Vallée de la Renardière": x 615,11 y 251,88 z 85 ($0^g.234$E $55^g.518$), the second is at the NW end : x 613,97 y 252,42 z 85 ($0^g.216$E $55^g.523$). The smaller (1000 x 50 m) outlier contains a phosphatic chalk outcrop within the "Bois de St Laurent": x 614,28 y 252,58 z 85 ($0^g.222$E $55^g.525$)(Mennessier et al., 1976).

The locality was discovered during the general expansion in the phosphatic chalk industry during the late nineteenth century (Lasne, 1890; Gosselet et al., 1894) but no details of these exploitations are known to the author. Recent reexamination of the local biostratigraphy (Mennessier et al., 1976) has demonstrated that the 5 - 6 m of phosphatic chalk that occurs in the valley is of Campanian Biozone h age, but the underlying white chalk has been refered to the early Santonian Biozone d. Monciardini (In: Mennessier et al., 1976) records a remanié earliest Campanian Biozone g microfauna within the phosphatic chalk. Elsewhere in the region the late Santonian to early Campanian is represented by ~30 m of chalk, indicating that erosion prior to the deposition of the phosphatic chalk must have removed a considerable thickness of sediment.

2.4 The Somme valley

Between Peronne and Amiens, the river Somme runs due east - west in a series of broad meanders. The river has incised through ~50 m of white chalk and flows over strata of late Coniacian age; Santonian to early Campanian chalks

outcrop in the river cliffs, but exposures are now few. Elsewhere, the Chalk is obscured by up to 10 m of loess-rich drift ("limons des plateaux"). In general, the Campanian outcrop is restricted to outliers containing phosphatic chalk, although the lithofacies is not exclusively, or even dominantly Campanian.

The outcrop includes near-complete late Turonian to early Campanian sequences in the most extensive sections. Exceptions to this occur in the successions at Curlu and Hem-Monacu, where early Santonian Biozone d sediments are absent (Monciardini in Mennessier et al., 1976). Early Santonian chalks elsewhere in the region are up to 30 m thick (Mennessier et al., 1976), indicating significant erosion prior to phosphatic chalk deposition.

Phosphatic chalks outcrop in the river valley in the area up to 6 km west of the A1 motorway (Fig. 2.39). They are principally of middle to late Santonian Biozone e age; much of the white chalk in the region is also of this age. Phosphatic chalk exposures have been recorded on the north (right) bank at Hem-Monacu, Curlu, Vaux and Suzanne, and on the south (left) bank at Feuillères and Eclusier-Vaux. The only exposure now visible (1979) is at Hem-Monacu.

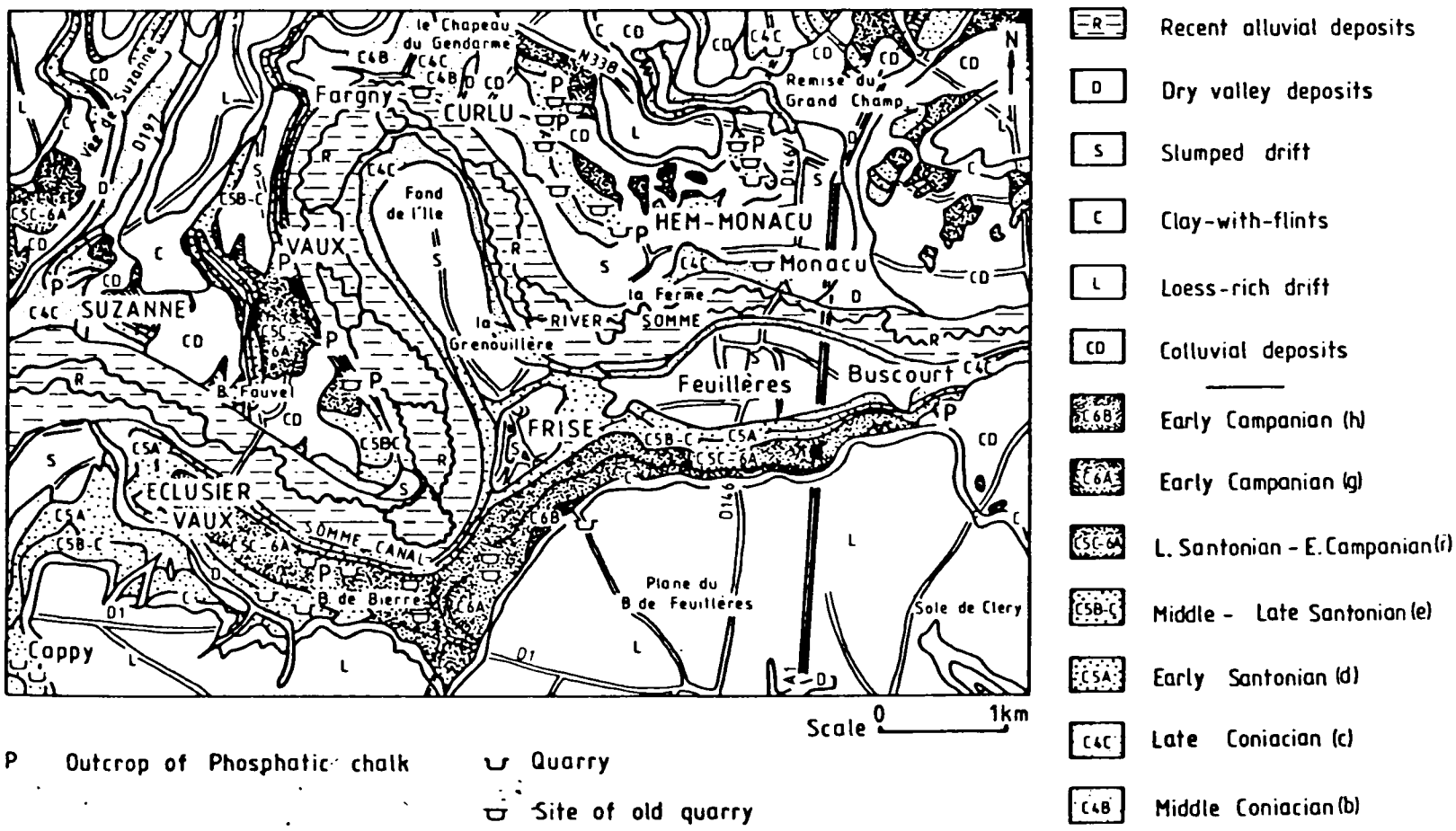


Fig. 2.39 Geological map of the Somme valley phosphatic chalk localities (Geology modified from Mennessier et al., 1976).

2.4.1 Hem-Monacu (Somme)

The village of Hem-Monacu lies on the north bank of the river Somme, 1 km west of the A1. Phosphatic chalk outcrops in two areas; the first, an extant quarry, lies 250 m NW of the village, on the south side of the road that links Curlu to the D146. The second, the site of a large complex of abandoned pits, lies between the Curlu - D146 road and the N338, 500 m west of the D146 and NNE of Hem-Monacu village.

2.4.1a Hem-Monacu quarry x 635,58 y 250,85 z 70 ($0^g.549$E $55^g.507$)

This quarry is the only extensive exposure of phosphatic chalk in the Somme valley. The main face is ~40 m long and runs east - west; it exposes ~6 m of chalk. Poorer exposure is present on the west face. The quarry is currently (1979) being actively filled with private refuse.

The major features of the quarry are two white chalk hardgrounds with apparent dips of ~5° to the west (Fig. 2.40A), the upper of which is overlain by 1 - 2 m of phosphatic chalk. The upper hardground (Fig. 2.40) is only present in the western half of the quarry, since to the east it passes laterally into the mélange bed.

The lowest sediment exposed is a resonant, soft white chalk (HM1/1,2/1) containing soft, light-brown phosphatized intraclasts and numerous limonite-stained calcarenitic burrow-fills and winnows. Limonite-preserved sponges are common. The top of the bed is taken at the surface of the lower hardground, the upper 30 cm of which is strongly-lithified but passes down into 65 cm of weakly-lithified chalk. The true dip of the hardground is approximately 8° SSW. Phosphatic-chalk filled Thalassinoides burrows spread horizontally, and are therefore particularly prominent, in a zone up to 50 cm below the lithified portion of the hardground. The hardground has a light-brown phosphatized top. To the west it is overlain by 10 cm of phosphatic chalk (HM1/2) containing abundant phosphatized and phosphate-veneered intraclasts up to 5 cm in diameter. This bed is apparently the source of the phosphatic chalk in the Thalassinoides systems of

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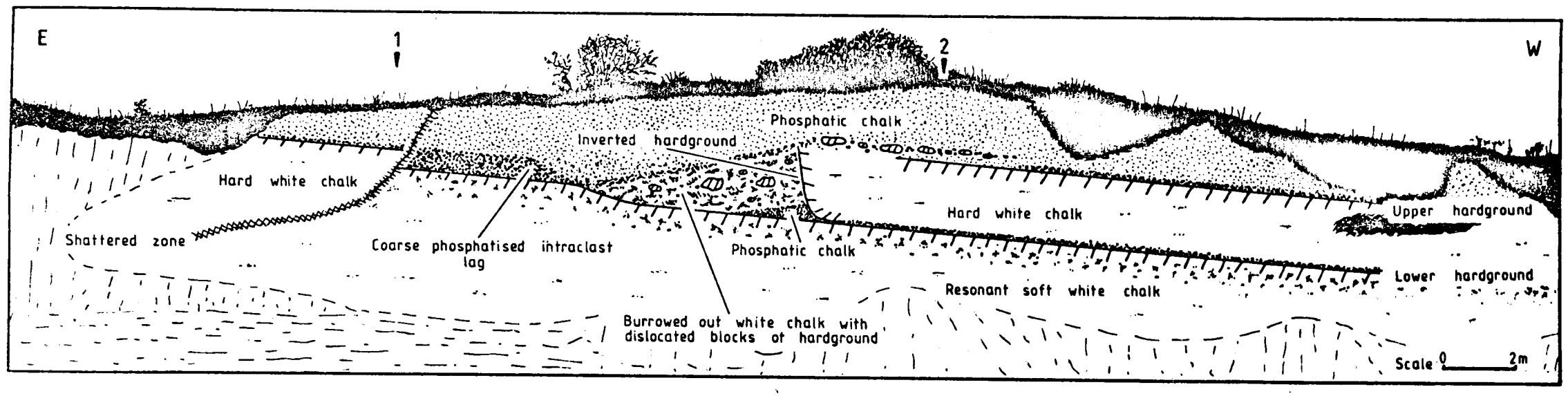

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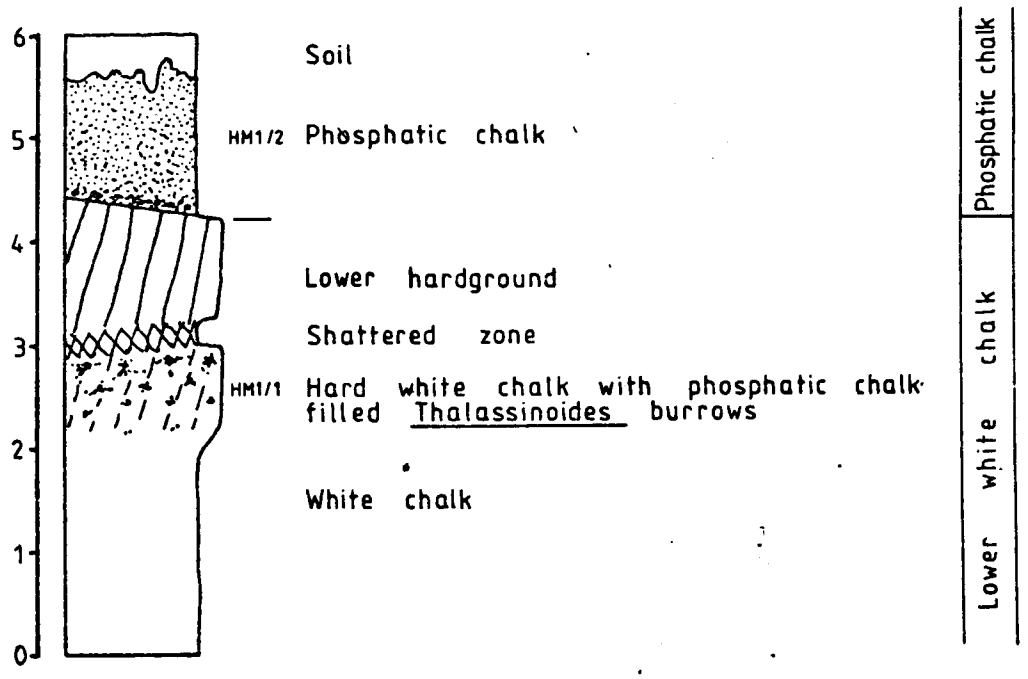

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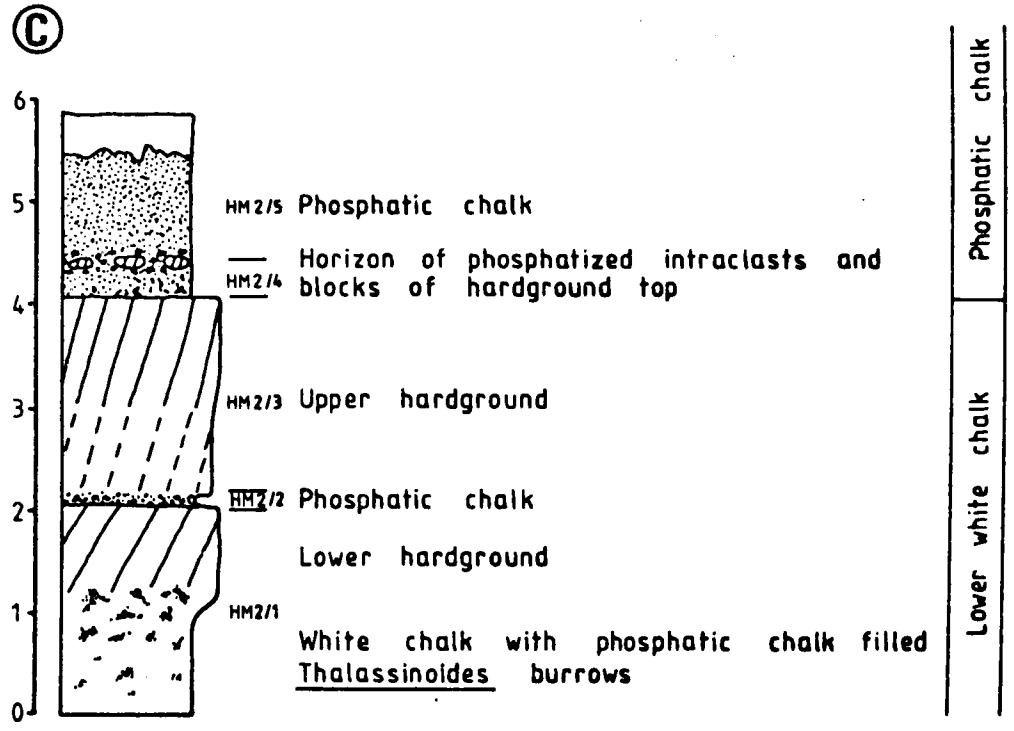


Fig. 2.40 Hem-Monacu quarry (Somme). A. Sketch of the main face. B. Lithostratigraphy of the eastern portion of the main face (1 in A.). C. Lithostratigraphy of the western portion of the main face (2 in A.).

the lower hardground. Above this unit in the western portion of the quarry, there is 1.90 m of white chalk topped by a hardground surface (HM1/3). The entire thickness of this chalk has been lithified. On the west side of the quarry the upper hardground has a shiny phosphate patina on its top surface and is overlain by a basal lag of iridescent-phosphate coated intraclasts, followed by ~1 m of phosphatic chalk (Fig. 2.40A). Towards the east however, the nature of the hardground top becomes more problematic. The phosphatized top disappears and the boundary between lithified white chalk and phosphatic chalk is indistinct. Furthermore, 30 cm above the apparent junction, there is a coarse conglomerate of dislocated blocks of hardground up to 20 cm long , associated with well-rounded, deep-brown intraclasts up to 1 cm across set in a matrix of phosphatic chalk (HM1/4). The intraclasts all have shiny skins and the hardground blocks have been encrusted by pycnodonteine oysters on their sides and tops. Other identifiable bioclasts include fragments of ventriculitid sponges, oyster and inoceramid debris and elasmobranch teeth.

Further east the section becomes further complicated and interpretation is hampered by the inaccessible nature of the face above the lower hardground. Several features are readily visible : a large 2 m block of hardground has been folded and inverted, so that it in-part rests on top of the lower hardground (Fig. 2.40A), the remainder dipping at an angle of 80° W. The way up of this block is clearly indicated by its phosphatized top surface and the abundant phosphorite filled Thalassinoides burrows originating from above it. To the east, ~ 2 m of eastward dipping mélange [the term is used descriptively (French : mixture); no genetic conotations are implied] chalk abutts against this block. It consists of a white chalk that has been burrowed-out by repeated phosphatic-chalk filled Thalassinoides tunnels. The unit further contains blocks of dislocated hardground up to 30 cm across, and is overlain by a thin wedge of richer phosphatic chalk (Fig. 2.40A). The mélange wedges out to the east, where the lower hardground is overlain by a 1 m thick, coarse, phosphatized and glauconitized intraclast pebble bed. This pebble bed is reverse faulted against the lower hardground. East of the fault the lower hardground is again covered by a thin phosphatized intraclast lag. The reverse fault continues through the varying thickness of phosphatic chalk

(HM2/2) that overlies the hardground sequence.

Tabatabai' (1977, p74-77) examined the quarry, which he termed Curlu 1. Unfortunately, he did not recognise the complex sedimentology and tectonics of the exposure and consequently much of his detailed petrographic work is of little value. He does, however, note that planktonic foraminiferans and calcispheres are the main constituents of the resonant white chalk, whereas the lowest phosphatic chalk (presumably west of the inverted hardground) has 45% benthonic foraminiferids and 5 - 15% coprolites.

The quarry is sited on the mapped boundary between late Coniacian Biozone c and middle - late Santonian Biozone e chalks (Mennessier et al., 1976). According to Monciardini (in Mennessier et al., 1976), there is an early Santonian Biozone d hiatus in the succession, although Tabatabai' (1977, p.143) assigns the phosphatic chalk to Biozone d.

The resonant white chalk contains a fauna that includes Inoceramus cordiformis J. de C. Sowerby and Micraster coranguinum; indicative of the middle - high M. coranguinum Zone. No diagnostic fossils were recovered from the lithified white chalk between the lower and upper hardgrounds, but fallen blocks of the burrowed-out white chalk and phosphatized-intraclast pebble bed contain an abundant fauna including ventriculitid sponges, Actinocamax verus, Echinocorys, Plagiostoma, Platyceramus fragments, cidarid debris and phosphatized internal moulds of gastropods and a scleractinian coral. The presence of common A. verus in the absence of Gonioteuthis is typical of the lowest phosphatic chalks, as noted previously by Lasne (1902, p57). De Grossouvre (1894a, 1899) records Belemnitella ex gr. grossouvrei (Janet) from the phosphatic chalk at this locality. The fauna of the phosphatic chalk indicates the upper part of the M. coranguinum Zone.

Hem-Monacu quarry displays a number of features that require further consideration :

(1) The breakup, dislocation, folding and inversion of blocks of hardground,

(2) The occurrence of a thick, coarse, phosphatized-intraclast unit down-dip of the fault through the lower hardground,

(3) The lithification of the thick sequence of white chalk between the upper and lower hardground surfaces and the hardening of the white chalk above

the shattered zone.

Hardground dislocation has been noted from a number of other phosphatic chalk sites, notably Beauval (2.3.2) and Hardivillers (2.8.1). Similar features have been described from Boxford (Jarvis and Woodroof, 1981; 2.11.3) and Downend quarries (Gale, 1980). In all these cases, dislocation appears to have occurred prior to, or concurrent with the deposition of the overlying bed. In this example the sedimentology of the immediately overlying phosphatic chalk has been considerably influenced by this synsedimentary tectonism. The presence of dislocated blocks of hardground within the burrowed-out white chalk and their encrusted sides indicate that breakup occurred prior to, or during, the deposition of this bed. This suggests that the white chalk is also a reworked product of material eroded from between the two hardgrounds prior to its lithification (see below). The burrowed-out texture would then have developed with the onset of phosphatic chalk deposition, due to sediment mixing by Thalassinoides burrow systems.

The phosphatic chalk beneath the mélange unit is presumably comparable to that which overlies the lower hardground. The angle of the lower hardground beneath the mélange, the wedge of phosphatic chalk beneath it and the wedging-out of the intraclast pebble bed, all suggest that rotational slipping of the mélange unit may have occurred along the surface of the lower hardground subsequent to the deposition of the phosphatic chalk; presumably due to loading.

The bed of hardground blocks that occurs above the upper hardground at its eastern extension was deposited after the initiation of phosphatic chalk sedimentation, since blocks occur within the basal lag that overlies that hardground. This indicates that hardground displacement continued after the formation of the mélange unit.

The termination of the intraclast pebble bed against the reverse fault indicates that the shattered zone is a synsedimentary fault within the lower hardground which was reactivated following phosphorite deposition. The lag then infilled the depression formed downslope of the upthrown portion of hardground. Similar lags have been noted in depressions in the basal hardground surface at Hardivillers (2.8.1). Down-slope concentration of the lag explains its unusual thickness at this point.

The inverted hardground is a portion of the upper hardground that has been displaced and folded, although the 'fold' may be a portion of initial hardground topography which has been subsequently upturned. If the latter is the case, displacement may have been entirely the result of hardground undermining, either by burrowing or currents; otherwise, a tectonic origin must be envisaged.

The next problem to be considered is the lithification of the white chalk between the lower and upper hardgrounds. Several possible explanations present themselves :

(1) Abnormally favourable conditions have enabled a single phase of seafloor lithification to penetrate 1.90 m below the hardground surface,

(2) The bed is composed of a number of hardgrounds superimposed one on top of another but with unrecognised surfaces,

(3) Lithification is the result of tectonism (cf. Mimran, 1977),

(4) Lithification is a Tertiary weathering phenomenon.

Even well-developed hardgrounds (e.g. the basal hardground at Beauval) generally only have a 30 - 60 cm zone of intense hardening, below which lithification falls off rapidly. Thicker complexes do occur (e.g. the Chalk Rock of southern England, the "Tun" and "Merle" in northern France) but these are all the result of the superimposition of several hardground surfaces to produce a thick (1 - 2 m) complex hardground. The depth of lithification may also be increased in abnormal sediments, for example the lithified phosphatic chalk hardground at Hardivillers (2.8.1); such a thick sequence is unknown in soft white chalks. There is no evidence for the presence of other hardground surfaces within the bed; if they were present, they would be picked out by mineralization, hardness differences, encrustation or boring.

If the mechanism was tectonic then its effect was highly localized, since it does not appreciably effect the underlying soft white chalk. On the other hand, there is evidence of synsedimentary dislocation of the upper hardground and the localized lithification associated with the shattered zone suggests that a tectonic mechanism is feasible. Such a process is, however, undocumented for such shallow depths of burial.

Hardening as the result of Tertiary weathering has been noted in other (non-

phosphatic) chalk localities in northern France. However, the absence of lithification of the phosphatic chalk and resonant soft white chalk suggests that this mechanism is unlikely.

In conclusion, the seafloor cementation that formed the upper hardground appears to have been overprinted by later tectonic(?) induration which has resulted in an abnormal thickness of lithified white chalk below the surface of the upper hardground and beneath the lower hardground above the shattered zone. Sedimentological conclusions can only be tentative without some form of three-dimensional control. The exposure emphasises the intimate relationship between hardground genesis, hardground dislocation and phosphatic chalk deposition. These factors will be considered later (Chapter 3).

2.4.1b Hem-Monacu phosphatic chalk pits x 636,47 y 251,57 z 90 ($0^g.566$E $55^g.514$)

Details of the phosphatic chalks at Hem-Monacu were first published in 1896 (Gosselet, 1896a, b; Parent, 1896), when workings consisted of two quarries and three mine shafts, all of which were located on the hillside north of the village.

The lower quarry exposed a well-developed basal hardground overlain by 10 cm - 1 m of basal lag, followed by 8 m of phosphatic chalk. The basal hardground dipped ~10° N, the actual dip depending on local hardground topography. It was penetrated by numerous phosphatic-chalk filled Thalassinoides burrows and supported coral patch reefs. These reefs, up to 9.5 m thick (Gosselet, 1896b), primarily consisted of the scleractinian coral Diblasus arborescens, which was first described from this locality (Parent, 1896). The basal lag consisted of bored intraclasts, inoceramid debris, Actinocamax verus, oysters and elasmobranch teeth.

The upper quarry exposed ~10 m of phosphatic chalk overlain by 1.5 m of white chalk. More significant data are available on the lithostratigraphy of the three shafts that were sunk into the hillside above the quarries (Fig. 2.41). Four separate beds of phosphatic chalk were recorded from above the basal hardground (Gosselet, 1896a p115; 1896b) although only three could be recognised by 1900 (Gosselet, 1900b p18). The section in the upper quarry (belonging to the "Société de St Gobain") was 400 m long and 10 m deep but badly fractured and weathered

(Gosselet, 1901b).

Nine beds were recognised in the three shafts. In all three, the lowest bed was the basal hardground (bed 1). In shaft A (Fig. 2.41) it consisted of a 20 cm

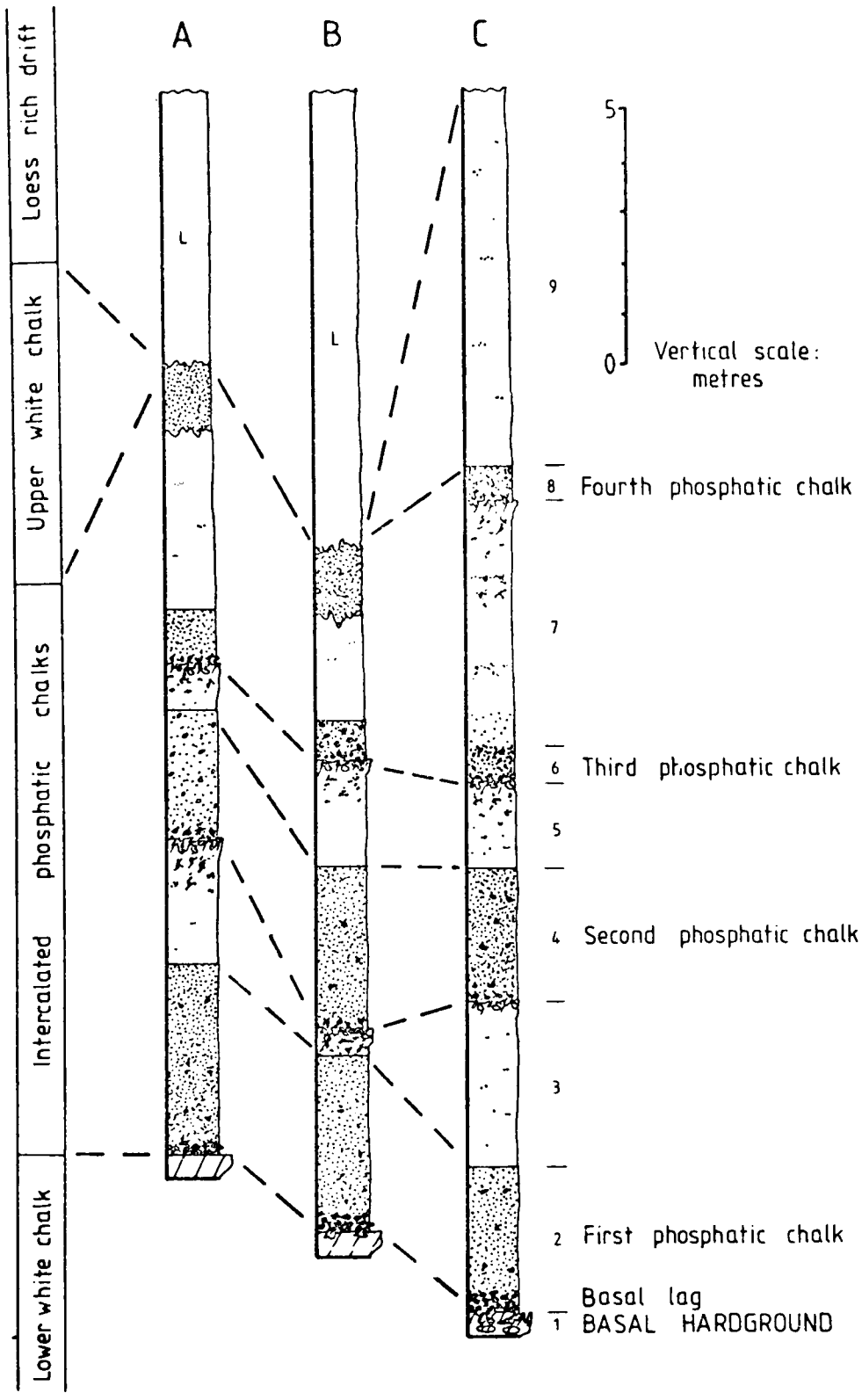


Fig. 2.41 Lithostratigraphical correlation diagram of the Hem-Monacu mine shafts in 1896. Based on data in Gosselet (1896a, b).

thick, strongly-lithified bed that was heavily bored ("nombreuses vermiculations") and penetrated by phosphatic-chalk filled Thalassinoides burrows ("larges perforations"). The top was coated by a shiny phosphate skin and encrusted by oysters. This basal hardground became progressively less indurated northwards (Shafts B, C), where it was overlain by a thicker basal lag of bored and rounded phosphatized intraclasts coated with shiny phosphate skins.

The overlying bed (2), a rich phosphatic chalk, thinned northwards from shaft A (where it was 3.80 m thick) to shaft C (where it was only 2.90 m). The succeeding bed (3) consisted of a lithified yellow chalk. At shaft A this bed was penetrated by "pen-sized" burrows (stenomorphic Thalassinoides?) infilled with phosphatic

chalk. The top of the bed was a whiter chalk with larger, phosphatic-chalk filled Thalassinoides systems. Laterally (shaft B), this level was represented by a burrowed-out white chalk, while at shaft C, it was a light-yellow, less well-lithified horizon containing more dispersed pelletal phosphate. Bed 4 (the second phosphatic chalk) was thickest at B and Bed 5 consisted of a white chalk with some dispersed phosphatic chalk, locally concentrated in burrows and winnows. This bed thickened rapidly from 0.90 m at A to 2.10 m at B. Borrowing became more pronounced at the top, particularly in shaft B. The third phosphatic chalk (bed 6) thinned northwards while the overlying yellow-white chalk (bed 7) with scattered phosphatic chalk was only complete in shaft C, where it was overlain by 0.70 m of rich phosphatic chalk. This phosphorite (bed 8) was represented by pelletal phosphate sands in the other two shafts, where it forms the base of the overlying Tertiary succession. Shaft C had a further 7.45 m of yellowish chalk (bed 9) above this phosphatic chalk.

The only biostratigraphical information available for these sites is the record of belemnites from the basal lag in the lower quarry (Gosselet 1896a p112) which were presumably Actinocamax verus, since this is the only species recorded from Hem-Monacu (Lasne, 1902; Gosselet in Lasne, 1902). The quarries have been mapped as being located in middle - late Santonian chalks (Mennessier et al., 1976) although the shafts (which lay to the north) presumably included younger chalks.

The mode of occurrence of the phosphatic chalk in these sections was somewhat different from that of localities with thicker beds of rich phosphatic chalk (i.e. Beauval, Hardivillers and Nurlu). Lithification of the basal hardground decreased northwards, despite the hardground dipping in that direction. Phosphatic chalk is, however, unknown from the north side of the hill, so the cuvette must terminate somewhere beneath it. It is suggested, therefore, that the dip of the hardground, measured by Gosselet (1896a) in the lower quarry, changes northwards and reverses in direction. This would explain the decrease in lithification of the basal hardground within the mine shafts, and the general decrease in the thickness of the phosphatic chalks in that direction. It should be noted, however, that the second phosphorite (bed 4) is thickest in shaft B and has a higher phosphate content in shafts B and C than in A.

2.4.2 Curlu (Somme) x 635,10 y 251,81 z 90 ($0^{g}.545$E $55^{g}.516$)

The village of Curlu lies NW of Hem-Monacu, on the north bank of the Somme, 3 km west of the A1 motorway. Phosphatic chalk outcrops in an area 500 m ENE of the village, on the east side of the track that joins the N338 to the Curlu - D146 road. Three quarries are located within the outcrop but only small exposures of barren white chalk are currently (1979) visible.

The first details of the section (Fig. 2.42) are given by Cayeux (1890b p236).

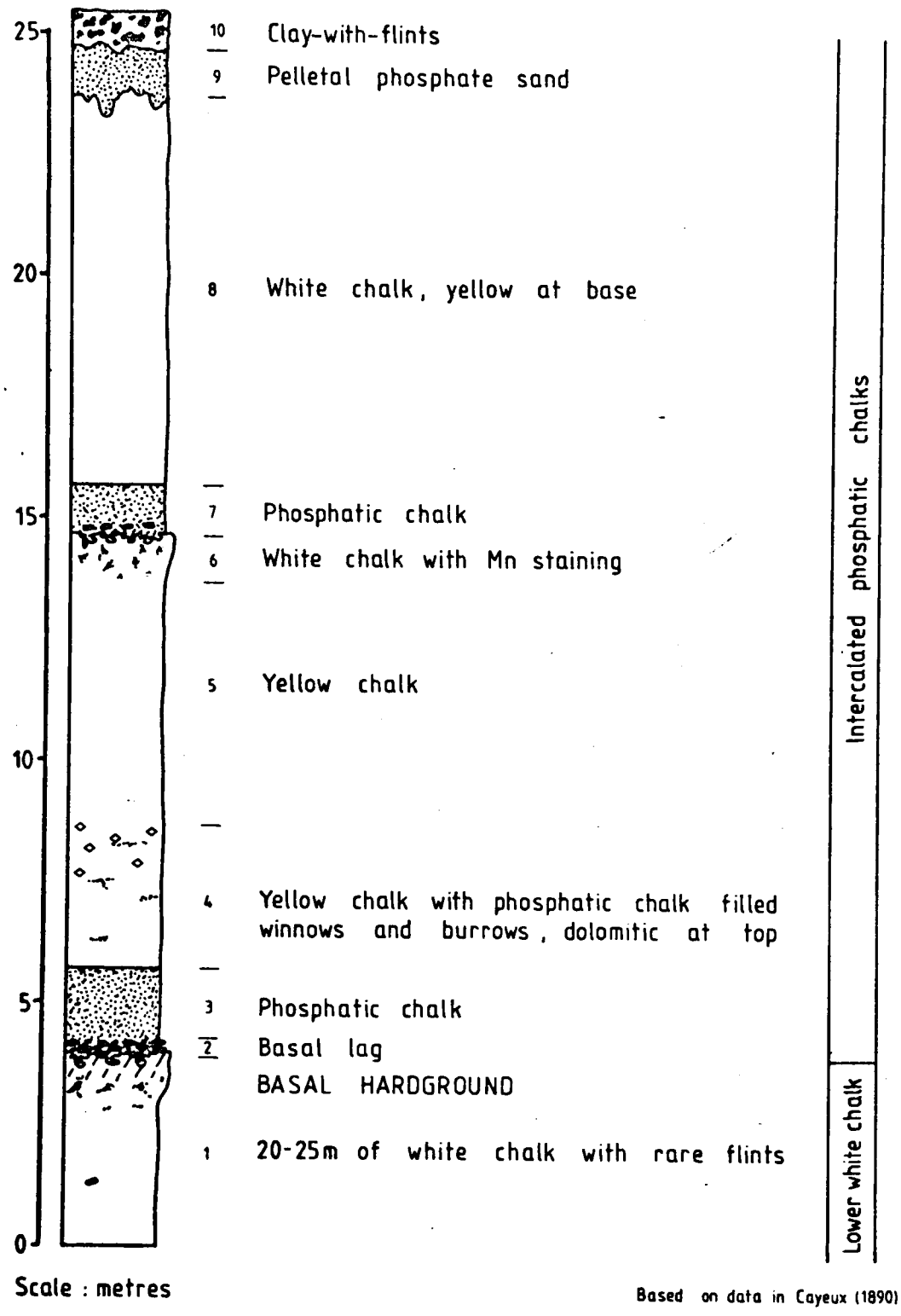


Fig. 2.42 Lithostratigraphy of the phosphatic-chalk bearing section at Curlu (Somme) in 1890.

Lasne (1892) figures a pelletal phosphate sand resting on white chalk at the "Carrière à la Grenouillère" near Curlu but Gosselet (1901a) is the only author to give details of the actual exploitation.

The phosphatic chalk was mined from a cuvette that was 100 m wide and 1 km

long. The entrance to the main subterranean workings was via a quarry which exposed a section of phosphatic chalk 60 cm thick, as compared to 5 m in the tunnels. The phosphorite in the quarry was underlain by a burrowed junction and contained less phosphate than that within the tunnels. More recently (Tabatabaï, 1977 p78), a temporary trench between Curlu and the N338 exposed 2.10 m of dolomitic and phosphatic chalks.

Cayeux (1890b) refers all the phosphatic chalk to the 'Belemnitella' quadrata Zone, although he does not actually record Gonioteuthis ex gr. quadrata from this locality. The area containing the quarries has been mapped (Mennessier et al., 1976) as middle to late Santonian Biozone e. The lowest phosphatic chalk, therefore, is probably of Uintacrinus socialis Zone age.

2.4.3 Vaux (Vaux-Eclusier of authors) (Somme)

The hamlet of Vaux lies on the north bank of the river Somme, 2 km ENE of Suzanne. Three phosphatic chalk outcrops occur in the general vicinity of the hamlet (Mennessier et al., 1976): (1) The river cliffs above the hamlet x 632,87 y 250,68 z 50 ($0^{g}.510E$ $55^{g}.505$), (2) The river cliffs 850 m SE of the hamlet x 633,19 y 249,92 z 50 ($0^{g}.515E$ $55^{g}.497$) and (3) The site of an old phosphorite quarry, 400 m SE of the above x 633,26 y 249,53 z 50 ($0^{g}.516E$ $55^{g}.494$). There are no exposures at the present time (1979).

Cayeux (1890b p238) gave details of a 10 m long exposure of a well-lithified hardground overlain by a thick phosphatized intraclast pebble bed and Gosselet (1901b p231) states that phosphatic chalk outcropped along the river cliffs for a distance in excess of 1500 m. These exposures displayed a complex overfold structure in the basal hardground and overlying phosphatic chalk (Fig. 2.43) (De Mercey, 1901; Gosselet, 1901b). Lasne (1902) mentions that phosphorite extraction was by means of galleries. A phosphatic-chalk filled Thalassinoides system within a bed of white chalk intercalated in the phosphorite (cf. the upper phosphatic chalk at Beauval, Section 2.3.2) acted as a good marker horizon.

Gonioteuthis ex gr. quadrata, Echinocorys and inoceramid fragments are recorded from the lag on top of the hardground exposed at the first locality

(Cayeux, 1890), but Actinocamax verus, Micraster and Conulus are typical of the lowest phosphatic chalk in the area (Lasne, 1902; Leriche, 1908). The absence of Gonioteuthis ex gr. quadrata in this latter association clearly indicates that the hardground exposed above the hamlet was not the basal hardground of the main phosphorite.

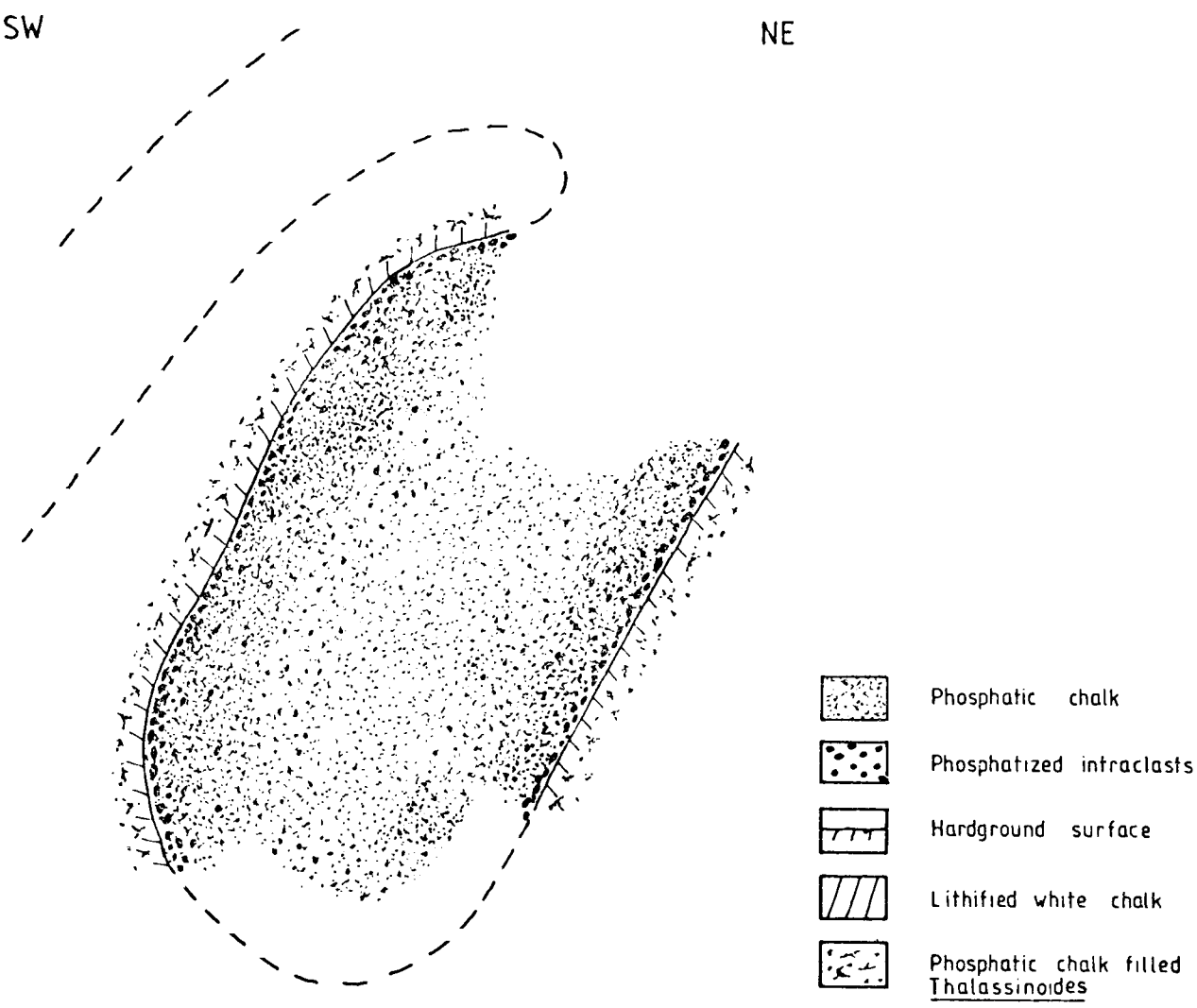


Fig. 2.43 The quarry of the "Société de St Gobain", Vaux (Somme) in 1901 (after Gosselet, 1901b).

Much of the classic fauna recorded from phosphatic chalks originated from Vaux, in particular elasmobranch teeth (Preim, 1896; Leriche, 1908), Mosasaurs (Thévenin, 1896), cirripedes (Leriche, 1908) and belemnites (Cayeux, 1890b; Lasne, 1902; Leriche, 1908). Thévenin (1896) also lists abundant Offaster pilula, Echinocorys and Micraster coranguinum. Clearly the succession includes a typical phosphatic chalk faunal sequence from the middle Santonian chalks with abundant A. verus at the base to early Campanian with beds of O. pilula and G. ex gr. quadrata at the summit.

2.4.4 Eclusier-Vaux (Eclusier of authors) (Somme)

The village of Eclusier-Vaux lies on the south bank of the river Somme,

alongside the Canal de Somme. Phosphatic chalk outcrops at the base of a quarry section in the river cliffs, 250 m SE of the village: x 633,25 y 248,08 z 75 ($0^{g}.516$E $55^{g}.479$). The quarry floor contains loose blocks of phosphatic chalk but only yellow-white chalk is exposed in the face (1978).

Cayeux (1890b) does not describe any exposure of phosphatic chalk on the south bank of the Somme but gives a log, from base to summit, of 20 m of yellow-stained white chalk, 3 m of hard yellow chalk (possibly a hardground) and 20 m of white chalk with nodular and tabular flints. Lasne (1892) records an exposure of phosphatic chalk at the base of a canal cutting between Frise and Eclusier-Vaux, and sketches an anticlinal structure in both the phosphatic and overlying white chalk.

Confusion between Eclusier-Vaux and Vaux-Eclusier by previous authors (e.g. Leriche (1908) erroneously states that Thévenin (1896) records Mosasaurus gaudryi Thévenin from Eclusier-Vaux; he in fact records it from Vaux-Eclusier), means that no conclusions can be drawn concerning the macrofaunal biostratigraphy of this locality. The quarry exposed middle Santonian to early Campanian chalks (Monciardini in Mennessier et al., 1976), but the phosphorite has not been dated separately.

2.4.5 Other localities

Two further sites are recorded on the most recent 1 : 50,000 geological map of the area (Mennessier et al., 1976). One lies on the north bank of the Somme, at the northern limit of the small town of Suzanne: x 631,06 y 250,30 z 75 ($0^{g}.480$E $55^{g}.501$). It is situated in middle - late Santonian Biozone e chalk. The other site is on the south bank, SE of the hamlet of Buscourt and east of the A1: x 638,23 y 249,44 z 90 ($0^{g}.591$E $55^{g}.492$). The outcrop is dated as late Santonian - early Campanian Biozone f. There is no exposure at either locality nor, to my knowledge, are they described in the literature.

2.4.6 Correlation of the outcrops

Correlation of phosphatic chalks on the banks of the Somme has been attempted by several authors (Cayeux, 1890b; Lasne, 1892; Delattre et al., 1973). Lasne 1892 regarded Vaux and Eclusier-Vaux as being opposite sides of a cuvette that had its axis along the river valley; Cayeux (1890b) and Delattre et al. (1973) also correlate Curlu, Vaux and Eclusier-Vaux but they considered that the section thinned dramatically to the south, suggesting that the cuvette axis was north of Curlu. Delattre et al. (1973), perhaps inadvertently, implied that the Hem-Monacu and Curlu outcrops are part of the same cuvette; this is clearly in error (e.g. Gosselet, 1901a).

Such lithostratigraphical correlations over distances of several kilometres have little more than superficial value, since individual phosphatic chalk cuvettes are rarely more than 1 - 2 km long (3.6.1). Thus inter-cuvette correlation requires a tight biostratigraphical control that, in the case of the Somme valley phosphorites, is currently lacking.

2.5 East of Péronne

The town of Péronne (Somme) lies at the confluence of the rivers Cologne and Somme, 46 km east of the city of Amiens (Somme) and 27 km ENE of St Quentin (Aisne). West of the town the Somme turns south towards Ham, but the Cologne maintains the east - west trend of the lower reaches of the Somme. In common with the geology of the adjacent regions, the Cretaceous outcrop is restricted to areas where fluvial erosion has removed the post-Cretaceous cover. The bulk of Cretaceous exposure consists of early Coniacian to middle Santonian white chalks (Gosselet, 1891; Celet et al., 1978). A small number of obscured, late Santonian to early Campanian outliers occur both north and east, and south and SE of Péronne, but the facies of these two regions are dissimilar. The chalks in the latter region are hard, dolomitic and contain little phosphate (Cayeux, 1890b; Celet et al., 1978); these will not be considered further. Those in the former area contain a number of phosphorite localities; these are the subject of the next section. The three largest late Santonian to early Campanian outliers are north of the Cologne, between Nurlu and Templeux-la-Fosse, NW of Tincourt-Boucly

and NE of Templeux-le-Guérard. A number of smaller outliers and several outcrops of older phosphorite are also situated in the region.

2.5.1 Mont-St-Quentin (Somme)

The village of Mont-St-Quentin is situated at the junction of the N37 and D43 on the northern outskirts of Péronne. A 1000 x 400 m, WSW - ENE elongated, late Santonian - early Campanian outlier that lies at the top of "le Blanc Mont" (NE of the village) was the site of a phosphorite working. This was situated on the east side of the D43, 900 m NNE of the village: x 643,65 y 250,34 z 110 ($0^g.674$E $55^g.502$). A second outlier lies 150 m NW of the first, but this is apparently non-phosphatic.

The site was being prospected for phosphatic chalk by 1890 (Cayeux, 1890b) and was being exploited by 1901 (Gosselet, 1901b). The phosphorite was mined from a 1.30 m thick bed of phosphatic chalk that thinned to 70 cm at the entrance to the subterranean workings. A quarry section at the entrance exposed a 50 cm thick, strongly-lithified, limonite-stained basal hardground that was penetrated by phosphatic-chalk filled Thalassinoides burrows. This was overlain by a 20 cm thick basal lag of phosphatized intraclasts, 20 cm of phosphatic chalk and ~2 m of upper white chalk. The phosphate content of the phosphorite was highest in the thickest sections and decreased with increasing attenuation of the phosphatic chalk.

There is no macrofaunal data on the age of the phosphorite, but Monciardini (in Celet et al., 1978) considered (on foraminiferal evidence) that it is early Santonian Biozone d age, although the outcrop (presumably of the overlying white chalk) is mapped (Celet et al., 1978) as late Santonian to early Campanian.

2.5.2 Nurlu - Templeux-la-Fosse (Somme)

The village of Nurlu lies at the junction of the N17 and D72, 10 km NE of Péronne; Templeux-la-Fosse is located at the intersection of the D181 and D184, 8 km ENE of Péronne and 4 km south of Nurlu. A $4\frac{1}{2}$ km long, irregularly shaped,

largely drift-obscured, late Santonian - early Campanian outlier runs 2 km NE - SW from the southern extremity of Nurlu village along the length of the N17, and then turns north - south to join the Templeux-la-Fosse portion of the outlier to the south (Fig. 2.44).

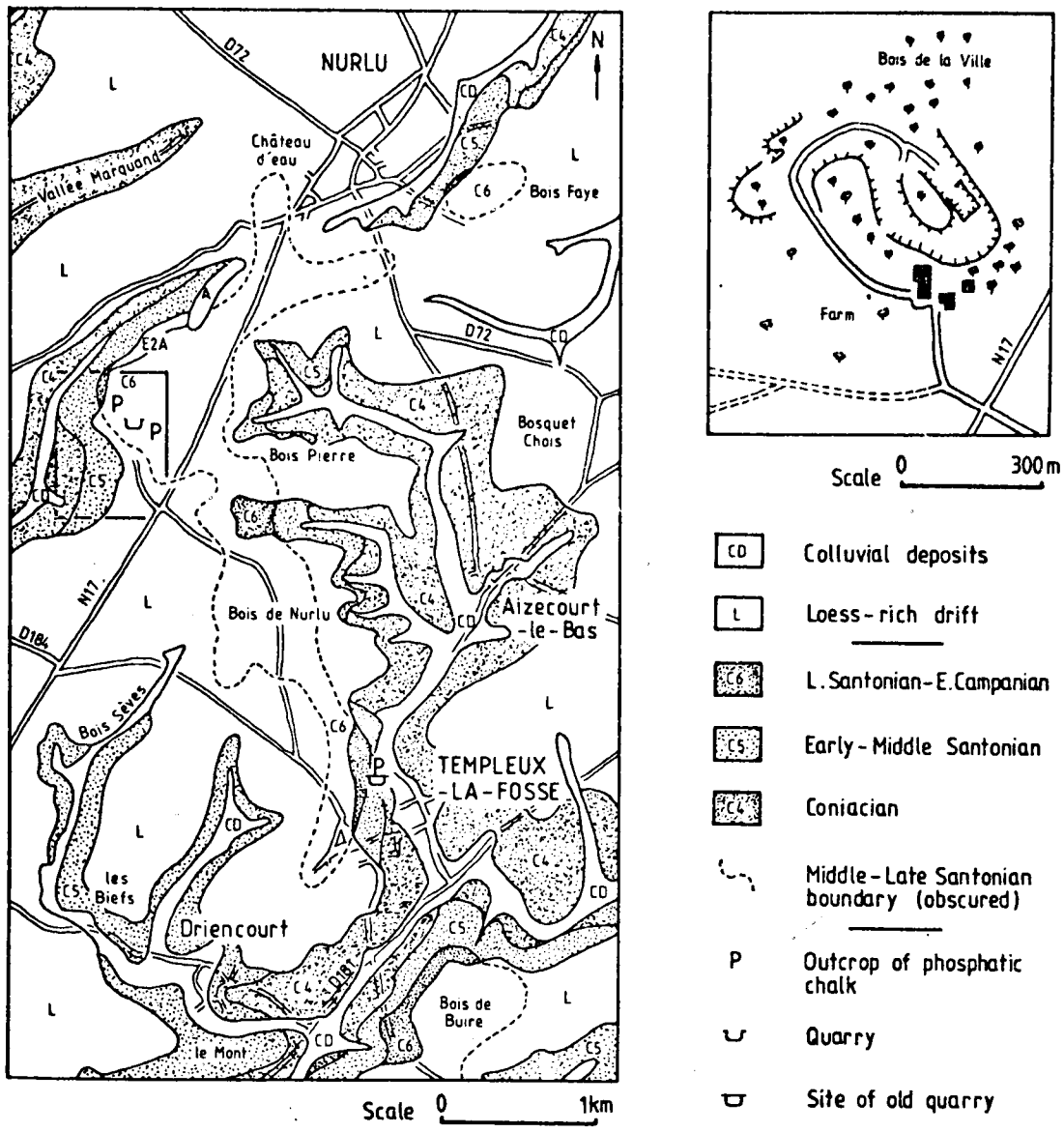


Fig. 2.44 Geological and location sketch maps of Nurlu quarry (Somme). Geology after Celet et al. (1978).

The first workings (Gosselet, 1901b) were situated in the vicinity of Templeux-la-Fosse, at the limit of the phosphatic chalk cuvette. A quarry a little to the north of the village exposed (Gosselet, 1900a) a 20 m thick section in 1900: x 649,25 y 252,44 z 125 ($0^g.761$E $55^g.523$). The exposure contained two prominent levels of phosphatic chalk, the lower of which contained ~25% P_2O_5, decreasing in phosphate content towards the south where, at the extremity of the quarry, it contained only 10% P_2O_5. This 6 m thick lower phosphatic chalk rested on top of a basal lag (Fig. 2.45) of phosphatized phosphatic chalk and white chalk intraclasts. The underlying poorly-lithified basal hardground was penetrated by a dense idiomorphic, phosphatic-chalk filled Thalassinoides system. The large-scale morphology of the basal hardground was predominantly bow-shaped in the quarry face but displayed a number of smaller-scale surface undulations which,

when traced in subcrop, had amplitudes of several metres. The upper surface of the

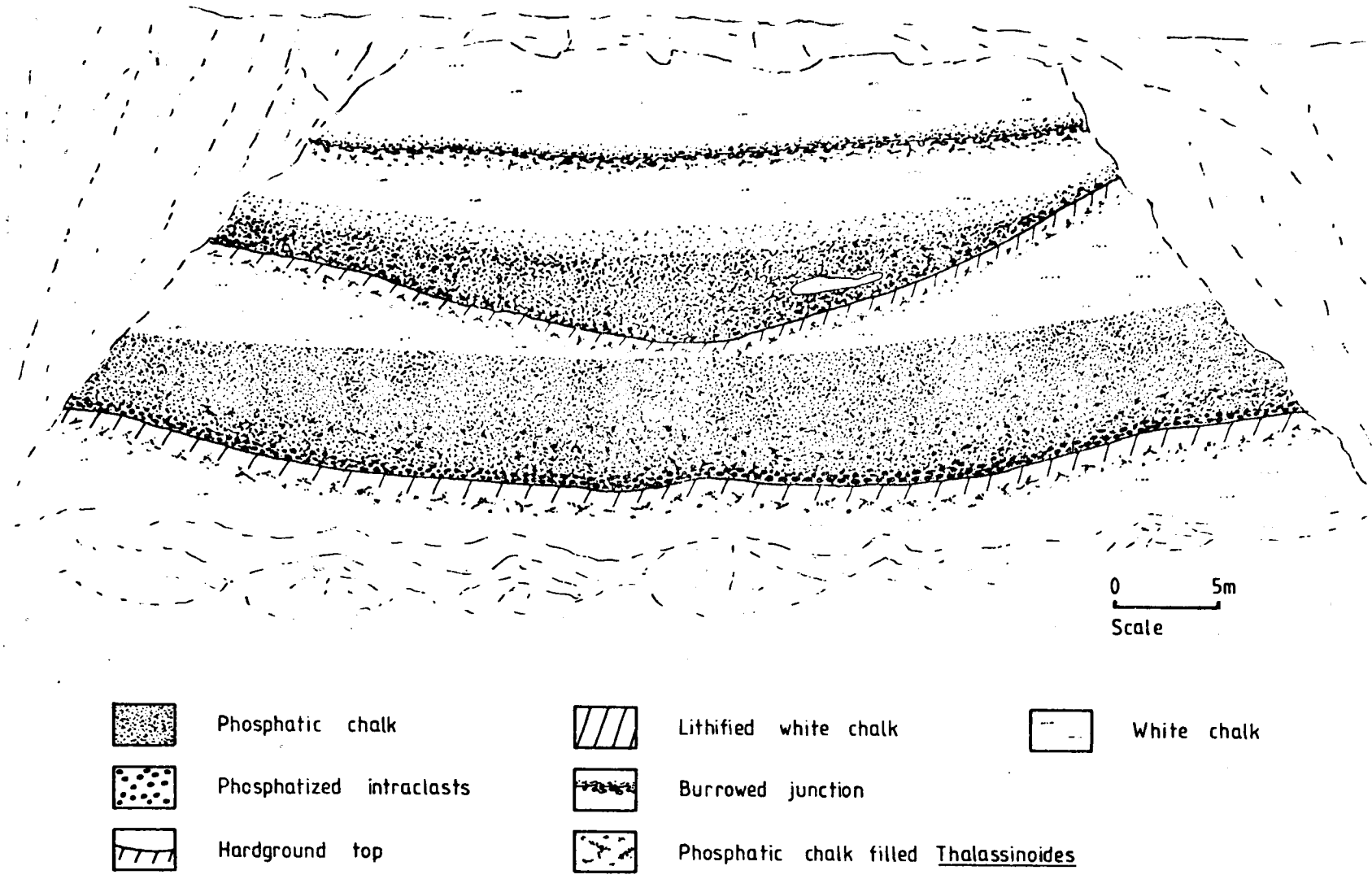


Fig. 2.45 Templeux-la-Fosse quarry (Somme) in 1900. Redrawn from Gosselet (1900a).

lower phosphatic chalk, however, did not mimic this topography but was subhorizontal (Gosselet, 1900a). The overlying 4 m thick intermediate white chalk was cut into, and at some points almost entirely removed, by the bow-shaped upper basal hardground that was also penetrated by a (albeit less well-developed) phosphatic-chalk filled Thalassinoides burrow system. The overlying richly phosphatic upper phosphatic chalk had a lenticular form, terminating against the upper basal hardground both within the quarry face and 25 m towards the east. It also enclosed a lens or block of white chalk and passed up, via a 1 m thick transitional top, into the overlying 9 m of upper white chalk which contained a 1 m thick bed of poorly-phosphatic chalk near its middle.

Although Templeux-la-Fosse quarry provided good exposure, the majority of the phosphorite (principally the lower phosphatic chalk) was extracted from a 3 km long tunnel system (Gosselet, 1901b; Douxami, 1908) that underlay the "Bois de Nurlu", to the north. The worked phosphorite was 9 m thick, consisting of a 3m thick upper and lower richly phosphatic zones separated by an intermediate zone of reduced phosphate content. The lowest of these three units terminated

laterally against the basal hardground, and there was a corresponding decrease in phosphate content throughout the section as the hardground became topographically higher. The nature of the basal hardground varied from a 1 m thick burrowed junction to a strongly-lithified hardground.

The section at Templeux-la-Fosse had been extended by 1908, when it exposed 3 m of lower phosphatic chalk (Douxami, 1908) overlain by 1 m of intermediate white chalk. This latter bed thinned northwards and underwent an intermediate stage of yellow-stained, burrowed-out white chalk before finally disappearing, the upper phosphatic chalk then resting directly on top of the lower. The section included 20 m of upper white chalk with scattered nodular flints and contained a strongly-lithified hardground towards its middle. A quarry NE of Templeux-la-Fosse exposed a section through phosphatic chalk and upper white chalk at this time (Douxami, 1908). This was probably the site of the present Nurlu quarry which is one of the two phosphatic chalk workings still (1979) being exploited for phosphorite. The quarry lies 350 m NW of the N17, 2 km south of Nurlu village (Fig. 2.44): x 647,65 y 254,60 z 140 ($0^g.736$E $55^g.544$). The quarry was studied by Tabatabaï (1977) who considered the microfacies and microfaunal zonation but does not describe the gross lithostratigraphy or macrofauna.

Nurlu quarry is a large 350 x 150 m, NW - SE elongated working situated on the hillside south of the "Bois de la Ville". Access is gained via the farm road south of the quarry and permission for entry may be obtained from M. Paillet at Fins (3 km north of Nurlu village). The quarry exposes three main sections, one on the east face and two on the west; all three may be conveniently divided into three units: a lower white chalk, a phosphatic chalk and an upper white chalk.

The exposure on the east face (Fig. 2.46) is the one being actively extended at the present time (1979). The base of this section (Section 1; Fig. 2.47) is formed by the surface of the basal hardground which dips at an angle of $\sim 10^{\circ}$ SW. At one point, however, the basal hardground has been breached and the uppermost 70 cm of lithified sediment (bed N1/1) revealed. This sediment consists of an intensely-lithified, buff-coloured, bioturbated, 0.1 - 5.0 mm mineralized intraclast (phosphatized and glauconitized) and bioclast (phosphatized and silicified) bearing white chalk (Fig. 2.48) that is penetrated by an intraclast-filled

NW SE

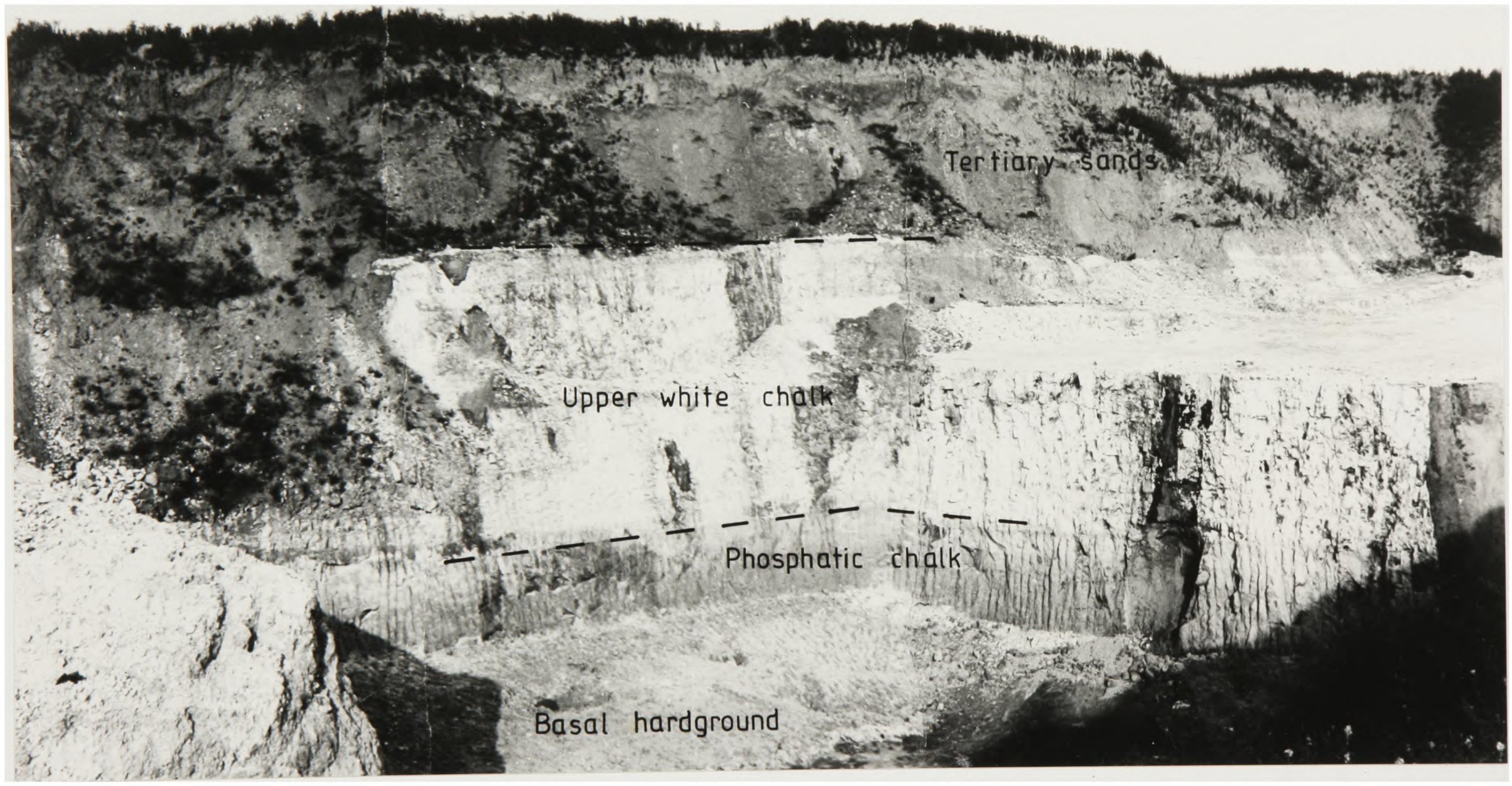


Fig. 2.46 The working east-face of Nurlu quarry (1978). The site exposes ~20 m of chalk and is the site of measured Section 1 (Fig. 2.47). The basal hardground forms the floor of the exploitation.

idiomorphic Thalassinoides system. The hardground sediment displays a diffuse

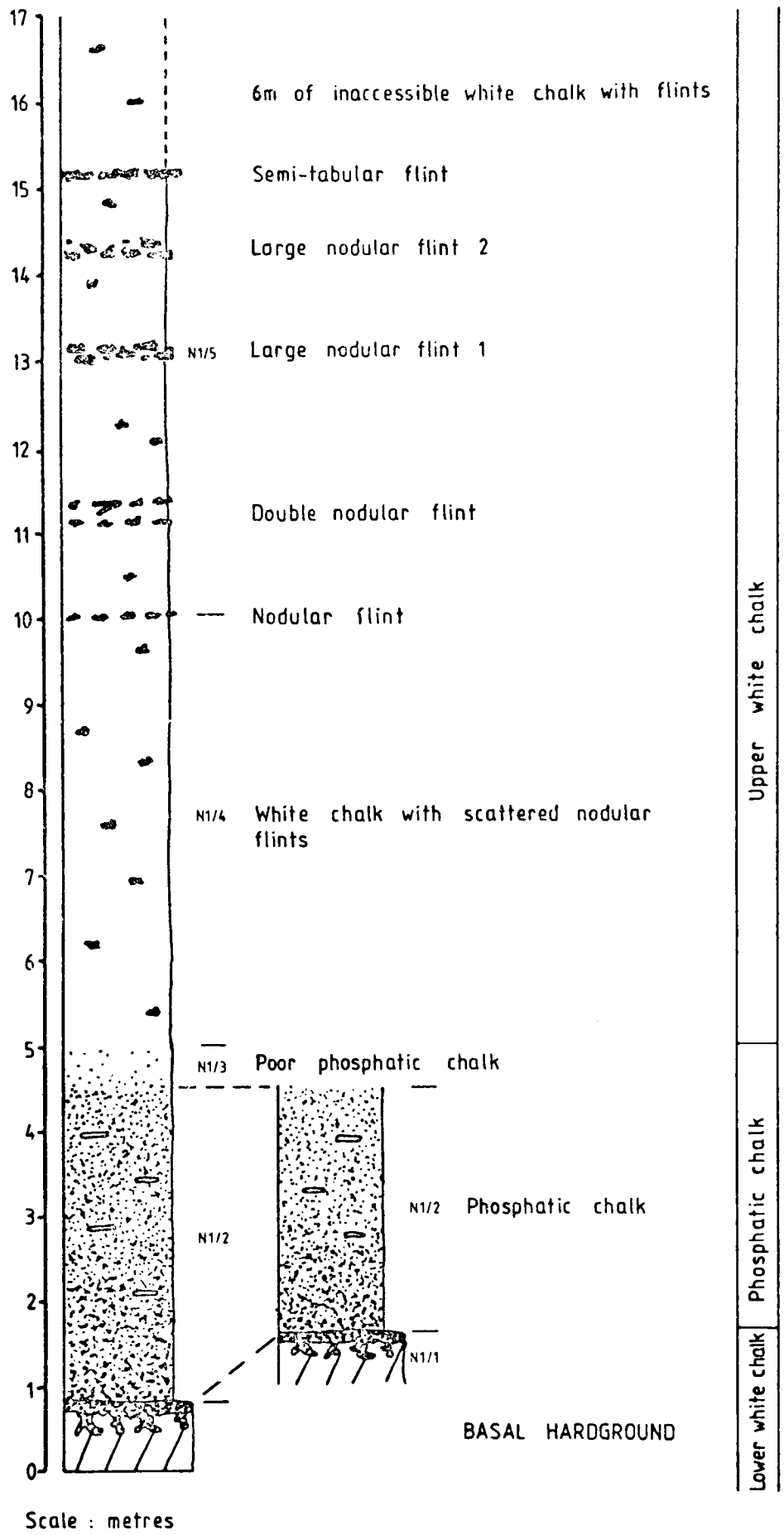


Fig. 2.47 Lithostratigraphy of the working portion of Nurlu quarry (SE corner) in 1978 (Section 1).

limonite staining throughout, and contains occasional goethitic blebs up to 5 mm across in its upper portion. 'Pyrolusite' is concentrated along the fracture system that riddles the lithified chalk. The upper surface of this hard white chalk is highly convolute, heavily phosphatized, and coated with an iridescent phosphate patina. Both the idiomorphic Thalassinoides system and the up to 15 cm deep convolutions (which may be erosional relics of a similar system) have been infilled by several generations of mineralized intraclast and bioclast packstone that has

been subsequently lithified within the burrows and led to their partial closure.



Fig. 2.48 Polished block of basal hardground top from the working portion of Nurlu quarry.

The intraclasts are predominantly 0.2 - 2.0 cm across, invariably coated with a shiny phosphate veneer and include bored and unbored, phosphatized, glauconitized and/or limonite-stained phosphatic and white chalks. Bioclasts primarily consist of partly-silicified comminuted Platyceramus, phosphatized sponge debris and fragments of thick-shelled oyster. This infilling of the initially idiomorphic burrows has led to the stenomorphism or restriction of the Thalassinoides system, the final infill of which consists of a soft, limonite-stained, intraclast-poor phosphatic chalk. Successive generations of fill are distinguished by their phosphatized and occasionally phosphate-skin coated upper surfaces (Fig. 2.48). The final 1 - 4 cm of the infill is characterized by an alternation of iridescent veneers (commonly encrusted by 'Terebella' phosphatica) and thin (0.1 - 2.0 mm) layers of sediment that have been plastered on top of the subhorizontal surface of the hardground during a final stage of accretionary lithification. This surface is overlain by a secondary, limonitic-clay filled solution seam.

It is noteworthy that boring (predominantly by polychaete worms) is restricted to the tops of bosses (Fig. 2.48) that must have stood proud of the earlier generations of intraclast fill. This suggests that, subsequent to their cementation, the burrow walls were not exposed at the sediment/water interface for any extended period of time. The absence of encrustation within these areas confirms this

observation. Infilling must therefore have occurred soon after lithification.

The basal hardground is overlain by 3.00 - 3.80 m of phosphatic chalk (bed N1/2) that thickens towards the SW in response to the dip of the basal hardground. The phosphorite in these freshly excavated faces is a distinctive deep chocolate-brown (Fig. 2.49), in contrast to the lighter shades seen in weathered sections. It is commonly coated by a thin, light-green film of (?)algae. The pelletal



Fig. 2.49 Typical colour and bioturbation styles of freshly-cut faces of phosphatic chalk, Nurlu quarry. Scale = 5 cm.

phosphate content and the grain size generally decrease from base to summit. Thin-shelled oysters are common throughout the unit, Gonioteuthis appears 1 m above the base and crushed Echinocorys are commonest in the uppermost $1\frac{1}{2}$ m. The dark colour of the rock makes white-chalk filled burrows particularly prominent. The most abundant trace fossil is a long (up to 30 cm), narrow (0.5 - 1.5 mm), straight, unbranched, white-chalk filled burrow that may be refered to the ichnogenus Trichichnus (Fig. 2.49). Broad (3 cm) meniscus-fill burrows (probably oblique sections of Teichichnus), Muensteria-like meniscate tubes, white-chalk rind burrows, idiomorphic Thalassinoides and Chondrites are also common (Fig. 2.49). These burrows become less distinct towards the summit of the bed, mainly due to the reduced contrast afforded by the decline in the phosphatic component.

The main body of phosphatic chalk is overlain by a 50 cm thick transitional zone (bed N1/3) of poorly phosphatic chalk containing patches of burrowed-out white chalk, phosphorite filled winnows and rare patches of soft white chalk

pebbles. Both the base and top of the bed are transitional.

The base of the upper white chalk consists of 5.00 m of soft white chalk with scattered nodular flints (bed N1/4) the top of which is taken at the first well-developed flint line. The overlying ~11 m of white chalk (bed N1/5) contains several prominent lines of nodular and semi-tabular flint and scattered nodular flints throughout (Fig. 2.47).

An extensive (~ 90 m long) exposure of phosphorite occurs on the west face, north of the access ramp (Fig. 2.50). The section contains four entrances to the tunnel system that has been excavated in the hillside west of the quarry. The quarry floor has been taken down to the surface of the basal hardground but a small, 1½ m deep pit on the east side of the section penetrates the hardground (Fig. 2.51) and exposes (Section 2; Fig. 2.52) the lower white chalk (bed N2/1). The hardground sediment is a hard, pale-yellow, bioturbated white chalk containing (particularly towards its top) a high proportion of pelletal phosphate and phosphatized intraclasts with occasional thin-shelled oysters and silicified Platyceramus fragments, which passes down into soft white chalk 40 - 60 cm below the hardground surface. Patches of glauconitized-chalk filled Chondrites and of limonitic sponge fragments occur within the lithified sediment. Small (1 - 5 mm) blebs of goethite are particularly prominent just below the hardground surface. Areas of more intense cementation are distinguished by their grey colour which contrasts with the white chalk infill of the Chondrites burrows that they frequently contain.

The hardground is penetrated by a predominantly idiomorphic, phosphatic-chalk filled Thalassinoides system (Fig. 2.51A). The phosphatic-chalk fill is rich in pelletal phosphate, contains a high proportion of small (1 - 5 mm) strongly-phosphatized intraclasts and displays a number of infill/reexcavation events. The walls of the burrow systems are generally unmineralized but the upper part of the system occasionally shows glauconitization of its roof. The width of the burrows varies greatly in the upper 10 cm of the hardground where portions of the complex have been stenomorphed by lithification (Fig. 2.51B). Tunnel diameter broadens to 2 - 5 cm below this (Fig. 2.51C) and then exhibits a progressive reduction in size with increasing distance from the surface so that 1 m below

Fig. 2.50 The west face of Nurlu quarry, 1978.
A. General view showing the access ramp which bisects the face. A large solution pipe cuts into the upper white chalk NE of the ramp. The letters indicate the position of photographs (B) and (C) and also approximate to the position of measured sections 3 and 2 (Figs. 2.54, 2.52) respectively.
B. The SW half of the face, the dashed line indicates the top of the phosphatic chalk. The basal hardground forms the floor of the quarry.
C. The NE portion, also with the top of the phosphatic chalk indicated, showing the entrances to the abandoned subterranean workings. The basal hardground is exposed in the floor of the quarry. The scale (circled) is 1.75 m high.

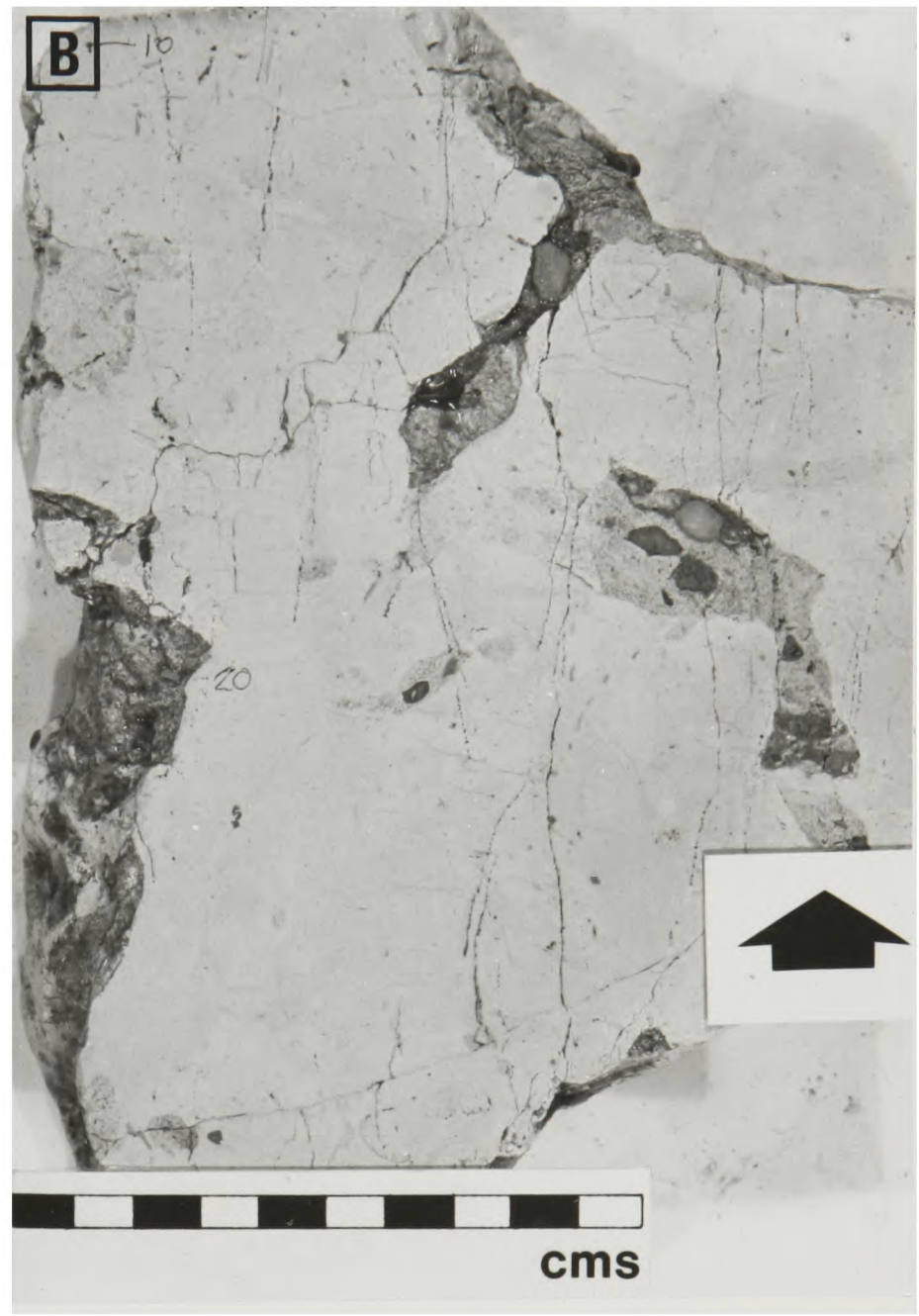

SW
NE
B
C
A


B


C



Fig. 2.51 The basal hardground at the west face, north of the access ramp, Nurlu quarry (Somme).
A. An exploration pit penetrating the hardground surface exposed (May 1977) a phosphatic-chalk filled Thalassinoides system within the lower white chalk. The hammer handle is 30 cm long.
B. Fractured hardground sediment 10 - 30 cm below the surface.
C. Polished block from 50 - 80 cm below the surface. The scale is in centimetres.





the burrows are generally only 2 - 5 mm across.

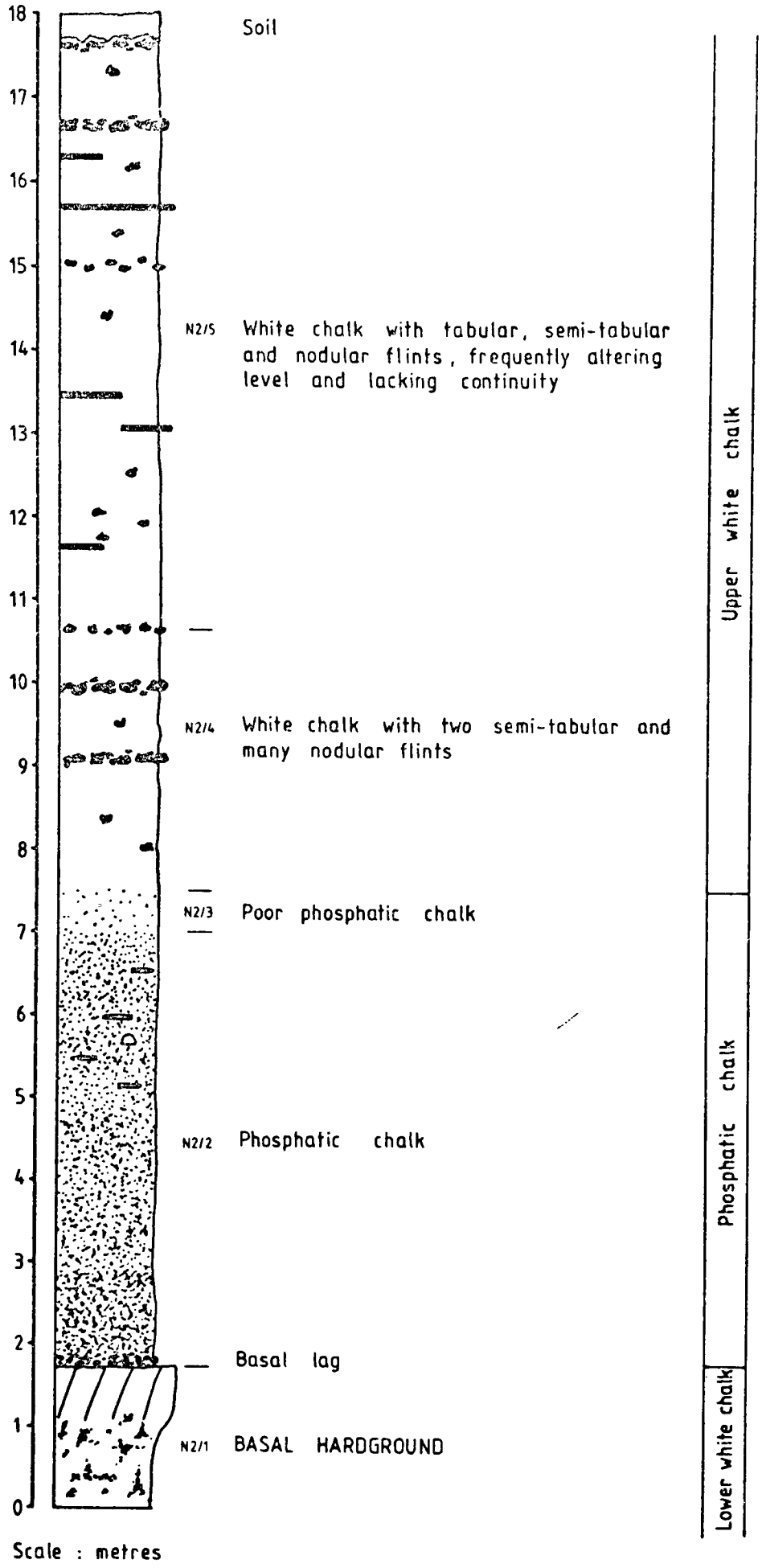


Fig. 2.52 Lithostratigraphy of the west face, north of the access ramp, Nurlu quarry (Section 2).

The upper 60 cm of the hardground contains a primary vertical fracture system in which individual fractures are generally 1 - 4 cm apart (Fig. 2.51B). Open (displacements of up to 1 mm) fractures have acted as foci for manganese and iron mineralization (limonite). Closed fractures have been glauconitized, indicating that the limonite in the open systems is secondary and suggesting that the fracturing is synsedimentary or early post-depositional. Fractures become

closer spaced around Thalassinoides burrows where phosphatic chalk has commonly been 'squeezed' into the open system. Where small areas of hardground sediment have been isolated by burrowing, fracturing has resulted in the formation of a breccia of 1 - 5 mm fragments of white chalk.

The hardground surface is highly convolute and contains scattered 10 cm deep, intraclast-filled depressions that have resulted from the undermining of the hardground top by the activities of borrowing organisms. The bases of these depressions exhibit a light-brown, dull, superficial phosphatization whereas the surface itself is heavily phosphatized and coated with a dark, rust-brown, iridescent phosphate patina. Bosses on the hardground surface have been intensely bored by polychaete worms, shallow depressions are more commonly encrusted by pycnodonteine oysters or 'Terebella' phosphatica but boring and encrustation are generally absent in the deeper hollows.

The 0.5 - 8.0 cm intraclasts that fill the deeper depressions are of four main types (Fig. 2.53) :

(1) Undermined and isolated blocks of the hardground surface; these exhibit the same boring, encrustation and mineralization styles as other portions of the surface. They commonly have a diffuse black colouration (organic matter?) immediately below their phosphatized tops that is distinct from the pyrolusite dendrites which they also contain. Similar patches were seen in the same situation below areas of laterally continuous top. This variety (Fig. 2.53a - c, g) is transitional to :

(2) Hard, dark rust-brown, shiny-phosphate veneered, strongly phosphatized, subangular - rounded intraclasts commonly encrusted by 'T.' phosphatica, Pycnodonte and Spondylus and invariably intensely bored by polychaete worms, although in some cases the bores originate entirely from the upper surface. (Fig. 2.53d - e).

(3) Glauconitized and phosphatized intraclasts of hardground sediment occasionally occur at the bottom of the depressions. Glauconitization dominates at the base and on their sides but phosphatization is more important on their upper surfaces. Mineralization generally only penetrates up to 5 mm into the intraclasts, although internally they are stained a deep

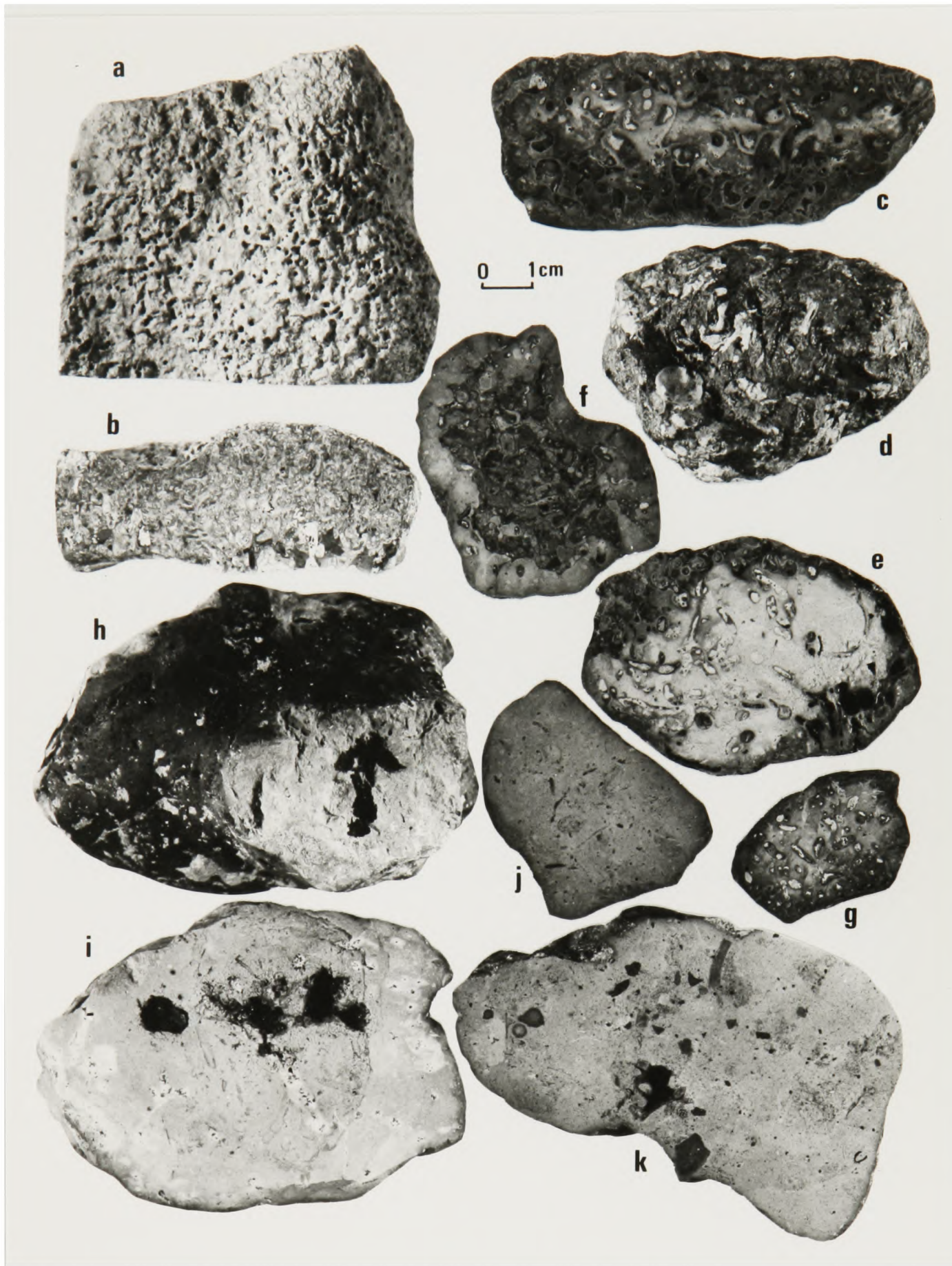


Fig. 2.53 Hardground surface and phosphatized intraclasts from the basal hardground, Nurlu quarry.
a-b. Top surface and polished cross-section of an undermined block of phosphatized and intensely worm-bored hardground top; a type (1) intraclast. c. Polished cross-section of a type (1) intraclast containing large worm-borings. d-e. Surface and polished cross-section of a type (2) intraclast; encrusted by Spondylus, worm bored from its upper surface and containing irregular goethitic blebs (bottom right) just below its phosphatized margins. f. The unbreached, phosphatized walls of a sponge contain an intensely-bored, phosphatized core. Polished cross-section. g. A small, limonite-stained type (1) intraclast with distinct, micrite filled worm-borings. Polished cross-section. h-i. Surface and polished cross-section of a type (3) intraclast. j-k. Type (4) intraclasts. Polished sections.

yellow-brown by limonite and commonly contain goethitic cores (Fig. 2.53h - i). (4) Softer, light-brown, dull-surfaced phosphatized intraclasts that lack encrustation and are rarely bored, although they commonly contain white-chalk filled Chondrites. Shallow (up to 5 mm), 0.2 - 5.0 cm wide surface troughs with sculptured sides often cut their sides. The sculpture consists of 0.1 - 1.0 mm deep reticulate scratch marks oriented subparallel to the trough axis. The troughs and their associated sculpture may be attributed to incision by passing burrowers into the sides of the intraclasts prior to the completion of induration. Similar scratch marks are known to occur on the insides of some Thalassinoides systems e.g. T. ornatus Kennedy (Kennedy, 1967) and conform with their interpretation as crustacean burrows; the scratches are produced during digging or by individuals moving through the system (Fig. 2.53j - k).

Dendrites of manganese oxide are present within all four types of intraclast and the main body of hardground sediment. It is noteworthy that where dendrites occur in limonite-stained sediment they are invariably surrounded by small patches of unstained chalk, presumably an oxidation/reduction effect associated with the later introduction of manganese.

An intraclast pebble lag, the basal lag, also occurs at the base of the overlying phosphatic chalk where it rests directly on top of a planar hardground surface. These 0.5 - 2.0 cm intraclasts are generally of the hard, dark rust-brown veneered variety (type 2) although scattered fragments of hardground top (type 1) are also represented. The basal lag includes a diverse association of bioclasts particularly fragments of ventriculitid sponges and Platyceramus but also including thick shelled oysters (e.g. Lopha semiplana, Pycnodonte vesicularis), cidarid spines, internal moulds of gastropods and bivalves, silicified Diblasus arborescens, Parasmilia, numerous Actinocamax verus, occasional Gonioteuthis granulata and elasmobranch teeth.

The basal lag is overlain by 5.30 m of phosphatic chalk (bed N2/2) which is unfortunately badly obscured by wash from the overlying Tertiary deposits. Although for the most part inaccessible, the transition from phosphatic chalk to upper white chalk is apparent by the change in weathering from the large blocky

style of the phosphorite to the finely fractured form of the white chalk. Gonioteuthis ex gr. quadrata occurs in the upper ~2 m of the phosphatic chalk and is particularly abundant in the upper 10 cm. Occasional crushed Echinocorys and Offaster pilula were found towards the top of the bed. The phosphatic chalk passes up into the upper white chalk via a 50 cm thick transitional zone (bed N2/3). The upper white chalk consists of a lower 3 m (bed N2/4) of white chalk with nodular flints and two semi-tabular flints, overlain by ~8 m of white chalk (bed N2/5) with tabular, semi-tabular and nodular flints that frequently change level and lack lateral continuity.

A third, ~60 m long section south of the access ramp contains two tunnel entrances to the subterranean workings (Fig. 2.50). The face has not been worked for some time and is largely overgrown and inaccessible, except for the region of the scree slope at the southern end of the exposure. The phosphatized and phosphate skin coated surface of the basal hardground outcrops in the quarry floor but is obscured by soil and no further details were discernible. The hardground is overlain (Fig. 2.53) by 1.60 m of rich phosphatic chalk containing an intraclastic lag at its base and prominent fractures in its middle and at its top. The overlying 1.70 m of phosphorite shows a decline in phosphate content, its top being taken at the base of a line of hard, limonite-stained phosphatic chalk nodules (a weakly-developed, discontinuous hardground?). Lateral discontinuity of the fractures means that they cannot, in isolation, be used as viable stratigraphical markers and consequently the lowest 3.30 m of phosphorite is regarded as a single unit (bed N3/1). The 'nodule bed' is overlain by 1.10 m of moderately phosphatic chalk containing occasional, 5 - 10 cm, limonite-filled voids that have resulted from the breakdown by weathering of large pyrite nodules. The bed (N3/2) contains a well-developed fracture 40 cm from the base and its top is marked by a prominent, limonitic-clay filled fracture above which the phosphate content of the phosphorite decreases markedly. The final 2.70 m of the phosphatic chalk (bed N3/3) is not a phosphatic chalk sensu stricto since it contains $<5\%$ P_2O_5. It includes scattered nodular flints and rare Gonioteuthis ex gr. quadrata and two discontinuous lines of nodular flint at its summit (Fig. 2.54). The ~12 m of upper white chalk (bed N3/4) is badly obscured by wash and (except for the lowest 3 m) inaccessible. It

consists of a white chalk with tabular, semi-tabular and nodular flints that frequently alter level and lack continuity.

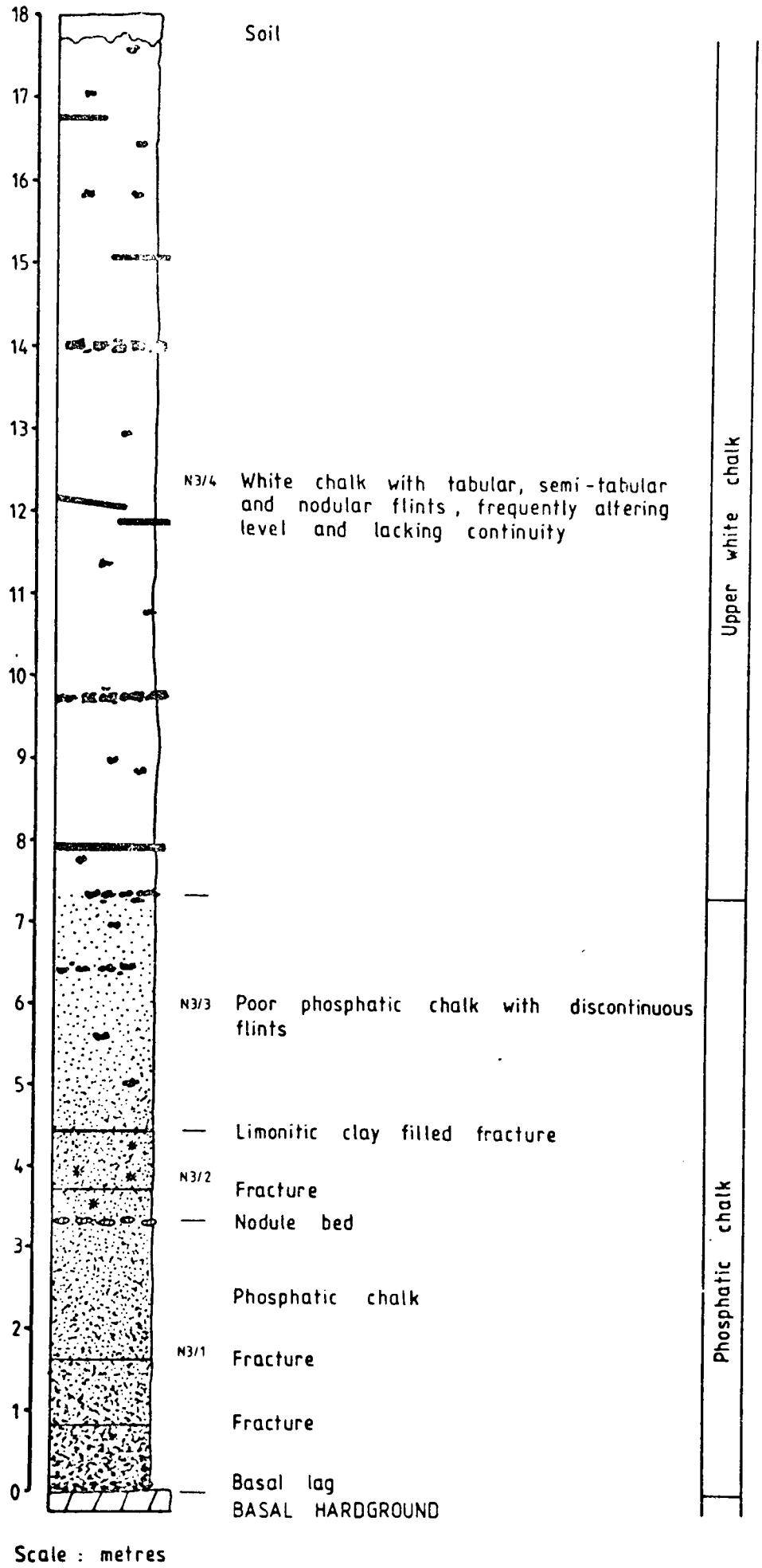


Fig. 2.54 Lithostratigraphy of the west face, south of the ramp, Nurlu quarry (Section 3).

Correlation of the three sections (Fig. 2.55) demonstrates the considerable large-scale topography that is present on the basal hardground and the resulting lateral variation in thickness of the phosphorite. Lateral discontinuity of flint lines in the upper white chalk (except perhaps for the three uppermost semi-tabulars of Section 1) means that they are of no lithostratigraphical value.

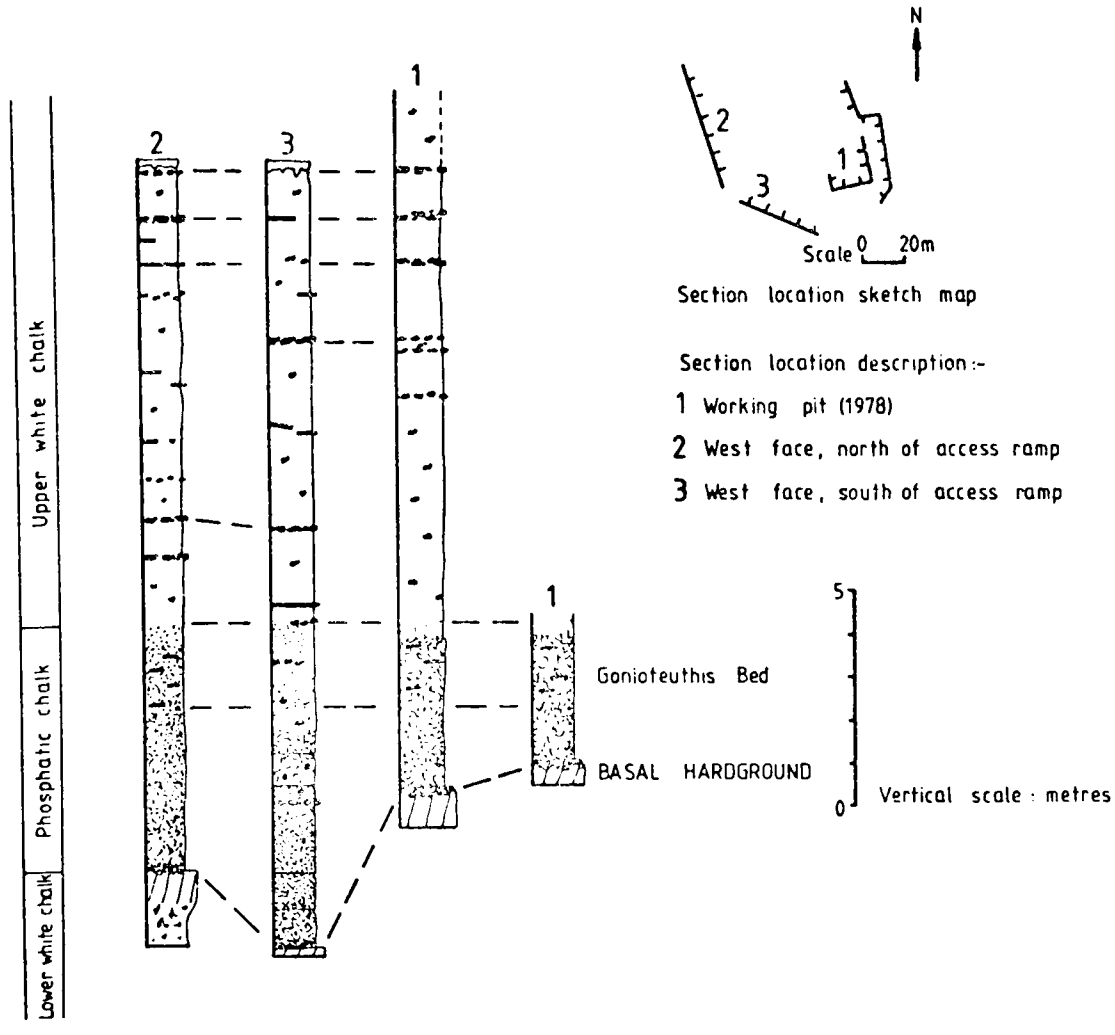


Fig. 2.55 Lithostratigraphical correlation diagram, Nurlu quarry.

The Nurlu - Templeux-la-Fosse phosphatic chalks are well known for their abundance of Gonioteuthis ex gr. quadrata (Gosselet, 1900a, 1901b; Douxami, 1908; Leriche, 1908) but no other macrofauna of biostratigraphical value has been described from the localities. However, Actinocamax verus occurs within the basal hardground, is abundant in the basal lag and is common in the lowest 2 m of phosphatic chalk. Gonioteuthis granulata has been recovered from the basal lag and G. ex gr. quadrata occurs throughout the upper half of the phosphatic chalk and is particularly abundant at the summit of the unit. Micraster coranguinum and Echinocorys also occur throughout the phosphorite although an undescribed low conical form of the latter (Fig. A3.2 nos. 1 - 4) is typical of the oldest phosphatic chalk. Offaster pilula occurs in the top metre of the phosphorite but no Offaster Bed could be recognised. The presence of A. verus, G. granulata and 'late' forms of M. coranguinum indicates a late M. coranguinum Zone age for the oldest phosphatic chalk. The absence of records of either Uintacrinus socialis or Marsupites testudinarius means that the presence of these two zones cannot be confirmed, although the uppermost phosphatic chalk is of undoubted O. pilula Zone age. The foraminiferal zonation (Tabatabaï, 1977; Monciardini in Celet et al., 1978) demonstrates, however, that Biozones d - g are all present in the phosphorite and therefore that a complete (if attenuated) early Santonian to early Campanian

succession is present. Phosphatic chalk deposition did not stop simultaneously throughout the region since Biozone h is phosphatic at Templeux-la-Fosse but not at Nurlu.

2.5.3 Templeux-le-Guérard (Somme)

The village of Templeux-le-Guérard lies at the junction of the D6, D331 and D101e, 16 km east of Péronne. A 1500 x 500 m, east - west elongated, late Santonian to early Campanian outlier caps the hill 750 m NE of the village. The western half of the outlier was the site (Celet et al., 1978) of an extensive complex of phosphatic chalk workings: x 659,20 y 252,42 z 135 ($0^g.915E$ $55^g.520$). A second, 800 x 250 m, NE - SW elongated outlier of comparable age lies below a thick sequence of drift on the hillside 1250 m NW of the village: x 657,71 y 253,07 z 135 ($0^g.892$ $55^g.526$).

Phosphorite extraction was restricted to solution pipe deposits in 1893 (Gosselet, 1893a) but by 1900 had been extended to include both open cast and subterranean workings in primary phosphatic chalks (Gosselet, 1900a, 1901a). The quarry sections exposed at that time a deep bow-shaped cross-section through a strongly-lithified basal hardground penetrated by phosphatic-chalk filled Thalassinoides burrows (Fig. 2.56). This depression was infilled by a single set

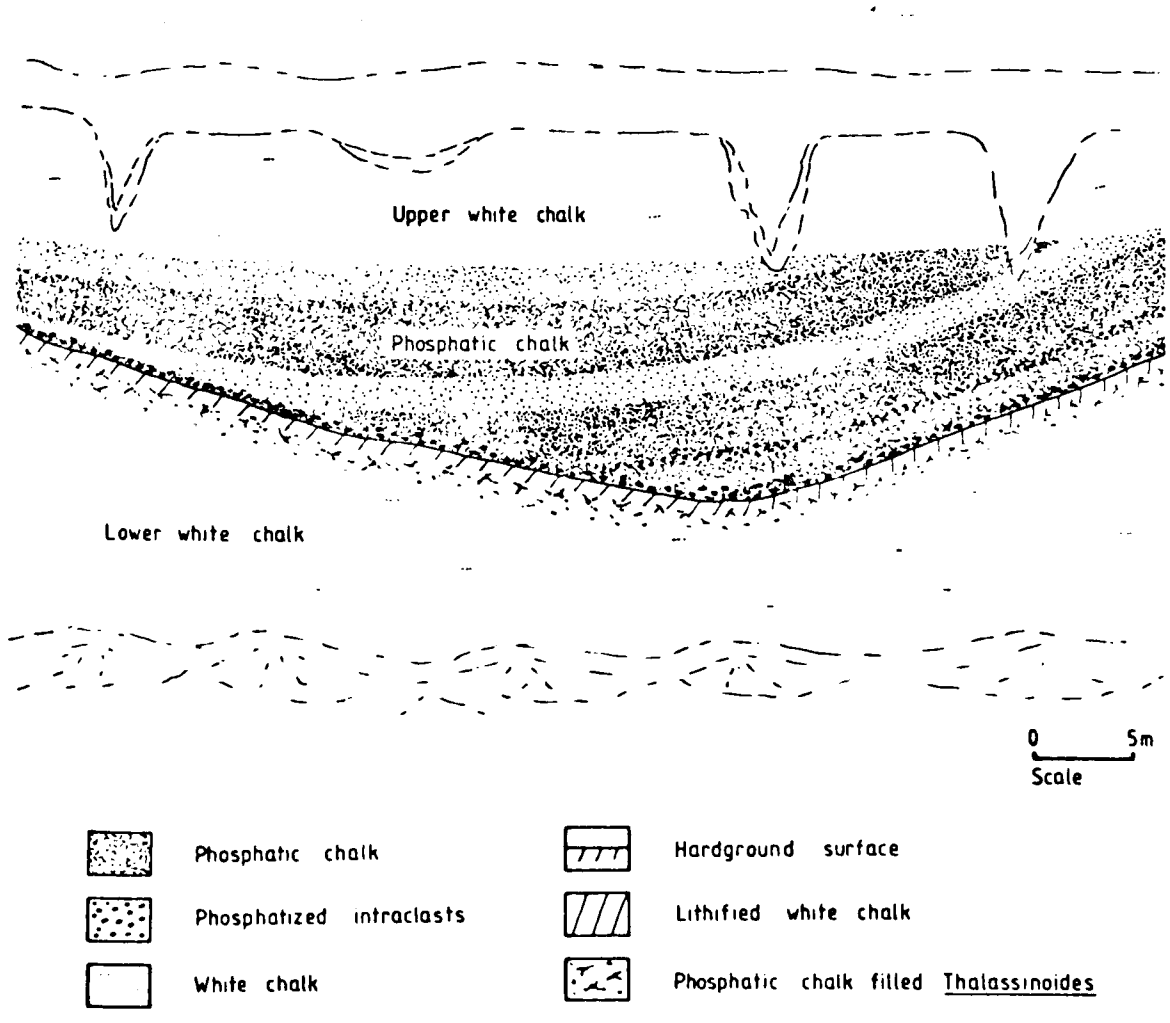


Fig. 2.56 Patin's quarry, Templeux-le-Guérard (Somme) in 1900 (redrawn from Gosselet, 1900a).

of low-angle cross-bedded phosphatic chalks. The basal hardground was directly overlain by 15 cm of phosphatized intraclasts and phosphatized and iridescent-phosphate veneered portions of hardground top. The basal hardground/lag sequence was overlain discordantly by a series of cross-beds 1.50 m of richly phosphatic (17% P_2O_5) chalk that was separated from the overlying 2.00 m of similar sediment by 12 cm of phosphorite containing a high proportion of phosphatized phosphatic-chalk intraclasts. There followed 1.90 m of poor phosphatic chalk overlain by 3.50 m of rich phosphorite with 18% P_2O_5. The final 3.00 m of phosphatic chalk yielded 6 - 9% P_2O_5 although 30 cm thick patches of sediment at the phosphatic/white chalk junction contained up to 11% P_2O_5. The upper surface of the phosphorite was subhorizontal and overlain by 6 m of white chalk which contained four secondary-phosphorite bearing Tertiary solution pipes, indicating erosion and redeposition of a now absent upper phosphatic chalk. Laterally, within the subterranean workings of the "Société Kuhlmann" the phosphorite could indeed be divided into an upper and lower unit, separated by a 6 m thick intermediate white chalk, although the upper of the phosphorites displayed poorer lateral continuity than the lower.

Leriche (1908) records Actinocamax verus, Gonioteuthis granulata and G. ex gr. quadrata from this locality. The presence of the first two belemnite species, in association with Lopha semiplana, Gryphaeostrea canaliculata and 'Terebella' phosphatica (Leriche, 1908, 1911) suggests a Santonian age for the basal lag. Two other faunal records of biostratigraphical value are the occurrence of Belemnellocamax ex gr. grossouvrei (Janet) in association with Gonioteuthis ex gr. quadrata, and the presence of Echinocorys striata (Lamarck). The first of these records indicates that B. ex gr. grossouvrei ranges into early Campanian phosphatic chalks and is not restricted to Santonian phosphorites as suggested by De Grossouvre (1894a, 1899, 1901, 1907). An early Santonian to early Campanian age for the phosphorite is confirmed by the foraminiferal evidence (Monciardini in Celet et al., 1978) that indicates the presence of Biozones d - f in a phosphatic facies.

2.5.4 Hargicourt - Villeret (Cologne of authors) (Aisne)

The village of Hargicourt lies at the junction of the D331, D57 and D101,

2 km east of Templeux-le-Guérard, 18 km east of Péronne and 15 km NNW of St Quentin. The village of Villeret is situated on the D57, 1½ km SE of Hargicourt; Cologne farm lies on the north side of the D331, 1½ km east of Hargicourt. The geology of the area is complex being composed of Coniacian to early Campanian chalks, Thanetian and Landenian sands, clays and gravels and a thick covering of drift. The largest late Santonian - early Campanian outcrop is the eastern extension of the Templeux-le-Guérard outlier (see above). Three smaller but similarly aged outliers are situated 2 km SE of Villeret (Celet et al., 1978) in the vicinity of "la Haute Bruyère" farm (Bellicourt of authors): (1) An 850 x 300 m, SW - NE oriented outlier with its axis along the unclassified road that joins the farm to "le Grand Priel" farm: x 662,61 y 250,15 z 145 ($0^g.971$E $55^g.497$). (2) A small (250 x 100 m), north - south elongated outlier situated 750 m SW of the farm: x 662,55 y 249,74 z 140 ($0^g.970$E $55^g.493$). (3) A small 350 m diameter outlier situated 750 m south of the farm: x 663,19 y 249,57 z 140 ($0^g.980$E $55^g.491$). A final phosphatic chalk site lies in an area of predominantly Coniacian chalks, 750 m NNE of Hargicourt: x 660,58 y 252,58 z 128 ($0^g.940$E $55^g.522$) but it is not known how this exposure is related to the workings described in the literature.

Phosphorite extraction in the area was initially restricted to Tertiary solution pipes (Gosselet, 1893a) but was subsequently extended to include the primary deposits (Gosselet, 1900a, 1901a). The workings situated within the late Santonian - early Campanian outlier NW of Hargicourt were owned by the "Société Kuhlmann" and consisted of a subterranean complex within two distinct levels of phosphorite, delimited by a north - south elongated cuvette. The lower phosphatic chalk was 5 m thick, contained 25% P_2O_5 at its base and 11% at its summit, and was overlain by a basal lag of phosphatized intraclasts. The upper phosphatic chalk, separated from the lower by 6 m of intermediate white chalk, consisted of a 3 m thick lenticle, 150 m long and 130 m wide, overlain by an upper white chalk and floored by a strongly-lithified upper basal hardground. The eastern extremity of the cuvette was exposed in a quarry 100 m east of the subterranean workings. This quarry displayed a basal hardground dipping at ~10° E, overlain by a richly phosphatic basal lag but only a thin poorly phosphatic chalk. A second quarry ("Chantier Doublet") to the south of the major workings displayed an 8 m thick

lower phosphatic chalk separated from a 50 cm thick upper phosphatic chalk by only 3 m of white chalk, the upper 1 m of which was intensely bioturbated by phosphorite-filled burrow systems. The occurrence of secondary phosphate sands within Tertiary solution pipes 8 m above the base of the upper white chalk in the vicinity of the subterranean complex suggests that a third level of phosphatic chalk was once present in the region.

The most extensive workings in the proximity of Hargicourt were the "Cologne farm" quarries owned by M. Mommert and the "Société du Vermandois". Their exact location is unknown, but a series of abandoned pits on the eastern outskirts of Hargicourt are in approximately the right area: x 661,35 y 251,69 z 135 ($0^g.948$E $55^g.513$). The exposures consisted (Gosselet, 1900a, 1901a) of three separate 'cuvettes' with north - south axes. The western quarry had been largely worked out by 1900 but can be reconstructed from the observations of the owner (see below). The central pit ("Mommert's quarry") provided the best exposure (Fig. 2.57) and displayed a number of important features:

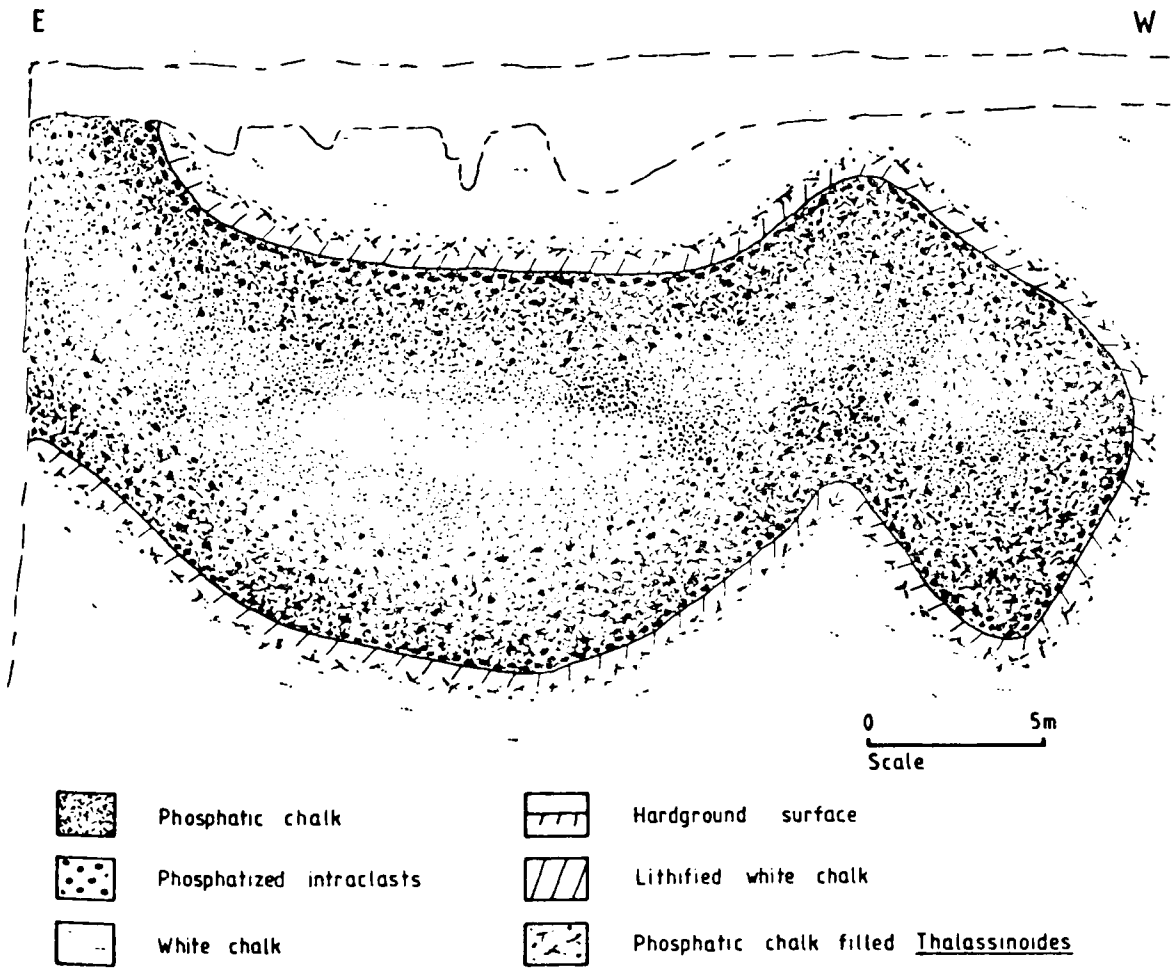


Fig. 2.57 Mommert's quarry, Hargicourt (Aisne) in 1900. Redrawn from Gosselet (1900a, 1901a).

(1) a poorly lithified basal hardground penetrated by a well-developed phosphorite filled idiomorphic Thalassinoides system,

(2) a basal lag containing 25% P_2O_5 and consisting of phosphatic chalk rich in phosphatized white chalk and phosphatic chalk intraclasts but no large frag-

ments of hardground top,

(3) ~ $5\frac{1}{2}$ m of phosphatic chalk containing 23% P_2O_5 at its base and 5% at its summit,

(4) an inverted repetition of the basal hardground/lag/phosphatic chalk sequence caused by recumbent folding of the strata,

(5) the occurrence of lenticles of phosphorite below the basal hardground, probably the result of bioturbation.

The hinge of the fold can be reconstructed from the records of the western quarry, where extraction was terminated by a vertical wall of basal hardground (cf. Beauval, Hardivillers). The removal of the overlying strata by subsequent erosion means that the age of the tectonic event that produced the recumbent fold cannot be acertained but, by analogy to similar folds elsewhere, was probably intra-Cretaceous and possibly synsedimentary or early post-depositional in origin.

The third working, 90 m across and situated 100 m east of "Mommert's quarry", exposed 6 m of phosphatic chalk underlain by a further unspecified thickness of phosphatic chalk and a basal hardground. The floors of all three workings rose northwards causing the phosphorite to pinch out in that direction.

The final exposure in the area lay 100 m north of Villeret, to the south of those described previously. A quarry cut into the hillside: x 661,35 y 251,11 z 120 ($0^g.948$E $55^g.507$), exposed a strongly-lithified basal hardground dipping at ~ 15° WNW and overlain by 75 cm of phosphatic chalk at the summit of the hill but 2.55 m at its base. The phosphate content of the phosphorite rose with increasing thickness of the unit so that in the thickest section it contained 23% P_2O_5 at its base and 18% at its summit. The phosphorite was overlain by 4 - 8 m of upper white chalk. The contact between the two lithologies dipped at a similar angle to the basal hardground.

The most extensive faunal records originate from the Hargicourt workings (Leriche, 1908, 1911) and include Actinocamax verus from the lower white chalk and lowest phosphatic chalk and Gonioteuthis ex gr. quadrata from the upper phosphatic chalk. Other records from the site include Gryphaeostrea canaliculata, Kingena lima Defrance, Terebratulina striatula (J. de C. Sowerby non Mantell), Cretirhynchia cf. woodwardi (Davidson), cidarids including Stereocidarid sceptifera

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teeth, cirripedes, serpulids, corals and ventriculitid sponges. G. canaliculata and 'T'. phosphatica are also recorded from Villeret. The belemnite evidence, which suggests an early Santonian to early Campanian age for the phosphorites, is supported by the limited foraminiferal data (Monciardini in Celet et al., 1978) which indicates the presence of Biozone e phosphorite at Hargicourt and phosphatic chalk of Biozone g age at "Haute Bruyére".

2.5.5 Bouchavesnes-Bergen (Somme) and other localities

The village of Bouchavesnes-Bergen (Somme), mentioned as a Micraster decipiens Zone phosphorite locality by Lasne (1892), lies on the N37 6 km north of Péronne. A small, 6 m high exposure is located in an old quarry complex on the east side of the N37, 200 m south of the petrol station in the village: x 641,75 y 253,36 z 125 ($0^g.647$E $55^g.531$). A 30 cm bed of phosphatic chalk is underlain by 3 m of white porcellaneous chalk containing siliceous incipient-flints and large sheets of Platyceramus prismatic shell layer. An idiomorphic, phosphatic-chalk filled Thalassinoides system penetrates down into the lower white chalk from the base of the phosphorite. The basal phosphatic chalk consists of a coarse phosphatic lag containing 0.1 - 1.0 cm, bored, subrounded - angular, phosphatized and limonite stained intraclasts; 1 - 3 mm glauconitized intraclasts; pelletal phosphate; abundant silicified, comminuted Platyceramus; oyster fragments, fish and echinoderm debris. Irregular masses of goethite/lepidocrocite up to 5 cm across occur at the base of the unit which decreases in grain-size towards its summit where it passes into the overlying 3 m of soft white chalk. No diagnostic macrofauna was collected by me but recent microfaunal work (Monciardini in Celet et a., 1978) suggests that the Coniacian age assigned to the deposit (Lasne, 1892) was in error and that the phosphorite is of early Santonian Biozone d or e age.

A small exposure of phosphatic chalk was located east of the village of Longavesnes (Somme), 10 km NE of Péronne (Gosselet, 1900a). The deposit has been dated (Monciardini in Celet et al., 1978) as being of Biozone e age.

An elasmobranch fauna has been recorded (Leriche, 1908) from the vicinity of Pontru (Aisne), 8 km NE of St Quentin, but no other details are known.

2.6 The Fresnoy-le-Grand and Etaves-et-Bocquiaux outliers

A sub-circular, $2\frac{1}{2}$ km wide, erosional outlier of Campanian chalk, capped by Tertiary sands and clays, is situated 6 km south of the town of Bohain-en-Vermandois (Aisne), NE of the source of the river Somme. The outlier is surrounded (except for a handful of small, close-by, associated outliers) for a minimum of 10 km by Coniacian to Santonian white chalk (Leriche and Celet, 1972).

Four main phosphatic chalk localities are located in the area: (1) Etaves-et-Bocquiaux, (2) Fresnoy-le-Grand, (3) Mericourt and (4) Montbrehain. All four have been described by Gosselet in a series of papers published between 1893 and 1901. There is no extant exposure (1979) at any of the sites, but Gosselet's descriptions provide adequate detail for a comparison to be made between the phosphatic chalks of the area and other exposures. The phosphorite is confined to the vicinity of the Campanian outlier, even though it is not exclusively of that age (e.g. Fresnoy-le-Grand). This may reflect an initially limited geographical distribution of the phosphatic chalk, or simply be due to a restriction of middle to late Santonian chalk to the region of the outliers. The importance of the former factor is impossible to gauge but the latter is certainly partly responsible for the present distribution.

2.6.1 Etaves-et-Bocquiaux (Etaves of authors) (Aisne)

The town of Etaves-et-Bocquiaux is a ribbon-settlement that runs NE - SW along the D31, the road joining the villages of Sebancourt and Croix-Fonsommes. The Campanian outlier is bisected by a NE - SW trending valley ("Vallée Claude Mont"). Etaves-et-Bocquiaux is situated in the SE sector of the outlier and the phosphatic chalk workings were sited on the valley sides, west of the town. Three main sites are recorded in the area (Leriche and Celet, 1972). The largest quarry complex was on the valley sides directly below the houses on the west side of the town: x 679,66 y 249,21 z 130 ($1^g.231$E $55^g.484$). This is the site of the majority of the descriptions in the literature.

The locality was discovered in 1893 when borings demonstrated the occurrence

of a phosphatic chalk that thinned to the NE and was thickest under the Campanian white chalk along the western portion of the town (Gosselet, 1893c). The sudden disappearance of the phosphatic chalk to the east was attributed to faulting (Gosselet, 1893c) but was probably due to the synsedimentary folding of the phosphorite (see below). By 1896, two quarries were being exploited (Gosselet, 1896a), the quarry of the "Société Anonyme" and "Duplaquet's quarry". These workings exposed a NE - SW section through a folded portion of basal hardground (Fig. 2.58A). The structure was best seen in the SW quarry ("Duplaquet's quarry"), where the

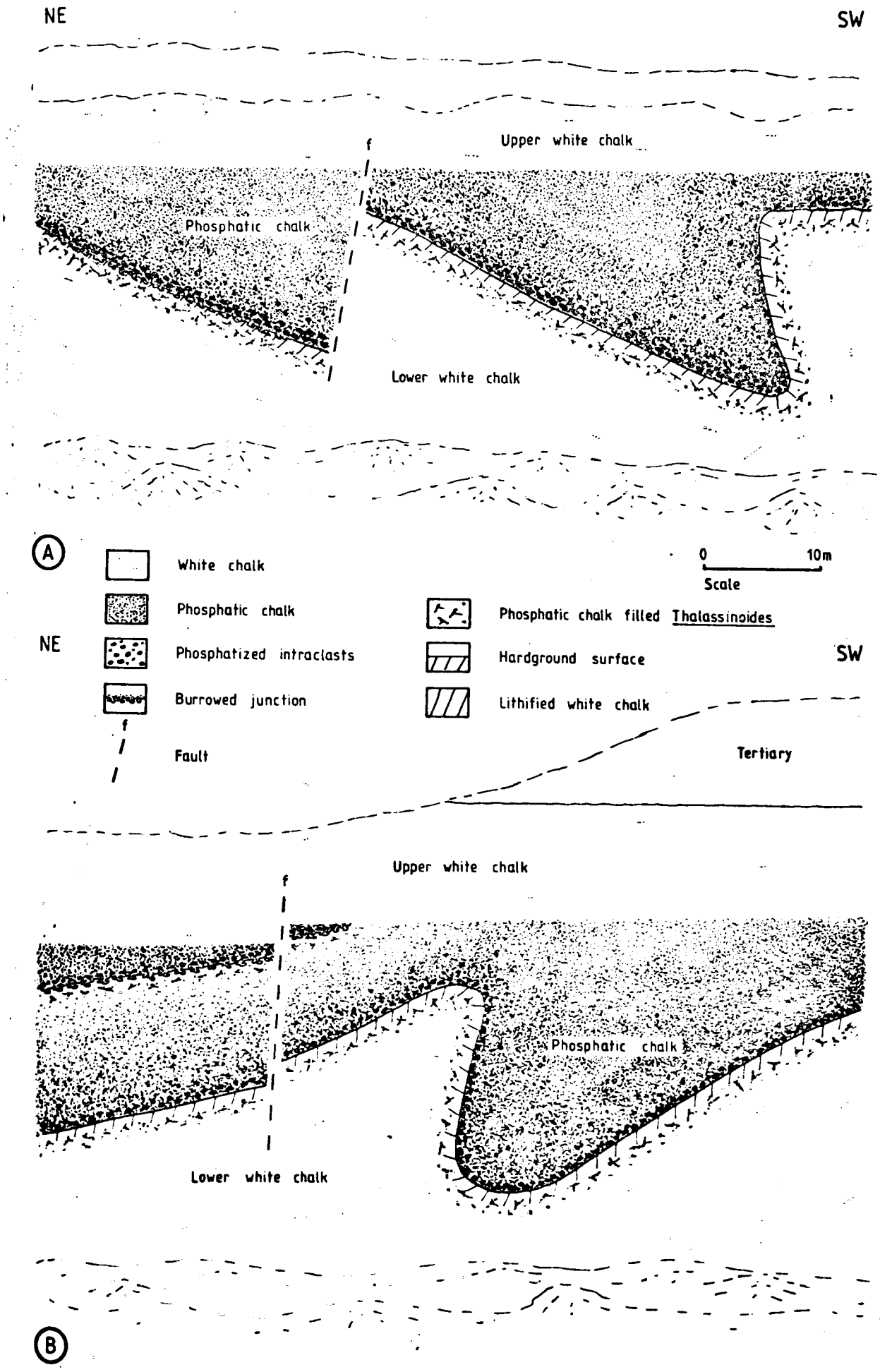


Fig. 2.58 Etaves-et-Bocquiaux quarries 1896 - 1901.
A. The quarry of the "Société Anonyme" (NE) and "Duplaquet's quarry" (SW) in 1896 (Redrawn from Gosselet, 1896a, 1900b, 1901a).
B. "Camus, Pagès and Company's quarry" in 1901 (Redrawn from Gosselet, 1901b).

basal hardground was deformed into a markedly-asymmetric syncline (Gosselet, 1896a, 1900b, 1901a), the two limbs of which dipped at 35 - 40° and 85° SW, the latter being overturned. The wavelength of the folding was 50 m and the amplitude 15 m (Gosselet, 1901a).

The basal hardground had a well-lithified, polychaete-bored top in the SW portion of the quarries but lithification decreased to the NE, where the basal lag rested on top of a burrowed junction, rather than a hardground. The basal hardground was penetrated by phosphatic-chalk filled Thalassinoides burrows and overlain by a thick basal lag consisting of phosphatized intraclasts that were encrusted by pycnodonteine oysters, adnate Spondylus and serpulids and coated with shiny phosphate skins. The lag contained a fauna of elasmobranch teeth, oysters and Gonioteuthis. The basal hardground was overlain by a varying thickness of phosphatic chalk that decreased in phosphate content away from the hardground. The folded sequence was unconformably overlain by a horizontally-bedded upper white chalk. The unconformity almost truncated the SW limb of the fold, indicating that a considerable thickness of phosphatic chalk had been removed.

By 1901 the section had changed dramatically (Gosselet, 1901b). A new working, the quarry of "Camus, Pagès and Company" had been opened in the old quarry of the "Société Anonyme". A fold structure was again visible, but the original asymmetric syncline had been worked-out and an asymmetric syncline and anticline (Fig. 2.58B) with NE dipping limbs was exposed. Apparently the dip of the limbs had reversed in direction over what was presumably a very short distance. The basal 'hardground' of the new exposure was poorly lithified but still overlain by a basal lag. Well-developed phosphatic-chalk filled Thalassinoides systems were also present. The overlying phosphorite was bisected by an intercalated, burrowed-out poor phosphatic chalk. The phosphate content decreased upwards from the base but a rich phosphatic chalk rested on top of the burrowed-out unit. The sequence was again unconformably overlain by a horizontally-bedded upper white chalk. The succession remained unchanged in 1902 (Rabelle, 1902) and no further details are available.

Two smaller sites also occur in this area. The first is situated on the west side of the D31, 200 m north of the hamlet of Beautroux and 2 km SW of Etaves-et-

Bocquiaux: x 678,65 y 247,94 z 130 ($1^{g}.216$ $55^{g}.471$). The second lies half-way between the D70 and the D31, 1250 m NE of the crossroads in Croix-Fonsommes: x 677,84 y 248,33 z 115 ($1^{g}.203$E $55^{g}.475$). These may be the localities of "Vanelles" and "Puy Ségur" mentioned by Gosselet (1896a) but insufficient information is available for positive identification.

2.6.2 Fresnoy-le-Grand (Aisne)

The town of Fresnoy-le-Grand lies on the D8, 3 km NE of Etaves-et-Bocquiaux and 5 km SE of Bohain-en-Vermandois. A phosphatic chalk quarry was located to the west of the town in the region of a small Campanian outcrop: x 676,70 y 250,30 z 130 ($1^{g}.185$E $55^{g}.495$), 1½ km NW of the main Campanian outlier (Celet, 1972). The quarry described by Gosselet (1893c, 1896a, 1897, 1900b)("Flour's quarry"),however, lay SE of the town near the "Moulin de Bois" (Gosselet, 1893c). This site is not marked on any map available to me. A third quarry, similarly unmarked, was mentioned by Rabelle (1902); it was situated near Fresnoy-le-Grand railway station, east of the town. The bulk of the data concerns "Flour's quarry", and the following descriptions are of that site.

The quarry exposed 1½ - 2 m of phosphatic chalk (Gosselet, 1893c) with a typical phosphatized intraclast lag, 40 cm thick, at its base. These intraclasts were encrusted by Spondylus, oysters and serpulids and heavily bored by polychaete worms. At this stage in the exploitation, no lithification of the underlying white chalk was recorded, but a well-developed phosphatic-chalk filled Thalassinoides burrow system was described (Gosselet, 1893c). The phosphatic chalk decreased in phosphate content upwards and was yellow-stained towards its top. The junction between the phosphatic chalk and the slightly-phosphatic upper white chalk was sharp. Several faults were described that had resulted in block faulting of the phosphorite/lower white chalk junction (Gosselet, 1893c).

By 1896 (Gosselet, 1896a) a 100 m long SE - NW trending section was exposed. The block faulting was no longer visible, but the phosphatic chalk was bisected by a clay-rich level. The phosphate content of the phosphorite decreased rapidly northwards due to a reduction in the proportion of pelletal phosphate and phos-

phatized intraclasts. The decrease was such that the P_2O_5 content of the lowest phosphatic chalk dropped from 14 to 6% over a distance of only 4 m. The top of the Thalassinoides system was coated with a shiny phosphate skin that continued down into the upper portions of the burrow systems. I have only seen such skins on lithified and usually phosphatized chalks, although Gosselet (1896a) only mentions 'pockets' of lithification. It is suggested that if induration was restricted in its distribution then the skins must have been confined to lithified areas.

Subsequent exposure (Gosselet, 1897, 1900b) provided further lateral control. The phosphate content of the lowest metre of phosphatic chalk decreased both NE and NW (Gosselet, 1896a, 1897) from 20 to 6% P_2O_5 over a distance of 20 m (Fig. 2.59). A well-lithified basal hardground was not exposed until 1900, when the

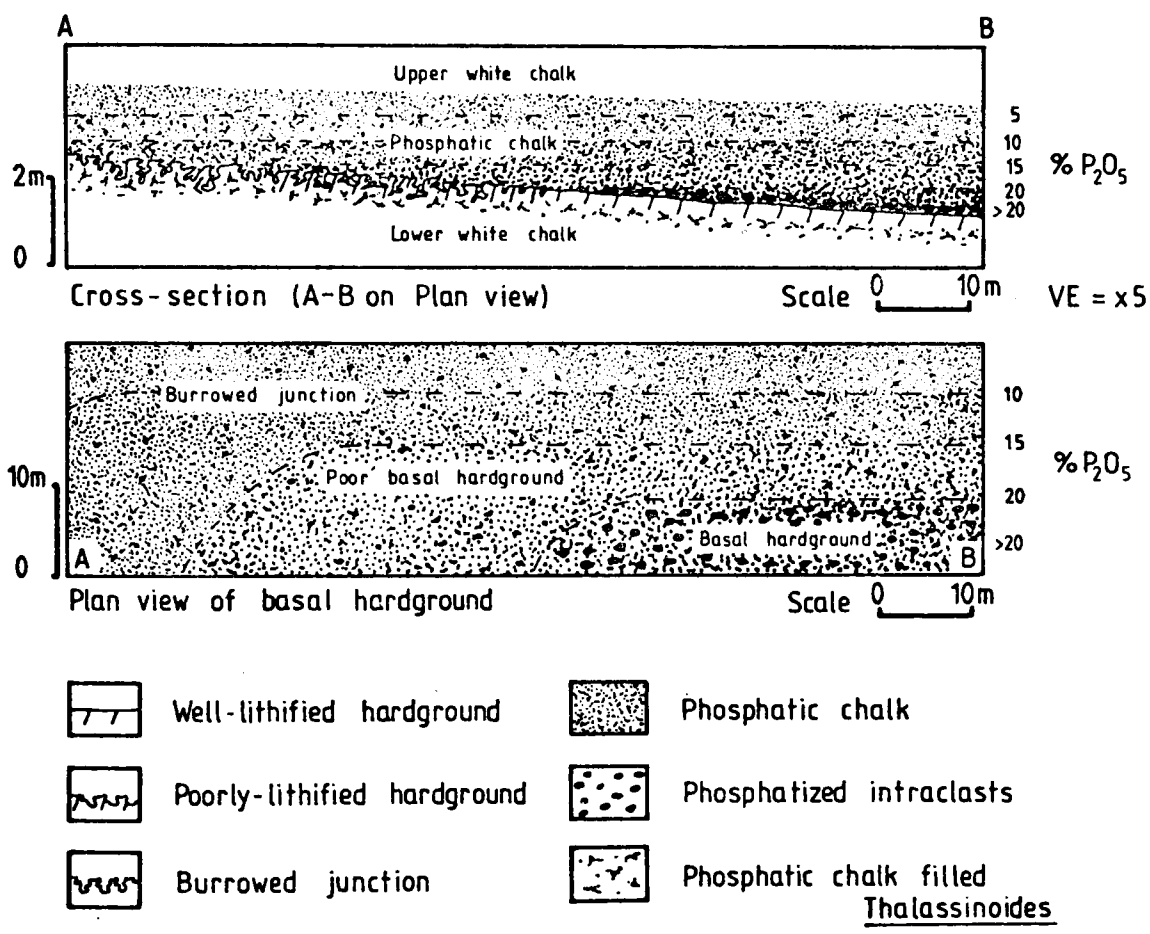


Fig. 2.59 Schematic diagram of "Flour's quarry", Fresnoy-le-Grand (Aisne). Interpretation of data in Gosselet (1893c, 1896a, 1897, 1900b).

relationship between the rich phosphatic chalk and well-lithified basal hardground became apparent (Gosselet, 1900b fig1; Fig. 2.59). It should be noted that from observations at other sites I infer a slight dip on the basal hardground, although Gosselet (op cit.) does not record any dip in his descriptions.

Gonioteuthis ex gr. quadrata has been recorded from Fresnoy-le-Grand (Leriche, 1908) but there are no other faunal records of biostratigraphical significance. G. ex gr. quadrata indicates an early Campanian age for the phosphatic chalk.

Gosselet's descriptions of "Flour's quarry" are the most complete records of a lateral transition from a basal hardground to a burrowed junction. They clearly

illustrate a positive correlation between hardground lithification and the phosphate content in the overlying phosphatic chalk. However, the phosphorite exposed was thin (only 2 m), which suggests that the exposure was located either on the margin of a larger cuvette or near the axis of a very shallow one.

2.6.3 Méricourt (Aisne)

The hamlet of Méricourt lies on the north side of the D8, 2 km SW of Fresnoy-le-Grand. The Campanian outcrop caps the NW - SE ridge on which Méricourt is built. The outcrop is approximately 1 km long and 250 m wide, and lies 2 km west of the main Etaves-et-Bocquiaux outlier. No phosphatic chalk outcrop is marked on the current geological map of the area (Leriche and Celet, 1972). Gosselet (1893c) records an exposure 1 km south of "Flour's quarry" at Fresnoy-le-Grand. If his location of "Flour's quarry" is correct, then Méricourt quarry may have been the small quarry NE of Croix-Fonsomme: x 677,84 y 248,33 z 115 ($1^{g}.203$E $55^{g}.475$), mentioned under Etaves-et-Bocquiaux (see above).

Méricourt quarry exposed 2 m of highly-fractured phosphatic chalk overlying a 10 cm thick basal lag (Gosselet, 1893c). The lower boundary of the phosphorite was a burrowed junction, lithification being weak or absent. The lowest phosphatic chalk contained 16 - 18% P_2O_5 passing up into a 20 cm transitional zone (with only 7% P_2O_5) at its top. The upper junction between the phosphatic chalk and the overlying 1 m of white chalk with scattered pelletal phosphate was sharp. The uppermost unit consisted of $1\frac{1}{2}$ m of white chalk (Gosselet, 1897, 1900b). No biostratigraphical data are available.

2.6.4 Montbrehain (Aisne)

The town of Montbrehain lies 8 km WSW of Bohain-en-Vermandois and 5 km NW of Fresnoy-le-Grand. A small Campanian outlier is situated $2\frac{1}{2}$ km south of the town, on the eastern side of the D283, approximately half-way between Montbrehain and Fontaine-Uterte: x 673,74 y 249,56 z 135 ($1^{g}.139$E $55^{g}.488$). A phosphatic chalk site was located south of the town (Gosselet, 1893c), so this is the most likely location.

The working exposed 2 m of phosphatic chalk resting on a basal lag and burrowed junction (Gosselet, 1893c). The basal lag contained small Gonioteuthis, ventriculitid sponges, elasmobranch teeth and fragments of rudist. A phosphatic-chalk filled Thalassinoides burrow system penetrated up to 1.20 m below the burrowed junction.

2.7 The Hallencourt outlier

The town of Hallencourt (Somme) lies 17 km SSE of Abbeville and 3 km west of the N1. The town is situated on a broad flat-topped hill covered by clay-with-flints and loess-rich drift. A 4 x 1 km early Campanian outlier, obscured (except for a few scattered exposures: Fig. 2.60) by up to 3 m of drift, lies SE, east and NE of the town. The early Campanian caps a larger, 6 x 1½ km outlier of middle to late Santonian chalk. The area is surrounded by Coniacian to early Santonian chalk, much of which is also obscured by drift.

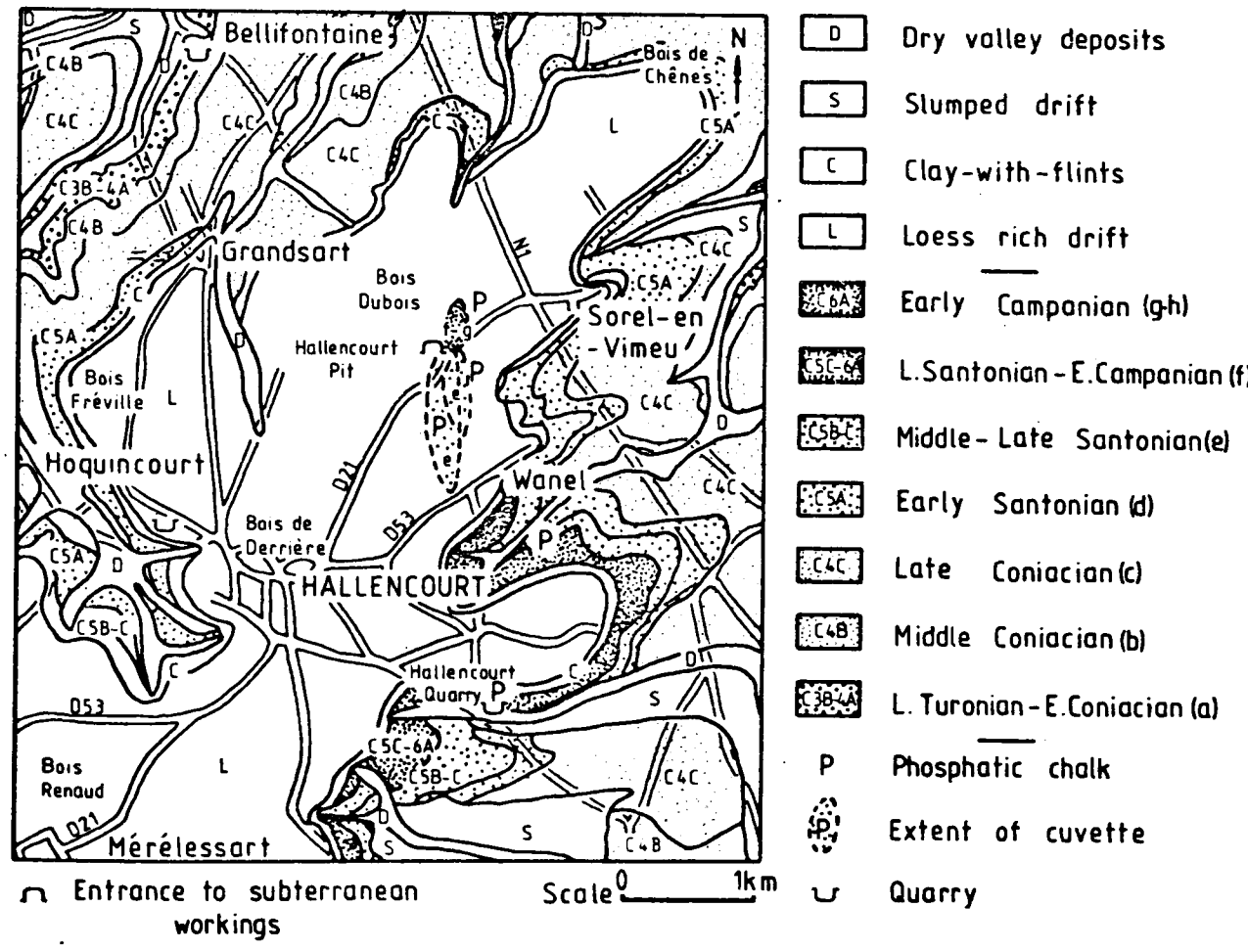


Fig. 2.60 Geological map of the Hallencourt area (Somme). (Modified from Mennessier et al., 1974).

Although phosphatic chalk was recognised at Hallencourt by Buteux (1849) and De Mercey (1867), the only detailed work on the area was produced during the last decade (Broquet, 1973; Mennessier et al., 1974). There are three areas of phosphatic chalk (Fig. 2.60) - one subcrop and two outcrops. The largest of the three is the

subcrop associated with the Hallencourt pit subterranean workings. The two outcrops are Hallencourt quarry (1½ km ESE of Hallencourt) and the "Valléenette" outcrop (2 km east of the town).

2.7.1 Hallencourt pit (Wanel of authors) (Somme)

The entrance to the subterranean workings is a pit head 2 km NE of Hallencourt, on the western side of the D21: x 568,16 y 256,71 z 115 ($0^g.494W$ $55^g.565$). The pit is one of two phosphatic chalk deposits being exploited at the present time (1979), the other being Nurlu quarry (Section 2.5.2). The pit is owned by "Etablissements Linet", who have been extracting phosphorite from the site since 1927 (Broquet, 1973). I was unable to examine the underground workings, so the bulk of the following description is based on Broquet (1973) and Mennessier et al. (1974), supplemented by material collected loose at the pit-head (Fig. 2.61).



Fig. 2.61 Hallencourt pit-head (Somme). The only remaining subterranean phosphorite working remaining in France.

Mapping of the gallery complexes has enabled the separation of three phosphatic chalk cuvettes. All three trend north - south (Fig. 2.60). The oldest is also the largest (1100 x 200 m) and is situated predominantly in the area between the D53 and D21, but also extends slightly north of the D21. It occurs at a depth of 59 - 60 m below the surface, contains 4 - 4½ m of phosphorite with 6 - 13% P_2O_5. The

intermediate cuvette is slightly smaller and more ovate (600 x 200 m). It is situated towards the northern end of the older cuvette, which it partly truncates (Fig. 2.62);its axis is displaced approximately 200 m east of that of the former cuvette. The subcrop is at a depth of 51 m and contains 3 m of phosphatic chalk

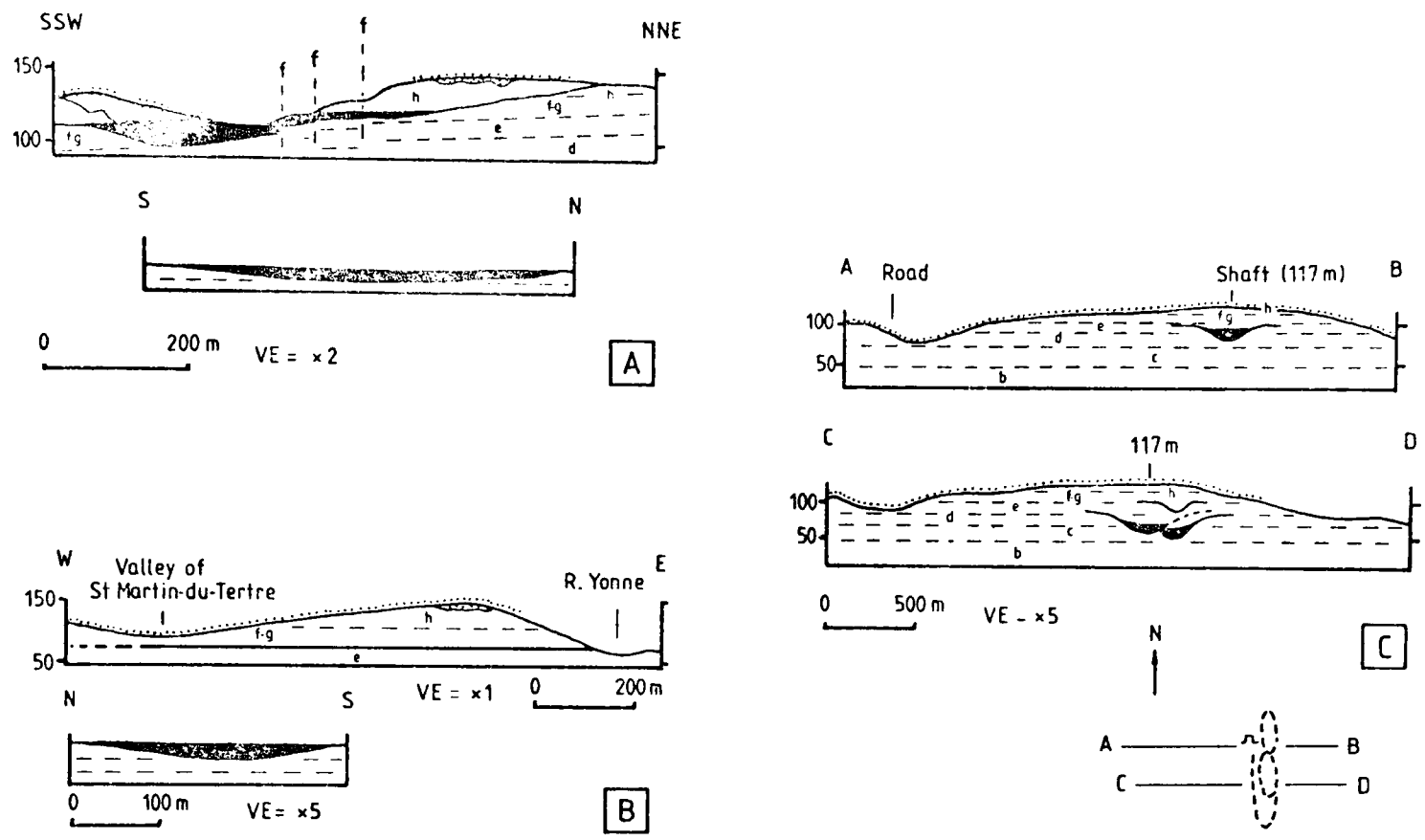


Fig. 2.62 Phosphatic chalk cuvette structures. A. Hardivillers (based on Lasne, 1892; De Grossouvre, 1901). B. St Martin-du-Tertre (based on Negre, 1913; Raguin, 1926). C. Hallencourt, cross-sections and plan view (based on Broquet, 1973). Black = phosphatic chalk; white = white chalk; stipple = Tertiary cover; dash = chalk bedding; small letters = foraminiferal biozones; f = fault. Note the similarity in dimensions.

with 10 - 19% P_2O_5. The youngest cuvette is the smallest (450 x 150 m) and lies to the north of the D21; north and stratigraphically higher than the former two cuvettes. It is at a depth of 30 - 36 m and is the only one being actively exploited (1979). It does, however, contain the greatest thickness of phosphorite (12 m) with 8 - 18% P_2O_5.

All three cuvettes have (at their base) a well-lithified, encrusted and bored basal hardground, coated with a shiny phosphate patina, in their central portions. The hardground surfaces have irregular topographies that have been infilled and masked by the overlying phosphatized intraclast lag. The basal hardgrounds are confined to the central regions of the cuvettes (Broquet, 1973 fig.3), becoming poorly-developed and indistinct at the margins, where the phosphatic chalks thin rapidly and finally disappear.

The detailed biostratigraphy of the deposits is based on foraminiferal zonation

(Monciardini in Broquet, 1973; Mennessier et al., 1974). The phosphatic chalk of the two oldest cuvettes is middle to late Santonian Biozone e. Both cuvettes are excavated in early Santonian Biozone d chalk and rest on hardgrounds of lithified, late Coniacian sediment. The youngest cuvette contains late Santonian to early Campanian Biozones f - g phosphorite that is cut into middle Santonian white chalk and rests, in part, on early Santonian strata.

Both Gonioteuthis ex gr. quadrata and Actinocamax verus have been recorded from Hallencourt (Leriche, 1911). The material collected by me originates from the youngest cuvette. Finds of stratigraphical value were a complete Echinocorys, and abundant Gonioteuthis ex gr. quadrata and Offaster pilula. The Echinocorys (Fig. A3.3 nos.5-8)is coated with a shiny phosphate skin and has patches of lithified, phosphatized sediment adhered to it. This is a typical basal lag preservation and suggests, on test morphology, an early Santonian age for the basal lag. It should be noted, however, that the biostratigraphy of Echinocorys morphotypes/species is not well-documented at this level. The G. ex gr. quadrata and O. pilula all had phosphatic chalk adhered to their surfaces, indicating the early Campanian O. pilula Zone, for at least some of the phosphatic chalk.

2.7.2 Hallencourt quarry (Somme) x 568,61 y 253,76 z 95 ($0^{g}.490W$ $55^{g}.536$)

Hallencourt quarry lies 1½ km ESE of Hallencourt, 50 m north of the track that joins Hallencourt and Dreuil-Hamel, on the west side of a small wood (Fig. 2.60). The quarry is being infilled with household refuse although, at the same time, being intermittently worked for white chalk and thereby extended westwards (1979).

The main face is approximately 75 m long and 12 m high and runs NW - SE; a smaller face 25 m long and 10 m high joins the main face at its northern extremity. The lower portion of the main face (the east face) and all of the northern face, are composed of soft white chalk with scattered flints. The north face can be divided into two beds (Fig. 2.63), the lower of which (HA1/1) contains two laterally-extensive tabular flints, a level of discontinuous tabulars (that change level and are discordant to bedding), two horizons of nodular flint, and scattered

nodular flint. The bed also contains abundant limonite-preserved sponges; its top is taken at the weak line of nodular flints 5 m above the quarry floor. The over-



Fig. 2.63 Litho-stratigraphy of the NW face, Hallencourt quarry.
A. General view of the exposure.
B. Sediment log.

lying bed (HA1/2) is a flintless white chalk with a horizon of crushed Echinocorys near the middle; scattered crushed Echinocorys occur throughout.

The lithostratigraphy of the main face (Figs. 2.64, 2.65) is more complex. The tabular flints of bed HA1/1 disappear at a fracture zone 10 m SE along the

main face, so that the lowest white chalk (HA2/1) cannot be easily subdivided. Three hardgrounds enter the face (Fig. 2.64) from the top of the quarry with steep, but progressively declining dips. The first (Hardground 1) enters the face in

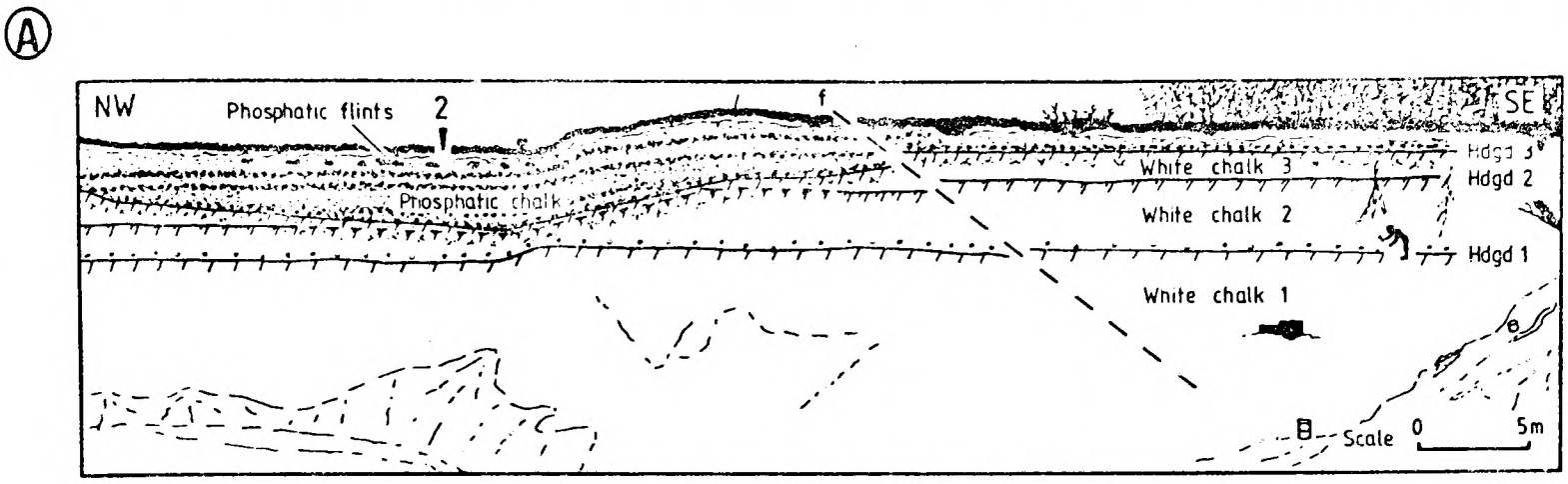




Fig. 2.64
The main face, Hallencourt quarry (Somme). A. Field sketch of the SE half of the main face. The number 2 indicates the position of measured section 2. B. Bow-shaped morphology of the basal hardground (Hardground 3).

the region of the fracture zone with a dip of ~10° but flattens out so that it runs horizontally, 9 m above the quarry floor. The hardground was accessible (1977) at the SE end of the face but further dumping has obscured (1979) this part of the exposure. It consists of a 30 cm lithified unit with a dull, light-brown phosphatized top overlain by 5 cm of white chalk rich in phosphatized intraclasts and ventriculitid sponges; a little pelletal phosphate was also present. The second hardground (Hardground 2) is less distinct and, at present (1979), totally inaccessible. It appears in the quarry face a few metres SE of Hardground 1 and has a comparable dip, but it maintains its initial dip over a greater distance and therefore converges with the lower hardground towards the SE. However, it diverges again 35 m from the end of the face (Fig. 2.64). The third hardground



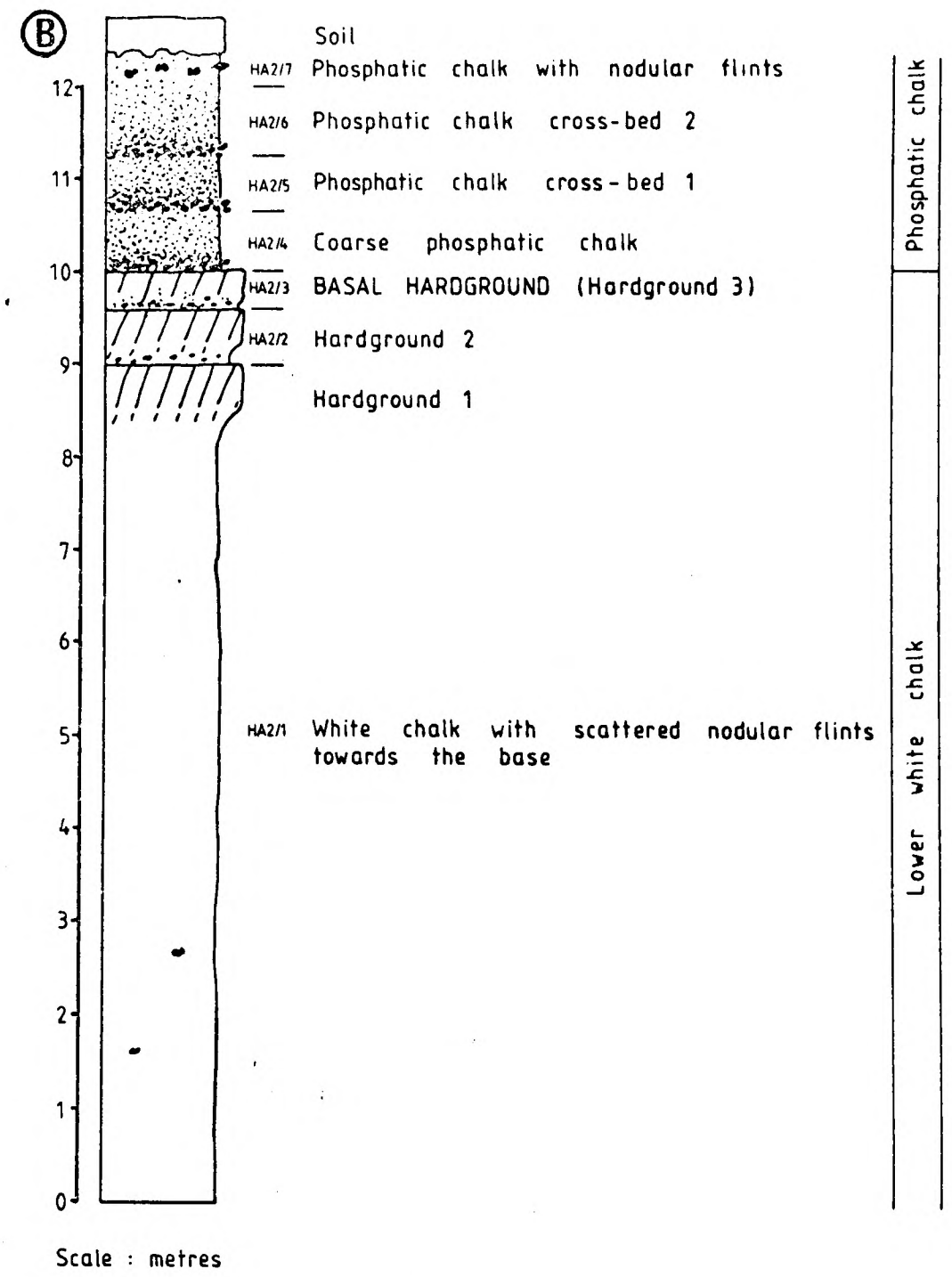
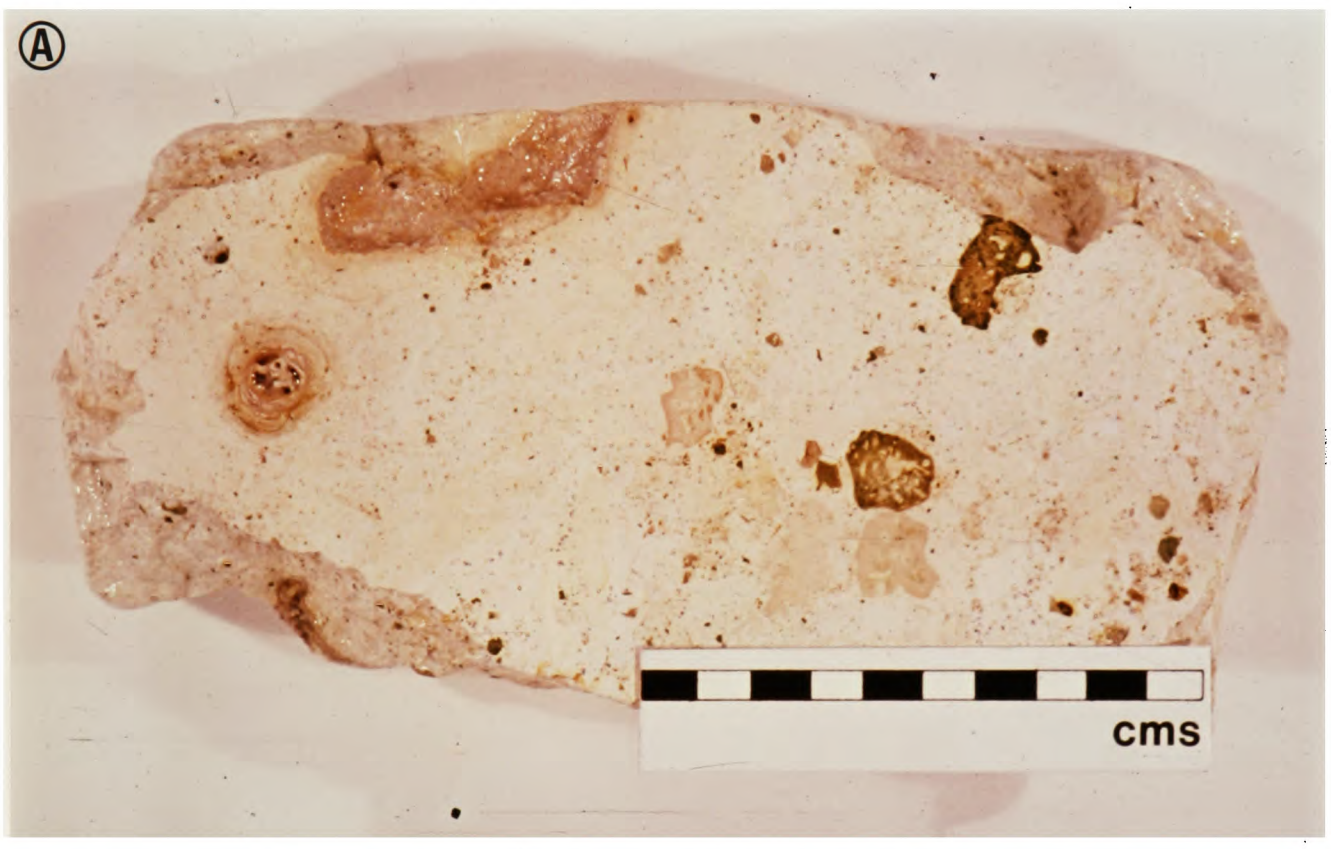


Fig. 2.65 Hallencourt quarry, lithostratigraphy of the thickest portion of the phosphatic chalk and underlying white chalk. A. General view B. Sediment log.

(Hardground 3) is the most prominent. It enters the quarry approximately one-third of the way along the main face with an initial dip of ~20°, so that it rapidly converges with the second hardground and becomes superimposed half-way along the face. The two surfaces remain superimposed for 15 m before diverging and regaining their identity. Hardground 3 is never less than 10 m above the quarry floor but may be examined in fallen blocks. The hardground sediment contains a high proportion of coarse sand to gravel grade carbonate, much of which has been glauconitized or phosphatized (Fig. 2.66A). The lithified zone has a minimum thickness of 40 cm; and the hardground surface is strongly phosphatized, bored by polychaete worms (Fig. 2.66B), encrusted by serpulid worms and coated in a complex series of



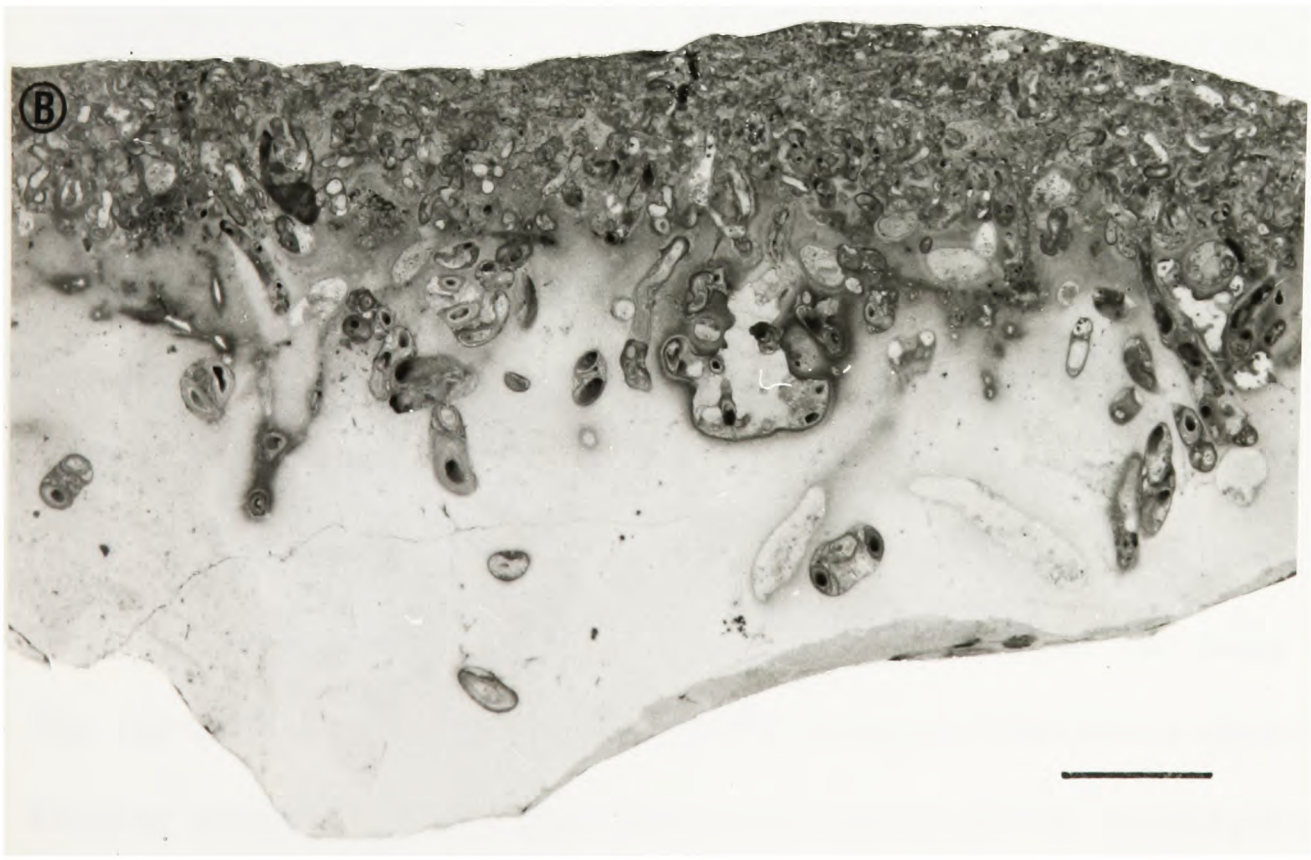


Fig. 2.66
Hallencourt quarry: sediment types I.
A. The basal hardground (Hardground 3). Polished surface.
B. Worm-bored top of the basal hardground. Polished surface. The scale bar = 1 cm.

phosphate skins. The hardground is penetrated by phosphatic-chalk filled Thalassinoides burrows, many of which have been infilled and later reexcavated by later generations of burrowers. The upper portions of the burrow systems are commonly lined by several sequences of phosphate skins. Hardground 3 (the basal hardground) is overlain by a basal lag of shiny-phosphate veneered, phosphatized intraclasts, followed by>2 m of phosphatic chalk.

The phosphatic chalk (beds HA2/4 - 7) contains two prominent horizons of coarse, phosphatized intraclasts that mark the bases of two shallow-angled cross-beds, dipping northwards (Fig. 2.67A). The phosphorite contains a high proportion



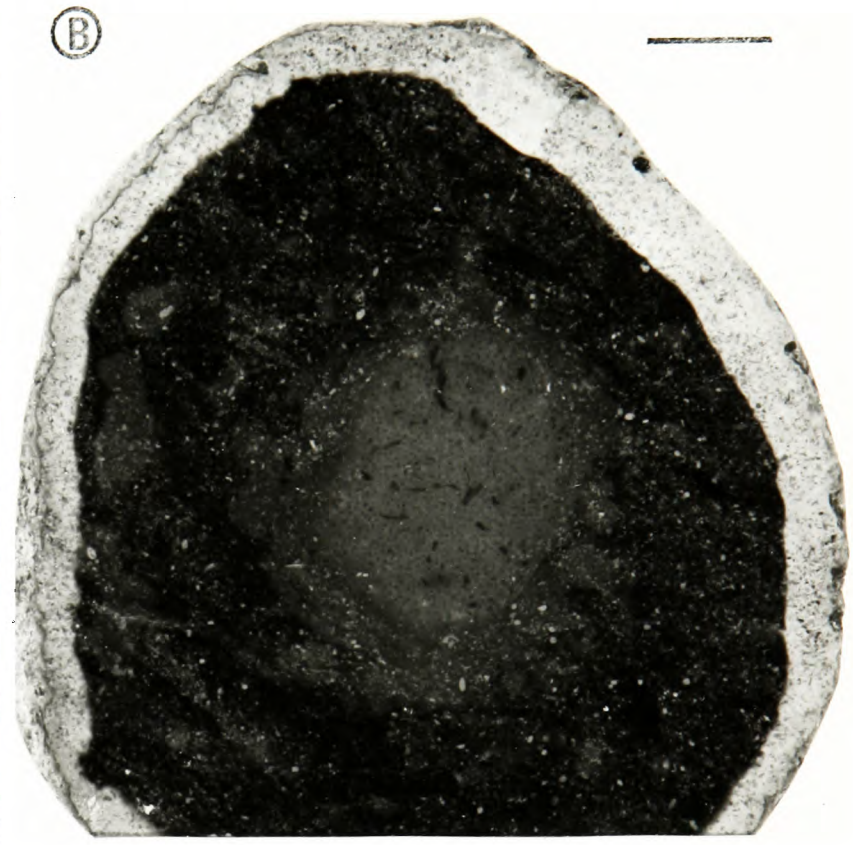


Fig. 2.67 Hallencourt quarry: sediment types II.
A. Close-up view of the cross-bedded intraclastic levels in the phosphatic chalk.
B. A phosphatic flint with a sponge at its core. Polished section. Scale bar = 1 cm.

of coarse calcarenite and gravel-grade carbonate, much of which is of echinoderm origin, including large amounts of asteroid and crinoid debris. The pelletal phosphate content of the phosphorite decreases rapidly upwards from the basal hardground, although minor concentrations occur at the base of each cross-bed. The top of the sequence (bed HA2/7) contains scattered phosphate and phosphate-bearing nodular flint. The flints are up to 30 cm across, have black cores and white rinds up to 1 cm thick (Fig. 2.67B). They contain scattered, discrete,

unsilicified phosphatic pellets throughout, in contrast to their carbonate component, which shows progressive replacement inwards, so that it has been completely silicified within the cores.

According to the geological map of the area (Mennessier et al., 1974), the quarry is located in late Santonian chalk (Fig. 2.60). The lower white chalk (HA1/1, HA1/2) contains the crinoid Uintacrinus socialis and fallen blocks of the lower white chalk bed HA1/2, yield Marsupites testudinarius. Plates of the latter crinoid have not been recovered in situ from bed HA1/2 and the crinoid brachials collected from the line of crushed Echinocorys in that bed resemble those of U. socialis more than M. testudinarius. The boundary of the two zones must therefore be within the upper two metres of bed HA1/2. South-east of the fracture zone, in the main face of the quarry, the U. socialis/M. testudinarius Zone boundary is taken at the surface of Hardground 1.

The phosphatic chalk yields abundant Gonioteuthis ex gr. quadrata and Offaster pilula in fallen blocks. These species indicate the early Campanian O. pilula Zone, Subzone of "abundant O. pilula". No diagnostic fauna was collected from the (largely inaccessible) beds between Hardground 1 and the basal hardground (beds HA2/2, HA2/3). It may be concluded that the quarry exposes a sequence of middle to early Campanian age.

2.7.3 The "Valléenette" outcrop (Somme) x 569,06 y 255,10 z 95 ($0^g.478W$ $55^g.549$)

The site lies 600 m south of the village of Wanel, 2 km west of Hallencourt. The outcrop is situated on the eastern side of the small valley of "Valléenette" (Fig. 2.60) and has been mapped as late Santonian (Mennessier et al., 1974), the same age as Hallencourt quarry. There is no exposure at the present time (1979).

2.8 Gournay-en-Bray to Breteuil

The town of Gournay-en-Bray (Seine-Maritime) is situated at the intersection of the N30, N15 and N31, 46 km east of Rouen and 26 km west of Beauvais. The town of Breteuil (Oise) lies to the NE at the junction of the N16, N30 and N181,

26 km NE of Beauvais and 29 km south of Amiens.

The outcrop between the two towns is dominated by varying thicknesses of Pleistocene clays and sands that mantle a late Turonian to early Campanian succession of chalks (Blondeau et al., 1978; Dollfus, 1930; De Mercey, 1907; Lemoine, 1912; Thomas, 1914). Gournay-en-Bray is situated on early Cretaceous strata, a result of uplift along the fault zone of the Pays-de-Bray axis (Fig. 2.2), but all of the phosphorite localities lie to the NE within late Cretaceous sequences. The Cretaceous outcrop is generally restricted to valley sections where fluvial erosion has cut through the post-Cretaceous cover. The bulk of Cretaceous sediment within the region is of Coniacian to Santonian age but Campanian chalks become more prominent towards the south. Tertiary deposits are restricted to the vicinity of Crevecoeur-le-Grand (De Mercey, 1907).

The phosphatic chalk outcrop is limited to two areas, the first is 5 km SE of Breteuil and includes the localities of Hardivillers and Hédencourt; the second consists of a NW - SE trending series of sites along the D95 between Savignies and Gerberoy, 10 km NE of Gournay-en-Bray. In contrast to most of the other exposures, only one of the localities (Hardivillers) is an outlier sensu stricto, the remainder consisting of residual pockets of pelletal phosphate sand resting in Tertiary solution pipes, and situated in areas where the primary phosphorite has been removed totally by post-Cretaceous erosion.

2.8.1 Hardivillers (Oise)

The village of Hardivillers lies 5½ km WSW of Breteuil at the intersection of the N30, D34, D61 and D510. Early Campanian chalks outcrop north, NE and east of the village (Fig. 2.68) but phosphatic chalks are restricted to a single, large (1500 x 500 m), WNW - ESE oriented outlier that is situated 1 km NE of Hardivillers and north of the N30. This outlier contains four large adjoining phosphorite quarries that lie to the south of "le Bois du Plantis" and east of, and within, the "Bois Guyot": NE quarry x 593,22 y 213,74 z 120 ($0^g.104W$ $55^g.137$); North quarry x 592,81 y 213,85 z 120 ($0^g.111W$ $55^g.138$); SW quarry x 592,63 y 213,68 z 120 ($0^g.113W$ $55^g.137$); South quarry x 593,04 y 213,46 z 120 ($0^g.107W$ $55^g.135$); extensive subterran-

nean workings penetrate beneath the two woods. Phosphatic chalk extraction ceased in 1972 and the quarry complex has been subsequently converted into a combined auto- and motor-cross circuit, but substantial exposure remains in all but the south quarry. Permission for entry may be obtained from M. Bizait at Breteuil.

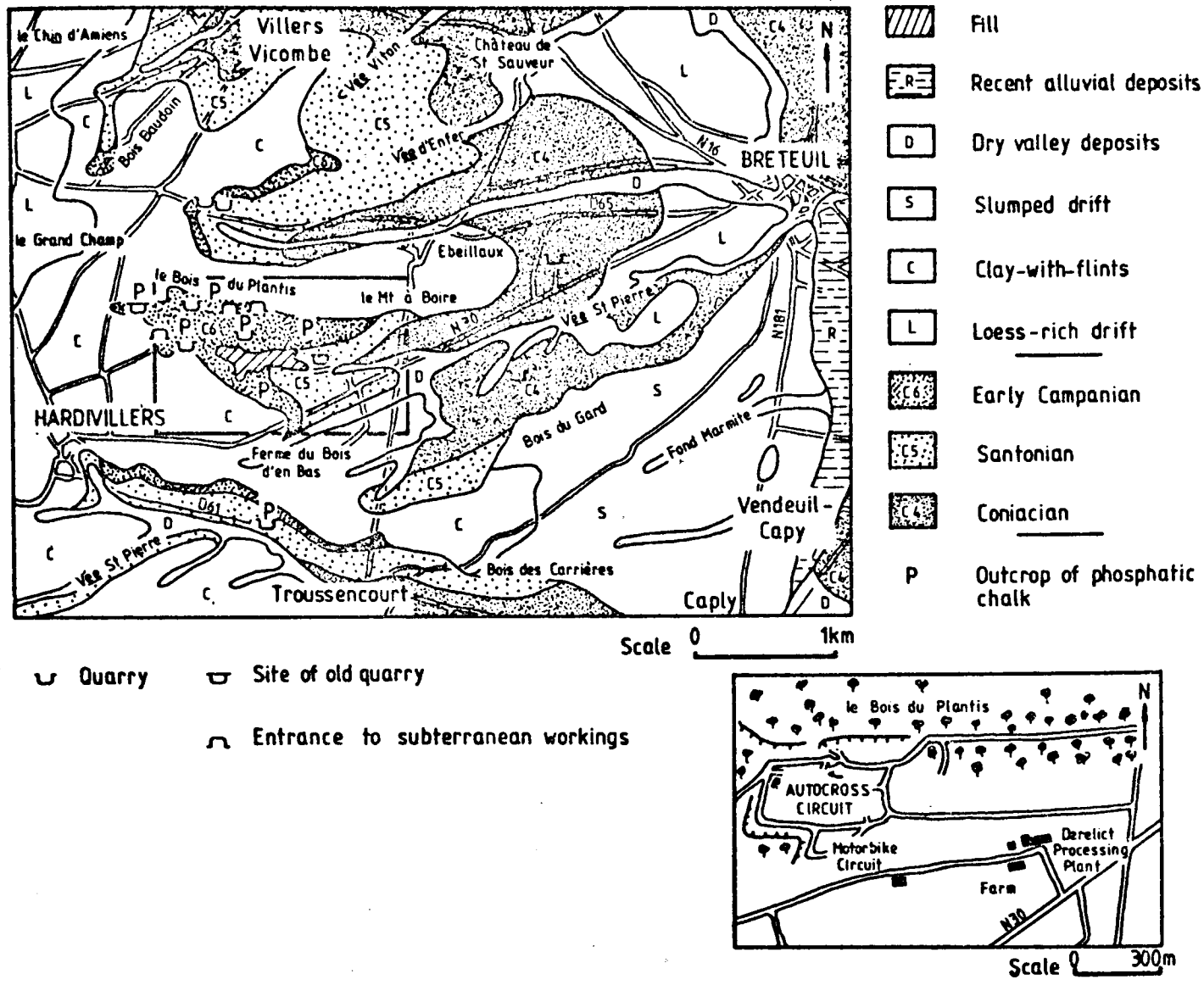


Fig. 2.68 Geological and location sketch maps of Hardivillers quarries. Geology modified from Blondeau et al. (1978).

First described in 1863 (although originally recognised as an abnormal facies by Graves, 1847), Hardivillers was one of the first phosphatic chalk localities to be discovered in France (De Mercey, 1863, 1887a, b; Meunier, 1891). The nineteenth century exploitations revealed that the phosphorite lay within a 1000 m long, 750 m wide and 20 m deep WNW - ESE oriented cuvette (Fig. 2.62) that had been cut into the underlying, horizontally-bedded soft white chalk (De Mercey, 1887b; Lasne, 1892; De Grossouvre, 1901). The base of the cuvette was marked by a strongly-lithified and mineralized phosphate veneered basal hardground, which was penetrated by phosphatic-chalk filled Thalassinoides burrow systems and encrusted by oysters. An exposure at "Budin's quarry", to the north of the phosphorite workings, demonstrated that the basal hardground had a dip of ~ 30° at the cuvette margins (De Grossouvre, 1894, 1901). The overlying phosphatic chalk, which contained ~ 15%

P_2O_5, increased in thickness from a few centimetres at the extremities of the deposit to 7 - 8 m (and exceptionally 16 m) at its axis. Up to 10 m of primary phosphate sands containing ~30% P_2O_5 occurred at the base of the phosphatic chalk succession and similar, thinner (0.1 - 1.0 m) beds were present throughout. Secondarily enriched phosphate sands with similar P_2O_5 contents occurred in solution pipes within the joint systems of the main body of phosphorite. The phosphatic chalk was overlain by ~20 m of white chalk with flints. The micro- and nanno-facies of the locality have been discussed by Tabatabai (1977) who unfortunately did not consider the gross lithostratigraphy.

The most extensive contemporary exposure is located in the NE quarry (Fig. 2.69) although recent (1978) modifications to the autocross circuit (Fig. 2.70) have obscured all remaining exposures of the basal hardground and underlying soft white chalk. The sequence may be conveniently divided into three units: lower white chalk, phosphatic chalk and upper white chalk.

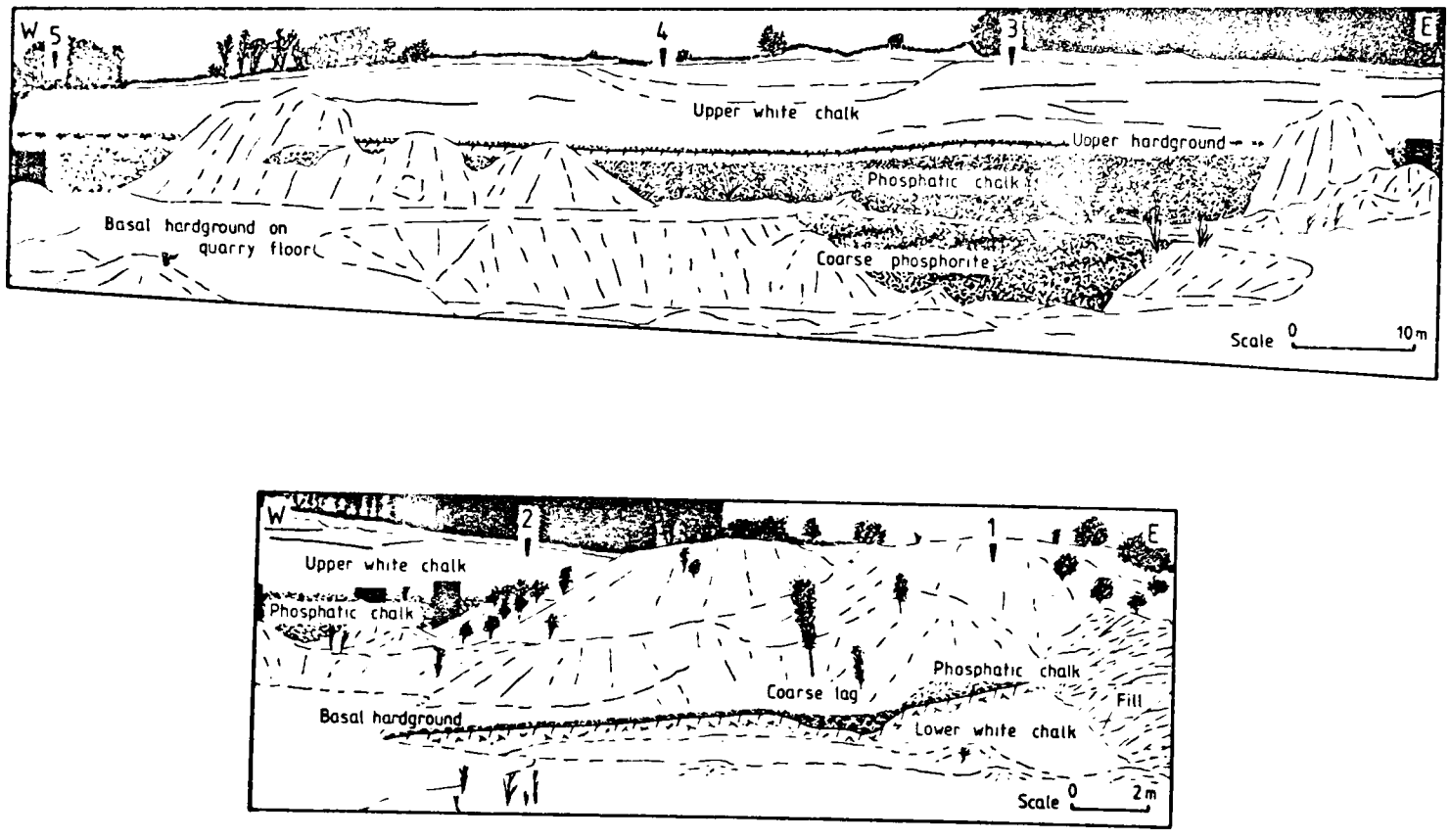


Fig. 2.69 Hardivillers NE quarry in May 1977. The numerals indicate the positions of the measured sections refered to in the text.

The lower white chalk was (1977) only exposed on the approach road leading to the NE quarry (Figs. 2.69, 2.71) where it consisted of $2\frac{1}{2}$ m of soft white chalk overlain by 50 cm of lithified hardground sediment, penetrated by phosphatic-chalk filled Thalassinoides burrows that spread horizontally in the underlying soft white chalk. The hardground surface was bored by bivalves and polychaete worms, and coated with a complex of shiny-phosphate veneers that had been encrusted by, and



Fig. 2.70 Hardivillers NE quarry, 1978. Outcrops of basal hardground (a) are restricted to the eastern side of the exposure. The top of the coarse phosphorite (b) and the top of the phosphatic chalk (c) are indicated. The upper hardground (d) is overlain by the final development of phosphatic chalk in the succession. The scale (circled) is 1.75 m high.

subsequently coated, pycnodonteine oysters and adnate Spondylus (Fig. 2.72). The

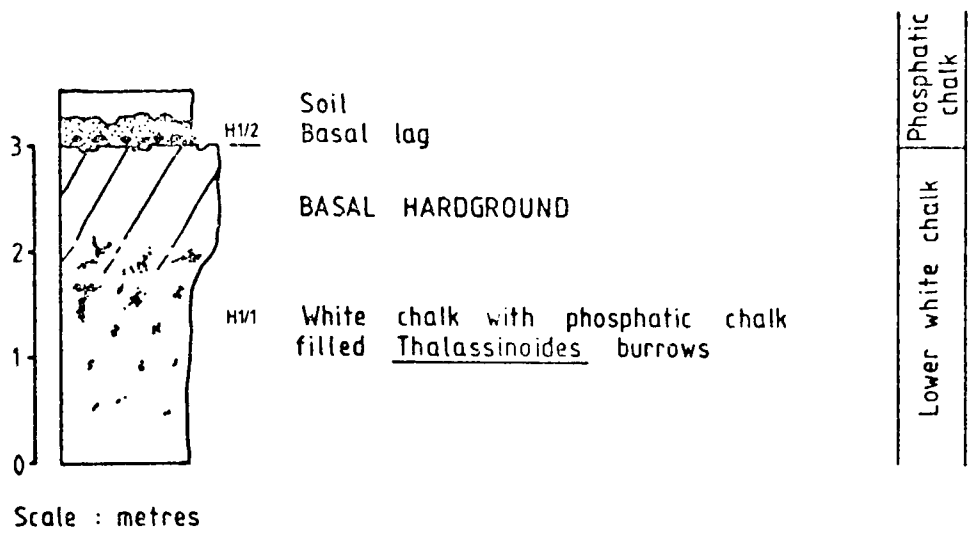


Fig. 2.71 Lithostratigraphy, eastern section on the lower approach road, Hardivillers NE quarry in May 1977. (Section 1).

surface was overlain by 0 - 5 cm of phosphatized intraclast lag in a phosphatic chalk matrix, most of which had been removed during the excavation of the section. The basal hardground had a general dip of between 5 and 15° W, but a 2 m wide, phosphatized-intraclast filled depression occurred in its surface about half-way along the exposure. The depression was partly the result of undermining of the hardground surface, since isolated slabs of the top still capped much of the deposit. These slabs consisted of a 2 - 5 cm thick bed of intraclast-bearing white chalk that had been subsequently phosphatized, bored, encrusted and coated with iridescent phosphate skins. The top of the slabs were encrusted by 'Terebella' phosphatica but their sides and undersides bore pycnodonteine oysters. The earlier generation of intraclasts within the unit were limonite-stained, glauconitized and/or phosphatized and were heavily bored by bivalves, polychaete worms and, occasionally, clionid sponges. Boring of the top itself (predominantly by polychaete worms) generally occurred prior to the preserved encrustation, and truncation of many of the bores indicates that significant erosion of the hardground surface took place before its burial. The depression was filled with a coarse lag of 0.5 - 5.0 cm, phosphatized (occasionally glauconitized), phosphate-skin coated, subangular - rounded irregular intraclasts encrusted by oysters and/or 'T.' phosphatica. The intraclasts consist of four distinct types:

(1) isolated and rounded fragments of intensely polychaete-worm bored hardground top (Fig. 2.72b,d)

(2) subsequently bored and mineralized fragments of hardground chalk from below the intraclastic top (Fig. 2.72e-f)

(3) lightly phosphatized fragments of hardground chalk (Fig. 2.72g),



Fig. 2.72 Hardground surface and phosphatized intraclasts from the basal hardground, Hardivillers NE quarry. a. Pycnodonteine-oyster encrusted surface of the basal hardground. b. A type (1) intraclast. c. A composite intraclast having a glauconitized core (right) surrounded by at least three generations of phosphatized sediment. Truncation of the right-hand side of the glauconitic centre may be attributed to fracturing prior to the final stage of reworking. d. A type (1) intraclast with a fractured, Spondylus encrusted left margin. e. A heavily limonite-stained type (2) intraclast. f. A type (2) intraclast with a limonitic 'front' immediately below its phosphatized margin. Patches of later phosphatized sediment (top right) have been plastered onto the initial surface. g. A type (3) intraclast. h. A type (4) intraclast. i. Phosphatic-chalk filled internal mould of Micraster cf. coranguinum (OUM KZ6903). A similar mould of a ventriculitid sponge (OUM KZ7342).

(4) lithified, poorly phosphatic chalk intraclasts (Fig. 2.72h).

The lithified phosphatic chalk, which is the dominant component of the type (4) intraclasts, also adheres to and infills borings within intraclasts of the other three types. Many of the nodules show several generations of boring, encrustation, mineralization and surface adherence of sediment (cf. 'hiatus concretions' sensu Kennedy et al., 1977). Large (0.5 - 5.0 cm) fossil moulds are abundant within the deposit particularly ventriculitid sponges, Micraster and Echinocorys but also including Diblasus arborescens, gastropods, nautiloids, heteromorph ammonites, Gonioteuthis, Platyceramus, Inoceramus and elasmobranch teeth. The moulds consist of a phosphatized, lithified phosphatic chalk coated with a shiny-phosphate veneer and are commonly bored by polychaete worms and encrusted by pycnodonteine oysters. Fragments of phosphatized test are preserved on the echinoids. The phosphatic chalk infill of the steinkerns indicates that their formation post-dates the formation of the hardground, which consists of lithified white chalk. This precludes the possibility of the lag fauna being remanié from an eroded soft white chalk, and suggests that the assemblage may be hardground associated.

Clearly the majority of intraclasts have originated from the dislocation and dissociation of the upper portion of the basal hardground but their external morphology excludes a unique mechanism. The accretion of later generations of sediment has masked many primary surface irregularities, while subsequent boring has produced a second-order topography. Nevertheless, three distinct types of surface morphology may be recognised:

(1) concave surfaces,

(2) planar surfaces,

(3) convex surfaces.

The occurrence of concave surfaces indicates that biological agencies were associated with the break-up. Many of the smaller (1 - 5 mm) diameter pits and channels truncate grain boundaries and may be attributed to boring, but the larger (0.5 - 1.0 cm) features are passive and are probably portions of burrow wall of a stenomorphic Thalassinoides system that penetrated the hardground prior to its break-up.

The planar surfaces also truncate grain boundaries but are generally restrict-

ed to intraclasts that have originated from the cemented intraclast lag which originally capped the hardground. Some examples may be fragments of truncated, planar top of the hardground but many exhibit planar surfaces normal to their top and are therefore interpreted as early diagenetic fractures. These have been subsequently coated with shiny-phosphate skins and encrusted by oysters, demonstrating that the fracturing was a seafloor process.

The majority of intraclasts have, however, a complex gross-morphology. Although partly the result of secondary addition of sediment, the dominance of rounded forms must be interpreted as being the result of mechanical abrasion.

Intraclast genesis, therefore, may be attributed to local in situ break-up of the basal hardground due to:

(1) a high density of Thalassinoides burrows that weakened the structure of the hardground and may have led to the isolation of some portions,

(2) further weakening and isolation by boring,

(3) early diagenetic fracturing of the hardground surface,

(4) mechanical break-up, abrasion, rounding and reworking.

A further factor is the location of the lag within a depression in a surface that had a significant inclination. If mechanical reworking was important in the formation of the intraclasts, it would have undoubtedly caused a degree of downslope movement and concentration of material in any surface irregularities. Such a downslope movement may be invoked to explain the high concentration of steinkerns within the lag, and explains the high density of intraclasts within such a limited area.

The basal hardground is also exposed in a limited number of further exposures in the NE quarry. A small tunnel entrance is situated in the middle of the main face above the coarse phosphorite that infills the depression in the middle of the quarry. The tunnel is the entrance to part of the extensive network of subterranean workings (with its own narrow gauge railway system) that honeycomb the hillside beneath "le Bois du Plantis". At the entrance the tunnel floor is >6 m above the base of the phosphatic chalk but 50 m north the tunnel floor (which is horizontal) exposes the surface of the basal hardground. In other areas within the complex 2 - 3 m domes in the basal hardground rise 30 - 40 cm above the

tunnel floor and have had to be cut through to allow access by the railway. Elsewhere, the hardground surface rises 1 - 2 m above the floor and results in 'dead ends' to exploratory tunnels. The network demonstrates the considerable large-scale topography that occurs on the surface of the basal hardground and the extreme lateral variations in thickness that must occur in the lowest phosphatic chalk.

Specimens of basal hardground collected from within the tunnels consist of >50 cm of strongly-lithified white chalk penetrated by stenomorphic Thalassinoides burrows with phosphatized walls. The phosphatic chalk that infills the system has also been hardened, and shows several generations of fill and reexcavation. The top of the lithified white chalk is overlain by 1 - 5 cm of a 'Terebella' phosphatica/shiny-phosphate veneer/pelletal phosphate complex that has been cemented on top and has sealed off the upper portion of the Thalassinoides system. Where this phosphorite top is absent the hardground has been bored by polychaete worms. The final reexcavation of the burrows is characterised by small (1 - 3 mm) sinuous burrows with a circular cross-section. These burrows have phosphatized walls and are lined by a 1 - 2 mm thick complex of iridescent-phosphate skins, they are infilled with a soft phosphatic chalk indicating that their vacation post-dates the lithification of the phosphorite that seals-off the earlier burrow system.

Similar examples of the hardground top were (1977) exposed in the face on the east side of the depression in the centre of the quarry but these have since been obscured. A fourth exposure is situated on the south side of the quarry where a large (90 x 60 cm) block of basal hardground has been fractured, dislocated and displaced a few centimetres vertically (Fig. 2.73). The synsedimentary nature of the break-up is demonstrated by the glauconitization, phosphatization and oyster encrustation of the fracture surface. The lithified sediment that forms the hardground contains both white and phosphatic chalk although textural relationships indicate that the former predates the latter.

The hardground surface is uneven, phosphatized, coated with a shiny phosphate veneer, densely encrusted by pycnodonteine oysters and contains numerous bivalve borings up to 1.5 cm across. The bulk of the sediment in the upper portion of the hardground is a strongly-lithified, phosphatized-intraclast bearing, richly phosphatic chalk. Unlike other sections in the quarry (and elsewhere) there is no



Fig. 2.73 A dislocated block of basal hardground, south face of the NE quarry Hardivillers. The hammer shaft is 30 cm long.

distinct hardground surface associated with the lithified white chalk component. Rather, both sediment types appear to have been deposited before lithification. That the white chalk was unconsolidated prior to the admixture of the phosphorite is shown by the general lack of sharp boundaries between the two types of sediment and the idiomorphic nature of the first generation of phosphatic-chalk filled Thalassinoides burrows. The hardground is also penetrated by a second generation of soft phosphatic-chalk filled stenomorphic Thalassinoides that generally follow and reexcavate the earlier idiomorphic system. Irregularities on the floor of the horizontal portions of the former system are typically filled by up to 1 cm thick buildups of thin (< 0.1 mm) shiny phosphate skins (the thickest skin complexes known to me) and similar, but thinner, complexes also line (and sometimes fill) the large bivalve crypts that penetrate the hardground surface. A number of other generations of sediment are present, for example some of the bivalve borings are infilled with an indurated poorly phosphatic chalk; phosphate-skin lined worm borings are restricted to a later generation of cemented phosphatic chalk that infills the stenomorphic Thalassinoides in the upper part of the hardground.

Glauconitization is sparse and generally limited to the roofs of burrows and to intraclasts, but a third concentration was found on the fracture surface along which the block has been displaced. In this latter case, the dark green colouration coats, but shows virtually no penetration of, both types of lithified chalk.

Flecks of goethite are common in the uppermost 3 cm of the hardground, an area which is also strongly limonite stained. 'Pyrolusite' also pervades the lithified material.

Phosphatized intraclasts up to 5 cm across are common in the phosphatic chalk that overlies and surrounds the dislocated block. The associated fauna includes ventriculitid sponges, Actinocamax verus, and scleractinian coral fragments. The basal hardground/lag couplet is overlain by an obscured sequence of phosphorite.

The absence of a hardground surface associated with the lithified white chalk is unusual, but may be explained by its removal by erosion subsequent to the initiation of phosphatic chalk sedimentation. Destruction of the uppermost 60 cm of a complete basal hardground would leave an unlithified white chalk containing a dense concentration of idiomorphic Thalassinoides burrows. Lithification of this sediment concurrently with, or subsequent to, erosion would result in a second order hardground identical to that observed in the dislocated block.

A complete sequence from basal hardground, through the phosphatic chalk and up into the upper white chalk is exposed at the eastern end of the main face (Section 2; Fig. 2.74), west of an entrance to a series of underground workings that have suffered roof collapse, and now form a deep (~10 m) trench system in the woods east of the quarry. The phosphatized and phosphate-skin coated surface

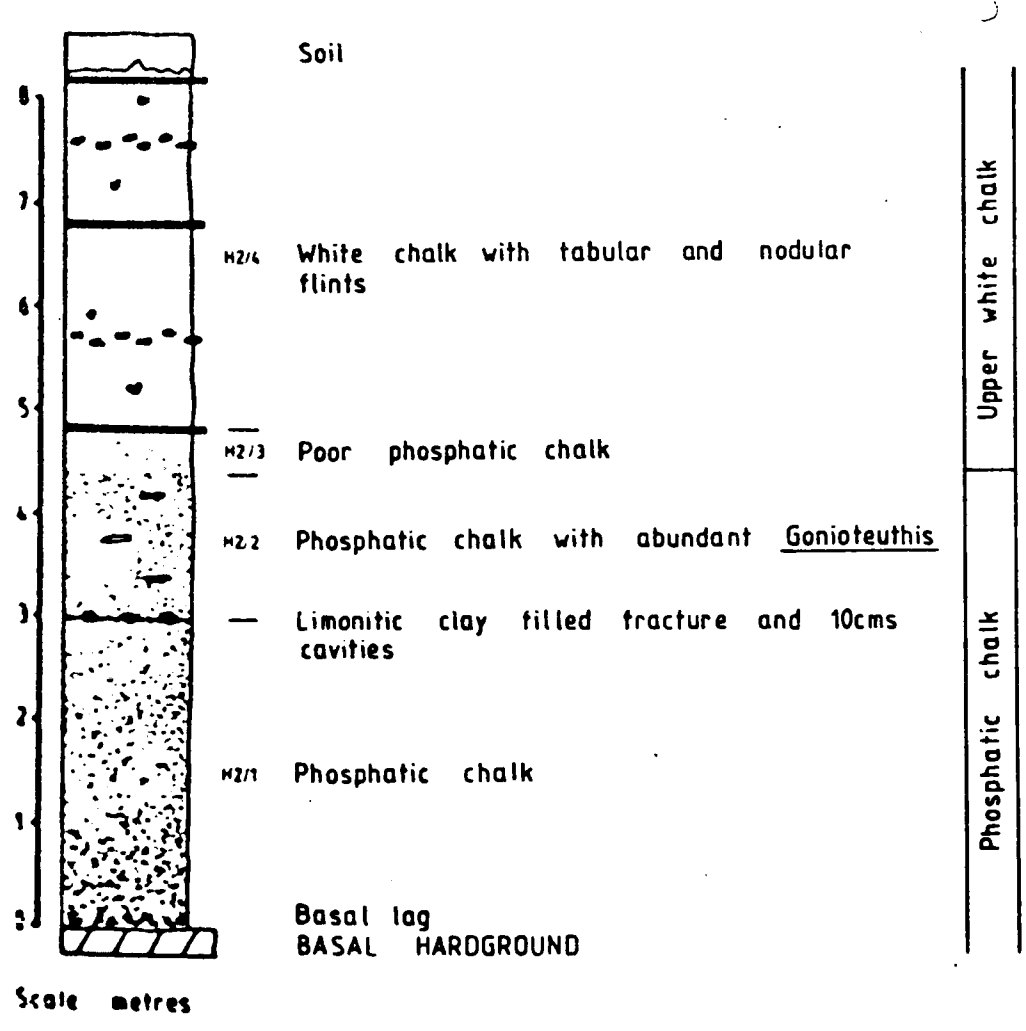


Fig. 2.74 Lithostratigraphy, eastern section within the vicinity of a collapsed tunnel system, NE quarry Hardivillers (Section 2).

of the basal hardground may be excavated at the base of the section, but is not naturally exposed. The hardground is overlain by $4\frac{1}{2}$ m of phosphatic chalk that contains a well-developed, limonitic-clay filled fracture and a number of 10 cm, similarly filled cavities ~3 m above its base. Gonioteuthis ex gr. quadrata is abundant in the phosphatic chalk (bed H2/2) that overlies the fracture and the bed is consequently termed the Hardivillers Gonioteuthis Bed. Above this, the pelletal phosphate content of the chalk declines rapidly and is negligible above the lowest tabular flint. The phosphorite is overlain by $3\frac{1}{2}$ m of soft white chalk with nodular and discontinuous tabular flints (bed H2/4).

The thickest sequence of phosphorite is exposed in the middle of the main face (Section 3; Fig. 2.75) where $>3\frac{1}{2}$ m of coarse phosphatic chalk (bed H3/1) is developed locally where the basal hardground forms a large depression in the middle of the quarry (Fig. 2.69). The base of the unit is not visible, but a burrowed-out white chalk horizon occurs 20 cm above the bottom of the section. The lowest phosphorite consists of a coarse phosphatic chalk containing up to 40% angular - subangular, light to dark brown, phosphatized, iridescent phosphate-skin coated intraclasts. These are generally 0.5 - 10.0 mm across but examples up to 3 cm occur at the base of the section. Both bored and unbored forms are common and larger examples occassionally exhibit encrustation by oysters or serpulid worm tubes. Internally they consist of a number of different types of chalk including microfauna-rich and microfauna-poor varieties. Large components include complete and fragmented oysters, particularly Gryphaeostrea and Lopha semiplana, and elasmobranch teeth including Lamna and Anacorax. Occasional examples of silicified Diblasus arborescens, 'Terebella' phosphatica, Actinocamax verus, Gonioteuthis (?)granulata, ventriculitid sponges, asteroid ossicles and internal moulds of gastropods were also recovered. The sand-grade component is dominated by benthonic and planktonic foraminiferans, comminuted Platyceramus, echinoid (particularly cidarid) plates and spines, bryozoa, coprolites and glauconitized internal moulds of foraminiferans. The matrix is a coccolith biomicrite. Other than elasmobranch teeth and oysters, however, the fauna is much less abundant and not as well preserved as that recovered from the Beauval basal lag (Section 2.3.2). The grain-size decreases upwards and there is a concurrent decline in the percent-

age of echinoid material, coprolites and vertebrate remains. The unit, which contains 15 - 25% P_2O_5, does not display any clear bedding or bioturbation, partly

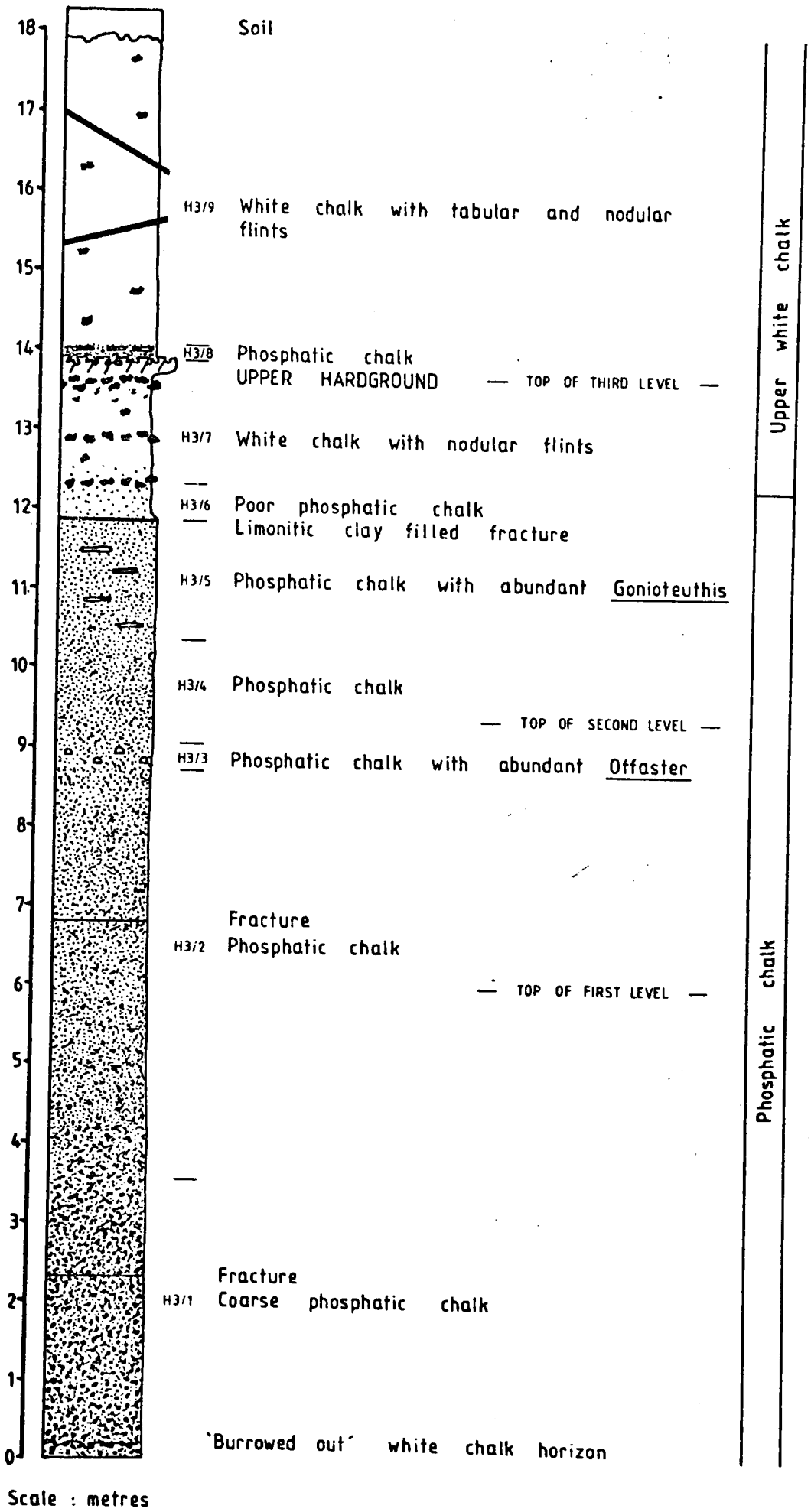


Fig. 2.75 Lithostratigraphy, central section of the NE quarry Hardivillers (Section 3).

because the face is weathered and covered in chalk wash. Concentrations of coarse sediment are indistinct, rarely horizontal, and can only be followed a few tens of centimetres laterally. Unfortunately, the deposit provides no evidence whether this lack of sedimentary structures is primary or due to subsequent bioturbation.

The coarse phosphorite is overlain by ~5 m of finer phosphatic chalk (bed H3/2) containing only 5 - 10% P_2O_5, a higher proportion of comminuted inoceramid and sponge spicules but fewer faecal pellets than the underlying bed. The top of the unit is taken at the base of a 30 cm bed (H3/3) of phosphatic chalk containing abundant Offaster pilula - the Hardivillers Offaster Bed. There follows $1\frac{1}{2}$ m of phosphatic chalk with little macrofauna overlain by $1\frac{1}{2}$ m of Gonioteuthis ex gr. quadrata-bearing phosphorite - the Hardivillers Gonioteuthis Bed - the top of which is taken at a limonitic-clay filled fracture that also marks the top of the main phosphatic chalk unit. Bioturbation is intense but more distinct in these upper beds which, despite their finer grain size, contain 10 - 15% P_2O_5.

The phosphatic chalk is overlain by a 40 cm transitional zone (bed H3/6) of poorly phosphatic chalk overlain by 1.70 m of white chalk with occasional phosphate-rich levels (bed H3/7) and abundant nodular flints. The top of this first bed of the upper white chalk is marked by a weakly-lithified, limonite-stained hardground. The surface of this upper hardground is discontinuous, phosphatized, convolute and penetrated by a dense network of idiomorphic Thalassinoides burrows filled with phosphatic chalk rich in 1 - 10 mm, subangular - rounded, phosphatized, bored intraclasts (Fig. 2.76) and G. ex gr. quadrata. The phosphorite (bed H3/8) infills the surface topography produced by the burrow system. The upper hardground and its associated phosphatic chalk are overlain by 4 m of inaccessible soft white chalk with tabular and nodular flints. Small (1 - 3 mm) white chalk intraclasts are common in the white chalk directly overlying the phosphorite.

A section taken 40 m west of the preceding one exposes the upper portion of the phosphatic chalk and ~9 m of upper white chalk (Section 4; Fig. 2.77). The succession is very similar, but the upper hardground is better lithified, overlain by a phosphatic chalk richer in pelletal phosphate, and is only 1.25 m above the top of the phosphatic chalk unit. The overlying upper white chalk contains a prominent semi-tabular flint at its base and a double tabular flint towards its summit. A final section (in the NE quarry) taken 30 m west of Section 4 (Section 5; Fig. 2.78) further displays the inverse correlation between the thickness of sediment between the upper hardground and the top of the phosphatic chalk and the degree of lithification of that hardground. The belemnite 'population' collected



Fig. 2.76 Polished block of the upper hard-ground, NE quarry Hardivillers.

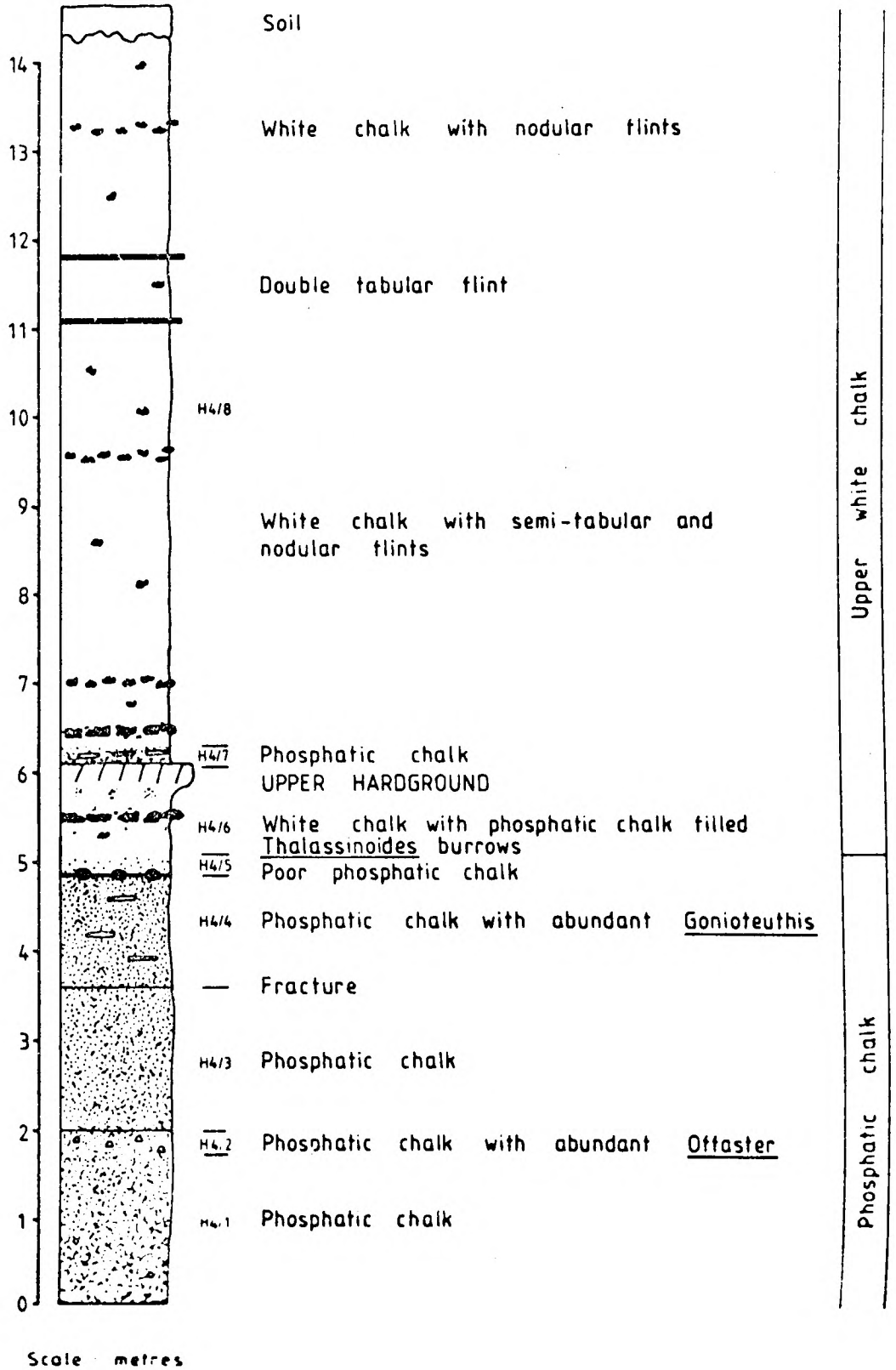


Fig. 2.77 Lithostratigraphy of the west-central section, NE quarry Hardivillers (Section 4).

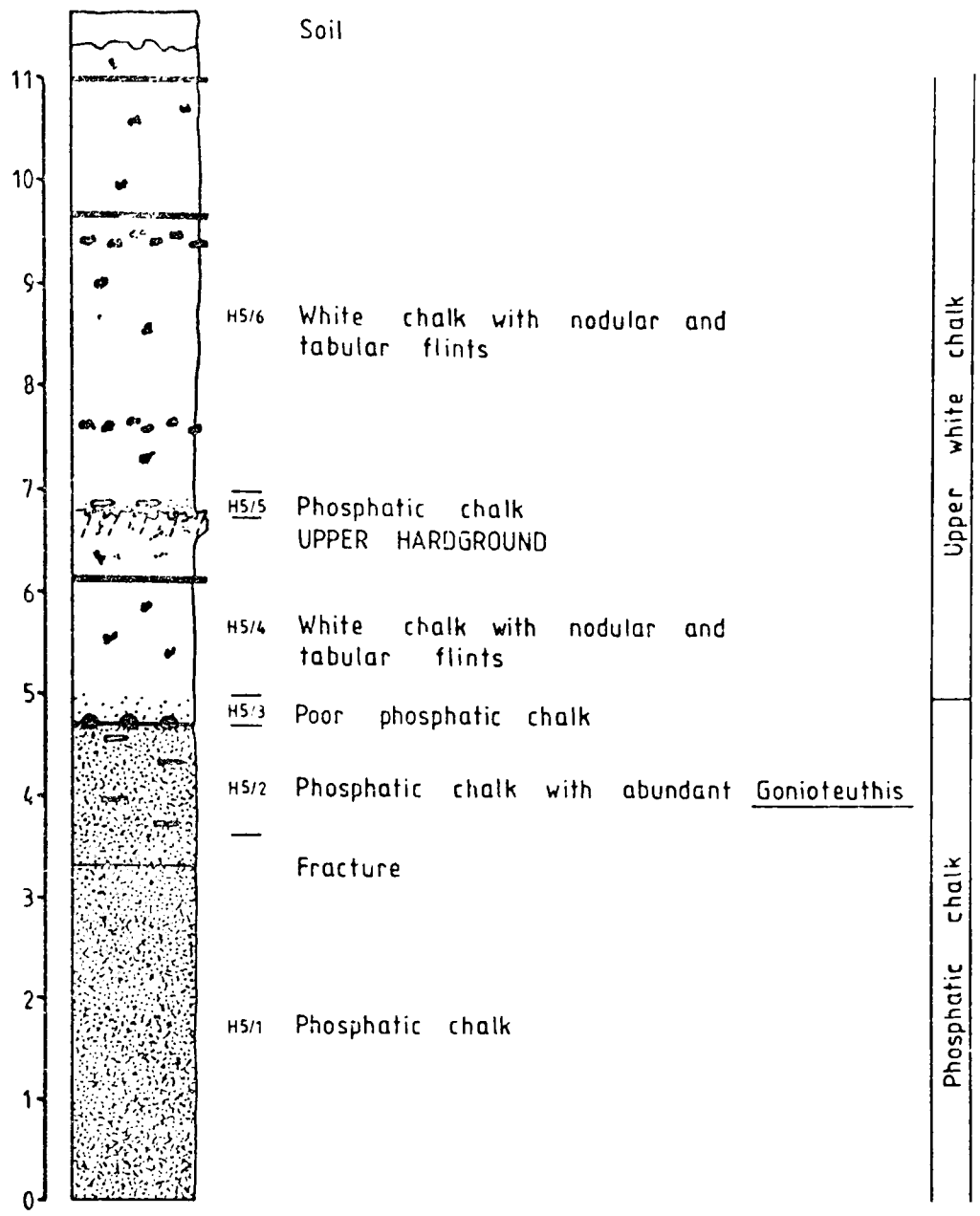


Fig. 2.78 Lithostratigraphy of the west section, NE quarry Hardivillers (Section 5).

from the Gonioteuthis Bed for statistical analysis (Chapter 4) was recovered from a section 10 m south of Section 5, on the SW side of the quarry.

The north quarry exposes a number of largely inaccessible sections through the uppermost phosphatic chalk and upper white chalk, but the SW quarry contains two more-readily examined exposures (Fig. 2.79). A tunnel entrance is situated in the SW corner of the quarry at the base of the ramp that links the north and SW quarries. Excellent exposure is present within the tunnel walls and at the base of the west face, by the side of the access ramp (Section 6; Fig. 2.80). The base of the tunnel coincides with the top of a strongly-lithified, phosphatized and phosphate skin coated hardground. The limited amount of hardground sediment collected indicates that it consists of a lithified and mineralized white chalk penetrated by phosphatic-chalk filled Thalassinoides burrows, and is therefore probably the basal hardground. The convolute hardground surface is overlain by a coarse phosphatized intraclast lag containing phosphatized phosphatic chalk intraclasts



Fig. 2.79 The main face of Hardivillers SW quarry, 1978. The numerals indicate the location of measured Sections 6 and 7. The scale (circled) is 1.75 m high.

up to 10 cm across. The basal lag is overlain by 1.65 m of rich phosphatic chalk

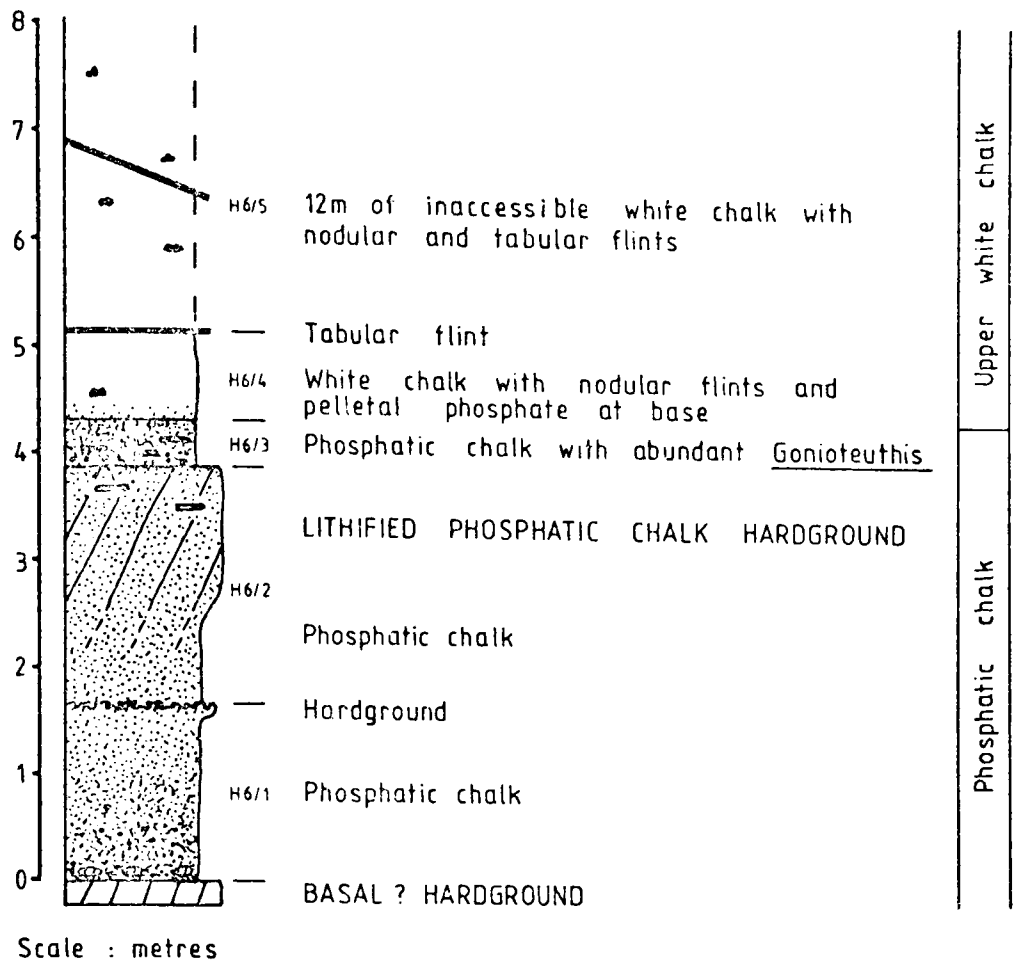


Fig. 2.80 Lithostratigraphy of the west section, SW quarry Hardivillers (Section 6).

(bed H6/1) the top of which is taken at the surface of a 20 cm thick nodular hardground consisting of a discontinuous irregular surface, underlain by limonite-stained, phosphatized phosphatic chalk nodules and overlain by a coarse phosphorite containing occasional Echinocorys and Gonioteuthis. This minor hardground is followed by 2.20 m of phosphatic chalk (bed H6/2) the top of which is intensely-lithified, limonite-stained and contains 'pyrolusite'-lined fractures and abundant Gonioteuthis ex gr. quadrata. The surface of the lithified unit is convolute, phosphatized, coated with a series of iridescent phosphate veneers, and penetrated by several generations of phosphate-skin lined, soft phosphatic-chalk filled Thalassinoides burrows (but shows no evidence of encrustation or boring). This bed is termed the Hardivillers Lithified Phosphatic Chalk Hardground. The stenomorphic nature of the upper portion of the burrow systems gives way to an idiomorphic morphology 60 cm below the hardground surface, despite the fact that lithification is discernible up to 1.40 m below. The hardground sediment is superficially a normal phosphatic chalk that has been hardened by the introduction of cement into the pore spaces of the micritic matrix. The hardground surface is overlain by 45 cm of rich phosphatic chalk containing large (up to 5 cm) phosphatic chalk intraclasts and abundant G. ex gr. quadrata (bed H6/3). The base

of the overlying bed (H6/4) is a limonitic-clay filled fracture that marks the top of the phosphatic chalk unit. The bed consists of a soft white chalk with nodular flints and occasional phosphatic-chalk filled burrows, particularly at its base. Its top is marked by the first tabular flint. The remainder of the upper white chalk consists of ~12 m of inaccessible, chalk-wash covered soft white chalk with abundant tabular and nodular flints (bed H6/5).

A second smaller section is visible 20 m east of the preceeding one, on top of a tunnel entrance that has been obscured by scree, and above the level of the exposed tunnel. The base of the section (Section 7; Fig. 2.81) exposes 1.30 m of rich phosphatic chalk with abundant G. ex gr. quadrata (bed H7/1). The pelletal

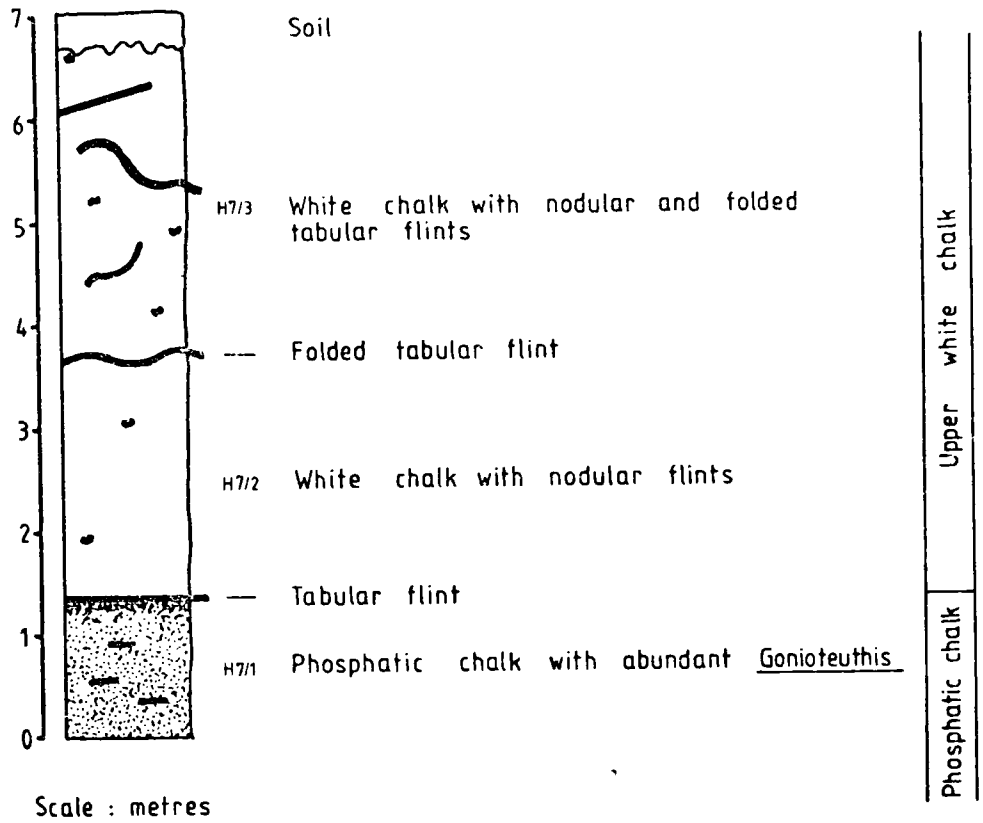


Fig. 2.81 Lithostratigraphy of the central section, SW quarry Hardivillers (Section 7).

phosphate content of the bed increases dramatically in the upper 10 cm. The top is planar and overlain by a tabular flint followed by 2.40 m of soft white chalk (bed H7/2) with nodular flints but no pelletal phosphate, even at its base. Such a sharp transition from phosphatic chalk to upper white chalk is unknown elsewhere in the quarry complex but has been noted at other localities (e.g. Faucouzy). The remainder of the section (bed H7/3) consists of white chalk with nodular, tabular and folded tabular flints.

Lithostratigraphical correlation (Fig. 2.82) is straightforward for the NE quarry, but is less certain when the SW quarry sections are included. The correlation diagram highlights a number of important features:

(1) there is considerable topography on the basal hardground,

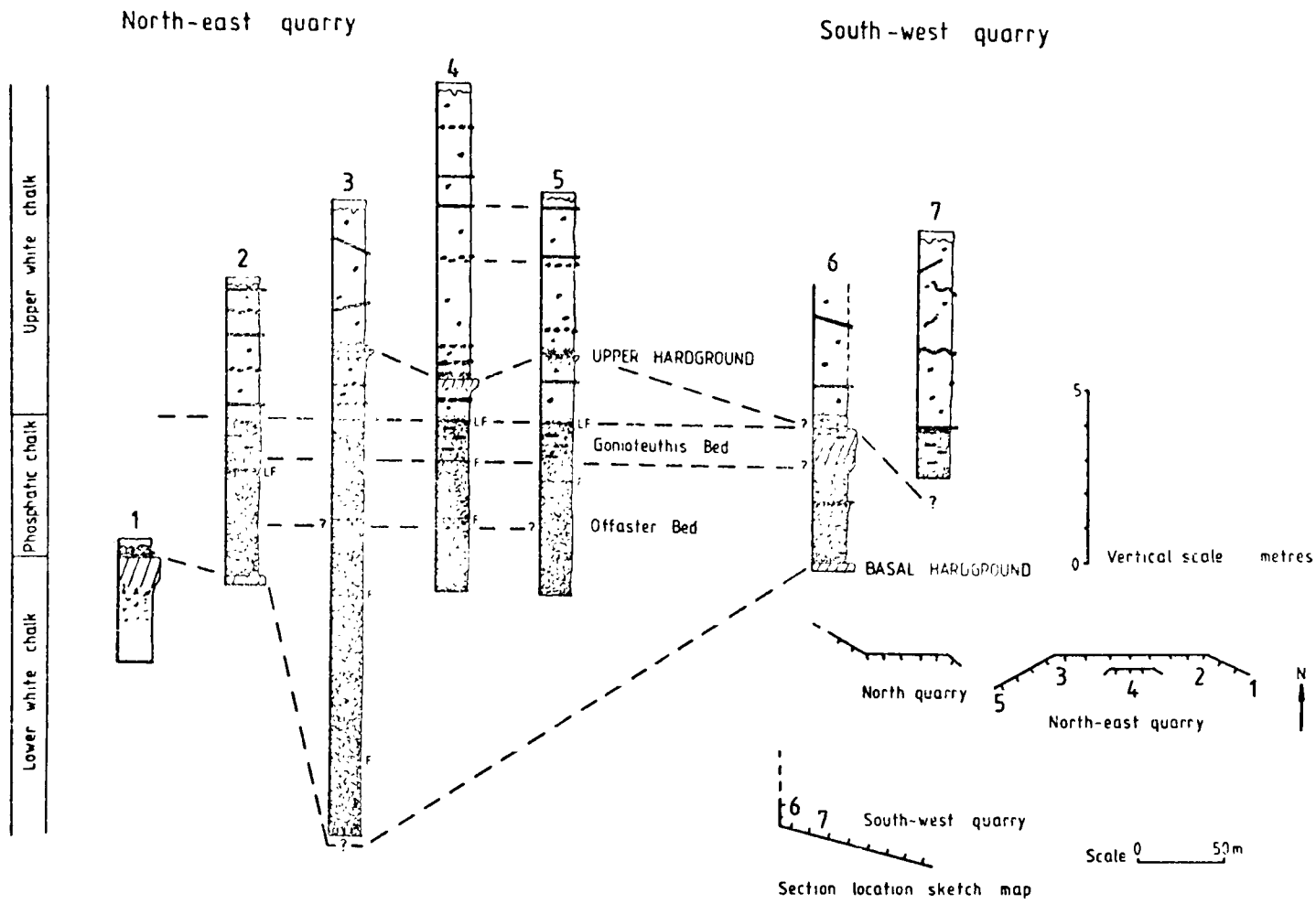


Fig. 2.82 Lithostratigraphical correlation diagram of Hardivillers quarries.

(2) there are substantial thickness variations in the phosphatic chalk (> 8 m) over relatively short (50 m) distances,

(3) the lowest phosphatic chalk becomes coarser as the thickness of the unit increases,

(4) a bed of abundant O. pilula - the Hardivillers Offaster Bed - can be recognised in the upper portion of the phosphatic chalk in all suitably exposed sections,

(5) a bed of abundant G. ex gr. quadrata - the Hardivillers Gonioteuthis Bed - occurs at the summit of the phosphatic chalk,

(6) an upper hardground, overlain by a bed of phosphatic chalk containing numerous G. ex gr. quadrata, occurs within the upper white chalk.

(7) in the NE quarry there is a positive correlation between development of the upper hardground and attenuation of the immediately underlying white chalk, suggesting that the upper hardground and the Lithified Phosphatic Chalk Hardground may be laterally equivalent,

(8) there are no laterally persistent horizons of flint in the upper white chalk.

Early work by De Mercey (1863, 1887) established that the white chalk underlying the phosphorite contained Micraster coranguinum and that the phosphatic chalk

was typified by Gonioteuthis ex gr. quadrata. Lasne (1892) later showed that Belemnitella appears in the uppermost phosphatic chalk and he considered that this, together with the occurrence of 'high zonal' forms of Echinocorys and large (5 - 6 cm) Pycnodonte vesicularis (Lamarck), indicated that the Hardivillers phosphorite was younger than that in the Doullens region (e.g. Beauval, Orville). The most comprehensive work to date on the macrofaunal biostratigraphy of a phosphatic chalk was undertaken by De Grossouvre (1894a, b, 1899, 1901, 1907) at Hardivillers, who recognised five units in the quarry:

(1) a lower white chalk with M. coranguinum and Actinocamax verus separated by a 'discordance' from,

(2) a lower phosphatic chalk containing M. coranguinum and A. verus,

(3) an intermediate phosphatic chalk containing Gonioteuthis ex gr. quadrata and Offaster pilula,

(4) an upper phosphatic chalk with G. ex gr. quadrata and Belemnitella and,

(5) an upper white chalk with G. ex gr. quadrata, Belemnitella and Micraster pseudoglyphus De Grossouvre.

He also records Echinocorys, Lopha semiplana, 'Ostrea' boucheroni Coquand, fragments of Scalpellum, Stereocidaris sceptifera and a fragment of 'Pachydiscus' leptophyllus Sharpe from the phosphatic chalk.

Recent work on the microfaunal succession (Tabatabaï, 1977; Monciardini in Blondeau et al., 1978) confirms the late Santonian to early Campanian age of the phosphatic chalk suggested by the macrofauna. The lower white chalk has not been dated using microfauna, but the lowest 4 m of phosphorite has been (Tabatabaï, 1977) assigned to the middle Santonian Biozone e and the overlying $1\frac{1}{2}$ m to Biozones e - f - the Santonian/Campanian boundary. The bulk of the remaining phosphorite is refered to the early Campanian Biozone g except for the uppermost 2 m which, in common with the upper white chalk, is regarded as being of Biozone h age. The succession is complicated, however, by the occurrence of a remanié Biozone e fauna within the phosphatic chalk of Biozones f - g age, elements of which appear remanié in Biozone h (Monciardini in Blondeau et al., 1978).

My present study of the macrofaunal zonation confirms the earlier work of De Grossouvre (op cit.) except for his record of Belemnitella mucronata Schlott-

heim which is regarded as being a misidentification of B. praecursor Stolley (see Chapter 4 for more details). A number of diagnostic species of Echinocorys were recorded that confirm the general biostratigraphical scheme seen at Beauval. E. elevata, characteristic of the M. testudinarius (and possibly the U. socialis) Zone was collected from the middle of the phosphatic chalk. E. truncata, typical of the base of the 'abundant O. pilula' Subzone of the O. pilula Zone occurs in the Offaster Bed but E.cf. depressula was recorded from the Gonioteuthis Bed. The occurrence of E. cincta within the Gonioteuthis Bed, 40 cm below the top of the phosphatic chalk, suggests a correlation with the E. cincta level of Brydone (1914) in southern England. Statistical analysis of a 'population' of Gonioteuthis ex gr. quadrata from the Gonioteuthis Bed demonstrates that the subspecies present is G. quadrata quadrata (Blainville) (Chapter 4).

The macrofaunal zonation produces the same problems as those found at Beauval, i.e. the absence of Marsupites testudinarius (and at Hardivillers, Uintacrinus socialis) in a succession where the microfaunal zonation and the occurrence of E. elevata indicate that the two zones should be present.

2.8.2 Hédencourt (St André-Farivillers of authors) (Oise) x 595,46 y 209,91 z 125 ($0^{g}.069$W $55^{g}.099$)

The village of Hédencourt lies on the D61, 5 km south of Breteuil. A small early Campanian outcrop is situated on the hillside 500 m west of the adjoining village of St André-Farivillers, but this is apparently unphosphatic (Blondeau et al., 1978). However, 800 m due east of Hédencourt a deposit of phosphorite was located within the clay-with-flints that overlie the Santonian white chalk in that area (De Mercey, 1907). The deposit is mentioned by Leriche (1911), who lists an extensive elasmobranch fauna but does not record any calcitic fossils, suggesting that the deposit was a secondarily-enriched phosphorite filled solution pipe similar to those worked elsewhere in the region (see below).

2.8.3 Gerberoy (Oise) x 563,50 y 204,49 z 195 ($0^{g}.560$W $55^{g}.435$)

The village of Gerberoy lies 10 km NE of Gournay-en-Bray and 20 km NW of Beauvais. A number of small, isolated pockets of primary and secondary phosporite were located in the general area (Lemoine, 1912) but the only site that is recorded lies on the north side of the D143, 450 m NE of "la Briqueterie" and 1250 m NW of Gerberoy.

The Campanian outcrop is restricted to pockets of phosphatic chalk that contain Gonioteuthis ex gr. quadrata and Lopha semiplana (Lemoine, 1912) and are underlain by Santonian white chalks.

2.8.4 Hanvoile (Oise)

The village of Hanvoile lies along the side of the D95, 12 km ENE of Gournay-en-Bray and 16 km NW of Beauvais. The Pays-de-Bray structure exposes sequences from late Jurassic to late Cretaceous age (De Mercey, 1907) but the youngest white chalk in the area is Santonian. Despite the lack of Campanian outcrop, three phosphorite workings were situated in the region (De Mercey, 1907): Subterranean workings on the south side of "Guillemont Hill", 500 m NE of the D95: x 567,95 y 201,20 z 170 ($0^g.492W$ $55^g.105$), a quarry on the west side of "St Simon's Hill", 200 m NE of the D95: x 568,31 y 200,68 z 180 ($0^g.486$ $55^g.052$) and, a quarry on the SE side of "St Simon's Hill", 150 m NE of the D95 and 300 m NW of the D22: x 568,72 y 200,31 z 180 ($0^g.480W$ $55^g.015$).

Generally, the phosphorite occurred in isolated pockets up to 3 m deep, but occasional larger solution pipes 5 - 15 m wide and 7 - 8 m deep (and one example 15 m deep) yielded 25,000 - 30,000 tonnes of secondary phosphorite by 1907. All of the deposits rested on early Santonian white chalk in areas of thick clay-with-flints deposits. The decalcified nature of the phosphorite, and therefore the lack of diagnostic macrofauna, means that a late Santonian to early Campanian age can only be infered by analogy to other phosphatic chalks.

2.8.5 Le Détroit (Oise) x 572,20 y 197,86 z 171 ($0^g.427W$ $54^g.977$)

The hamlet of le Détroit is situated on the D1, 1 km SSW of la Neuville-

Vault, 16 km east of Gournay-en-Bray and 11 km WNW of Beauvais. The site is only known from the early twentieth century mapping of the area (Thomas, 1914) which records a deposit of phosphorite in an area of Coniacian chalk (Thomas, 1914; Blondeau et al., 1974). It seems likely that the exposure was limited to a solution pipe similar to those seen further north-west.

2.9 Ribemont to Faucouzy

The villages of Ribemont and Faucouzy (Aisne) lie between the Canal de la Sambre à l'Oise and the river Péron, 15 km SE and 26 km ESE of St Quentin respectively. They are situated within a broad tract of land that contains extensive exposures of Coniacian to Santonian soft white chalks, only intermittently obscured by Tertiary and Quaternary deposits (Gosselet, 1901c; Goguel, 1964; Mathieu et al., 1971). The bulk of the outcrop is unphosphatic but phosphorites have been worked in the vicinity of the two villages.

2.9.1 Ribemont (Aisne)

The village of Ribemont is situated at the junction of the D13, D58 and D12 on the east bank of the canalised portion of the river Oise. The phosphatic chalk of the region has been described by Rabelle (1893, 1902) and Gosselet (in Rabelle, 1893; 1901b). The phosphorites consist of a number of phosphatized-intraclast rich, pyritic-nodule bearing phosphatic chalks, intercalated within a predominantly soft white chalk succession. The phosphatic beds are well-known for their abundance of belemnites, particularly Gonioteuthis ex gr. quadrata, which are termed "dents de loup" by the farm labourers of the area. One of the upper intercalations is commonly underlain by a strongly-lithified hardground that can be traced intermittently throughout the region.

A quarry section at Sénercy, a hamlet situated on the D13, 2 km SW of Séry-lès-Mézières and 6 km SW of Ribemont, exposed (Gosselet in Rabelle, 1893) a 1 m thick bed of phosphatized-intraclast rich white chalk intercalated within a sequence of soft white chalks: x 188,14 y 338,80 z 75 (1°184E 55°296). The intra-

clast bed was truncated by a ~3 m wide scour hollow the floor of which had been lithified, bored and overlain by a lag of reworked phosphatized-intraclasts from the primary intraclast bed (Fig. 2.83). The exposure provides, therefore, clear evidence of the connection between erosion and hardground genesis.

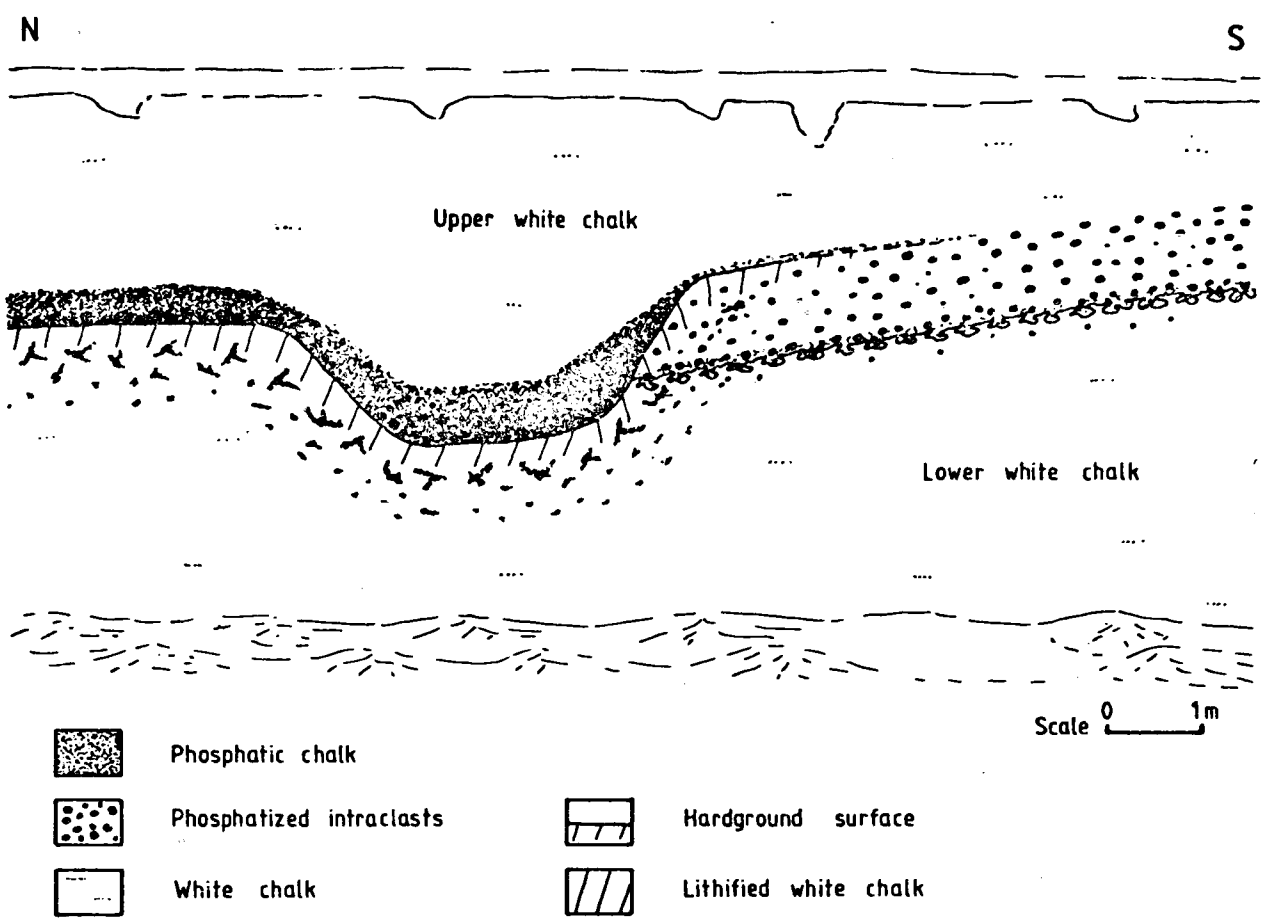


Fig. 2.83 Sénercy quarry (Aisne) in 1893. Redrawn from Gosselet (in Rabelle, 1893).

A quarry situated between Ribemont and Surfontaine exposed (Rabelle, 1902) a 60 cm thick bed of poorly phosphatic chalk containing G. ex gr. quadrata and Belemnitella underlain by 1 m of soft white chalk with G. ex gr. quadrata and overlain by 8 m of white chalk containing Belemnitella, Echinocorys and a small form of G. ex gr. quadrata (possibly G. quadrata gracilis (Stolley)). The presence of this last fauna suggesting that the exposure was in chalks stratigraphically higher than the other phosphorites outcropping in the area.

A phosphatic chalk quarry at Séru farm (Fig. 2.84), 4 km east of Ribemont: x 196,46 y 341,91 z 115 ($1^{g}.308$E $55^{g}.334$), exposed (Gosselet, 1901b) a lower white chalk with a 30 cm thick lithified top overlain by 20 cm of phosphatized-intraclast lag and 3 m of phosphatic chalk (capped with an 8 cm thick secondarily-enriched phosphate sand), and 6 m of upper white chalk. The phosphorite was deposited in a SE - NW oriented cuvette at the margins of which the phosphatic chalk thinned to a few centimetres. A small exposure 200 m west of the quarry

exposed a 1 m thick bed of heterogenous, slightly phosphatic chalk containing numerous oysters and Gonioteuthis. Phosphatic chalk exposures are also known from the vicinity of Séry-lès-Mézières, and Villers-le-Sec, 4 km SW and SE of Ribemont respectively.

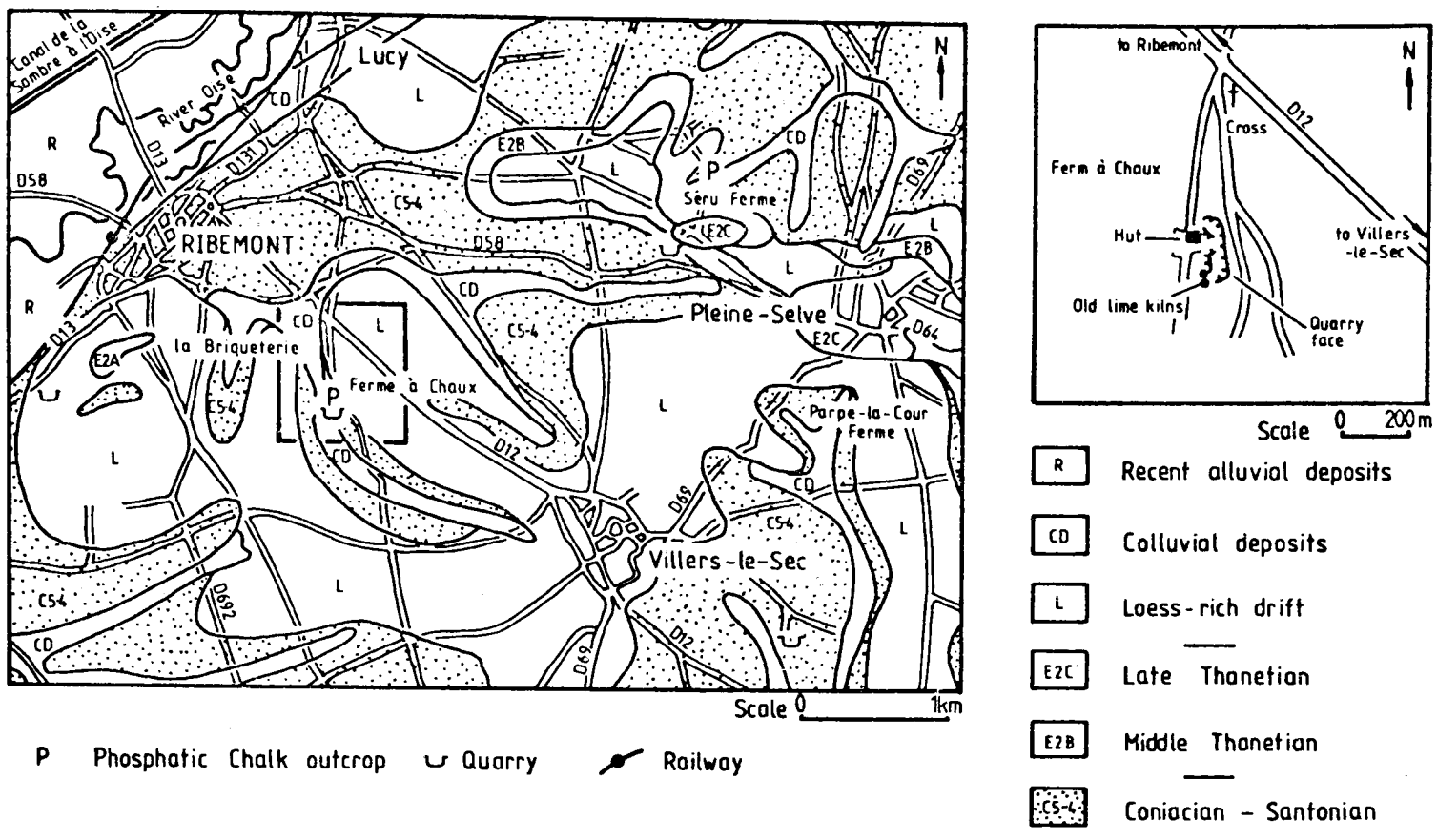


Fig. 2.84 Geological and location sketch maps of Ribemont quarry (Aisne). (Geology after Dollé and Dollé, 1939).

An abandoned quarry: x 193,47 y 340,63 z 90 ($1^g.263$E $55^g.319$) situated on the west side of the D12, 2 km SE of Ribemont (Fig. 2.84), exposes a section containing three beds of phosphatic chalk. The basal 6.50 m (Fig. 2.85) consists of a soft white chalk with two prominent horizons of large goethitic nodules (bed R1/1). Chocolate-brown phosphatized intraclasts, commonly with goethitic cores, occur throughout the succession, but are particularly abundant in the lower horizon of goethitic nodules, where they occur with numerous fragments of phosphatized ventriculitid sponge. Light-brown phosphatic-chalk filled burrows become more prominent towards the top of the bed. The blocky weathering style of the overlying 90 cm of phosphatic chalk distinguishes it from the surrounding white chalks. The bed (R1/2) is only poorly phosphatic and contains few intraclasts. It has a burrowed base and transitional top. The sediment contains a high proportion of fish debris, thin-shelled oysters and fragments of silicified Platyceramus, and scattered goethitic nodules. The phosphatic component is predominently concentrated in burrow fills and patches produced by winnowing. The first phosphatic chalk is

overlain by 2.30 m of white chalk (R1/3) containing numerous thin-shelled oysters

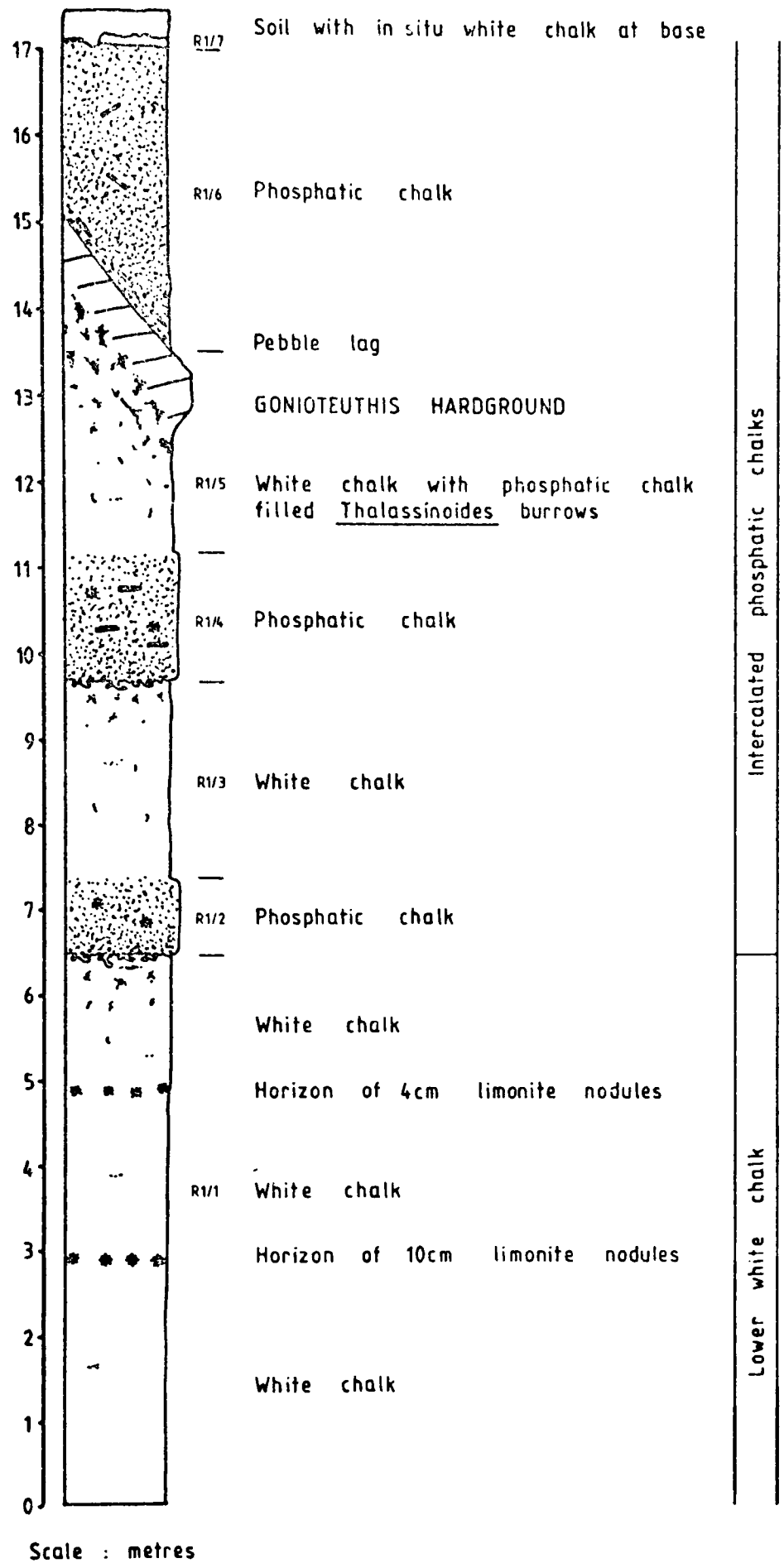


Fig. 2.85 Lithostratigraphy of Ribemont quarry (Aisne).

and patches of phosphatic sediment throughout. The overlying second phosphatic chalk (bed R1/4) is thicker (1.50 m) than the first and contains a higher proportion of calcarenite and pelletal phosphate. Intense bioturbation at the base of the unit has resulted in the development of a burrowed-out texture containing 0.5 - 3.0 cm, rounded - subangular, limonite-stained, weakly-lithified patches of white chalk surrounded by a phosphatic chalk matrix. The rounding and mineralization

of these patches may be related to the activity of burrowing organisms that have caused the isolation and rotation of small portions of white chalk (Fig. 2.86). The matrix, and the ~2 cm of sediment that directly overlies this pseudo-conglomerate is rich in 0.2 - 2.0 cm sponge-bored phosphatized intraclasts, silicified Platyceramus fragments, thin-shelled oysters and Gonioteuthis guards. The pelletal

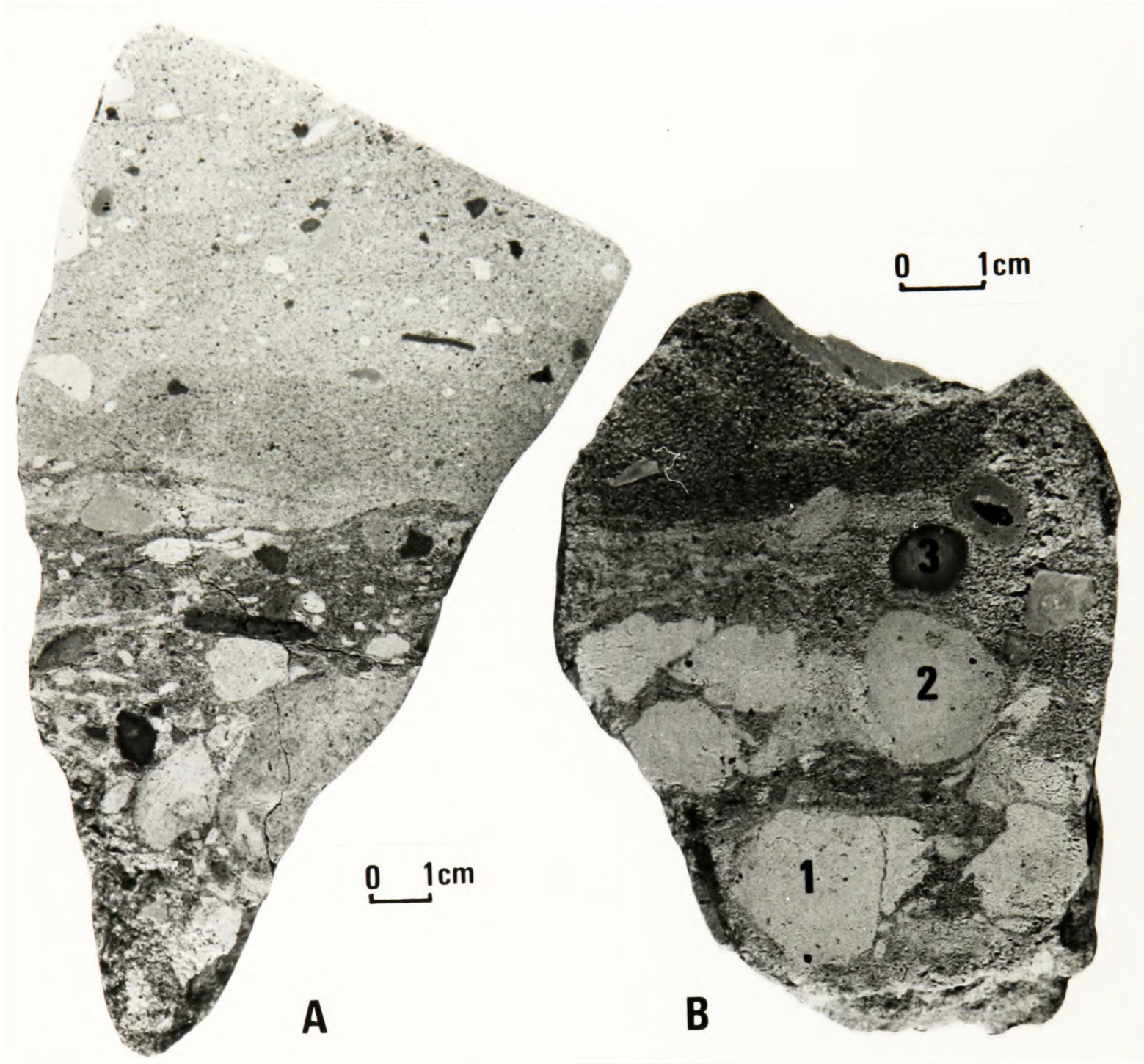


Fig. 2.86 Base of the second phosphatic chalk (bed R1/4), Ribemont quarry (Aisne). A. Lower 17.5 cm of the bed illustrating the high pelletal phosphate content of the lowest phosphatic chalk and the abundance of small subangular - rounded white chalk intraclasts throughout the unit. Polished block. B. Burrowed-out base of the bed showing the stages of isolation (1), rounding (2), and subsequent phosphatization (3) of patches of white chalk due to the activities of burrowers.

phosphate content of the bed drops at the planar top of this lower unit (Fig. 2.86), above which the phosphorite contains a high proportion of micrite, numerous 1 - 3 mm phosphatized intraclasts and 0.1 - 1.0 cm white chalk intraclasts, fish debris and thin-shelled oysters. The overlying white chalk (bed R1/5) also

contains scattered phosphatized intraclasts and oyster fragments. It varies in thickness from >3.50 to 1.70 m since it is truncated by a bowl-shaped, phosphatic-chalk filled depression (Fig. 2.87) the base of which consists of a 40 cm thick lithified chalk penetrated by phosphatic-chalk filled Thalassinoides burrows - the Ribemont Gonioteuthis Hardground. The top of the hardground is made up of phosphatized and bored cobbles up to 10 cm across that have been cemented by a pelletal phosphate rich matrix. The convolute, occasionally filigree surface of the hardground has been phosphatized a dull light-brown, bored by clionid sponges, and is encrusted with Spondylus. The overlying ~2 m of phosphatic chalk is an inhomogenous mixture of white chalk and richly phosphatic chalk containing rounded - subangular 0.1 - 1.0 cm phosphatized intraclasts. The bed (R1/6) lacks any number of distinct burrows although it is clearly intensely bioturbated. It yielded large numbers of Gonioteuthis ex gr. quadrata, thin-shelled Gryphaeostrea and Spondylus as well as Belemnitella praecursor, Offaster pilula (a phosphatized internal mould and a large (2 cm) unmineralized test), Echinocorys, Platyceramus, brachiopods, cirripedes, serpulid tubes and elasmobranch teeth. The fauna is predominantly concentrated at the base of the bed which decreases in grain size towards the top where it is overlain by 10 cm of white chalk. Both the hardground and the overlying phosphatic chalk have been severely shattered by weathering. Laterally (Fig. 2.87), two faults cut the exposure the most southerly of which has exposed a second, planar outcrop of the Gonioteuthis Hardground although in this area the overlying phosphorite is poorer in intraclasts and fossil material.

Faunal records from the phosphatic chalk of the Ribemont area include Actinocamax verus, G. ex gr. quadrata, Belemnitella, Belemnellocamax ex gr. grossouvrei, Lopha semiplana and elasmobranch teeth (Rabelle, 1893; 1902; Gosselet, 1901b; Leriche, 1908), all of which (excluding B. ex gr. grossouvrei) have been recovered by me from Ribemont quarry. Actinocamax verus is common in the lower white chalk (bed R1/1), has not been found in the first phosphorite or the overlying white chalk, but is replaced by Gonioteuthis in the second phosphorite and above. Gonioteuthis of a form transitional between G. quadrata quadrata and G. quadrata gracilis are abundant in the phosphatic chalk that overlies the Ribemont Gonioteuthis Hardground where they are associated with Belemnitella praecursor,

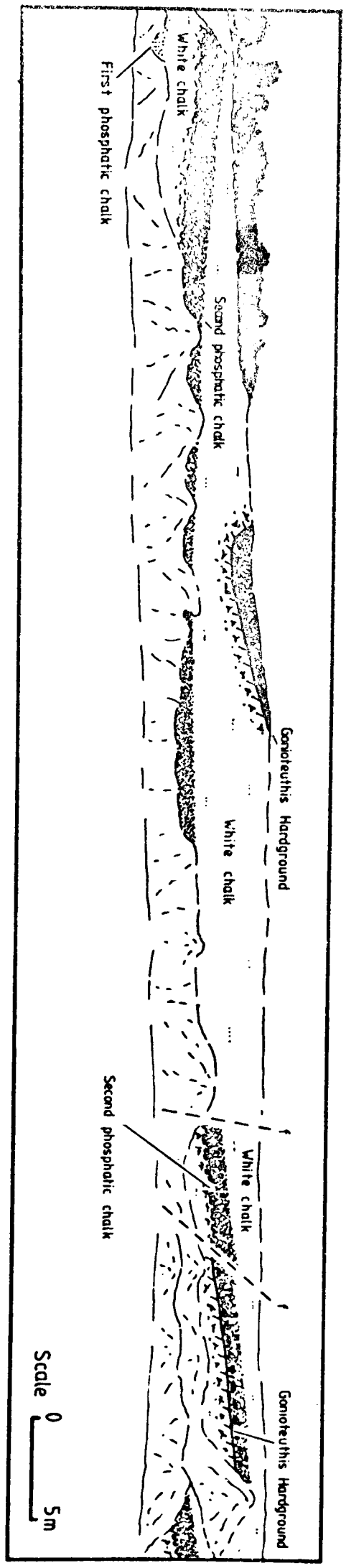


Fig. 2.87 Ribemont quarry, upper level, May 1977. f = fault.

Offaster pilula and an undiagnostic form of Echinocorys.

The mutual exclusiveness of A. verus and G. ex gr. quadrata is the same as seen elsewhere in the phosphatic chalk lithofacies. The zonal crinoids of the middle to late Santonian (Uintacrinus socialis and Marsupites testudinarius) are absent, so the presence of sediment of that age cannot be proven. The occurrence of O. pilula in the youngest phosphorite suggests the presence of that Zone (although O. pilula ranges into the overlying G. quadrata Zone). In conclusion, the macrofaunal evidence suggests that the beds are of early Santonian to early Campanian age.

2.9.2 Faucouzy (Aisne)

The village of Faucouzy lies at the junction of the D26 and D58, 600 m east of the N367. The chalk of the region is generally unphosphatic but an extensive quarry situated on the north side of the D58, 1750 m WNW of the village (Fig. 2.88) exposes several levels of phosphatic chalk. The quarry was worked intensively by the Germans during the First World War (Goguel, 1964) but has subsequently been converted into a motorcross circuit. The complex consists of two main quarries, a western quarry that lies by the side of the D58: x 691,75 y 233,63 z 129 ($1^g.416$E $55^g.328$) and a NE quarry that is situated 500 m north of the road: x 692,07 y 234,07 z 127 ($1^g.421$E $55^g.331$). The site has been considered by several authors (Goguel, 1964; Mathieu et al., 1971; Delattre et al., 1973; Devries et al., 1974) none of whom describe the lithostratigraphy of the deposit.

The majority of the faces in the western quarry are badly degraded but two 40 cm thick beds of calcarentic phosphatic chalk with burrowed bases and transitional tops and containing Gonioteuthis (?)granulata and elasmobranch teeth, occur near the top of the section. The NE quarry, on the other hand, exposes four sections containing phosphatic chalks. As it enters the NE quarry, the main path that joins the two quarries passes through a narrow cutting which displays two well-exposed, contrasting sections through the summit of a rich phosphatic chalk and the overlying soft white chalk. The western section (Section 1; Fig. 2.89) exposes 3.50 m of deep chocolate-brown rich phosphatic chalk (bed F1/1) at its

base. This contains a high proportion of coarse (1 mm) pelletal phosphate and 1 - 5 mm phosphatized intraclasts and bioclasts concentrated in winnow patches and burrow fills, and occasional goethitic nodules. The size and proportion of

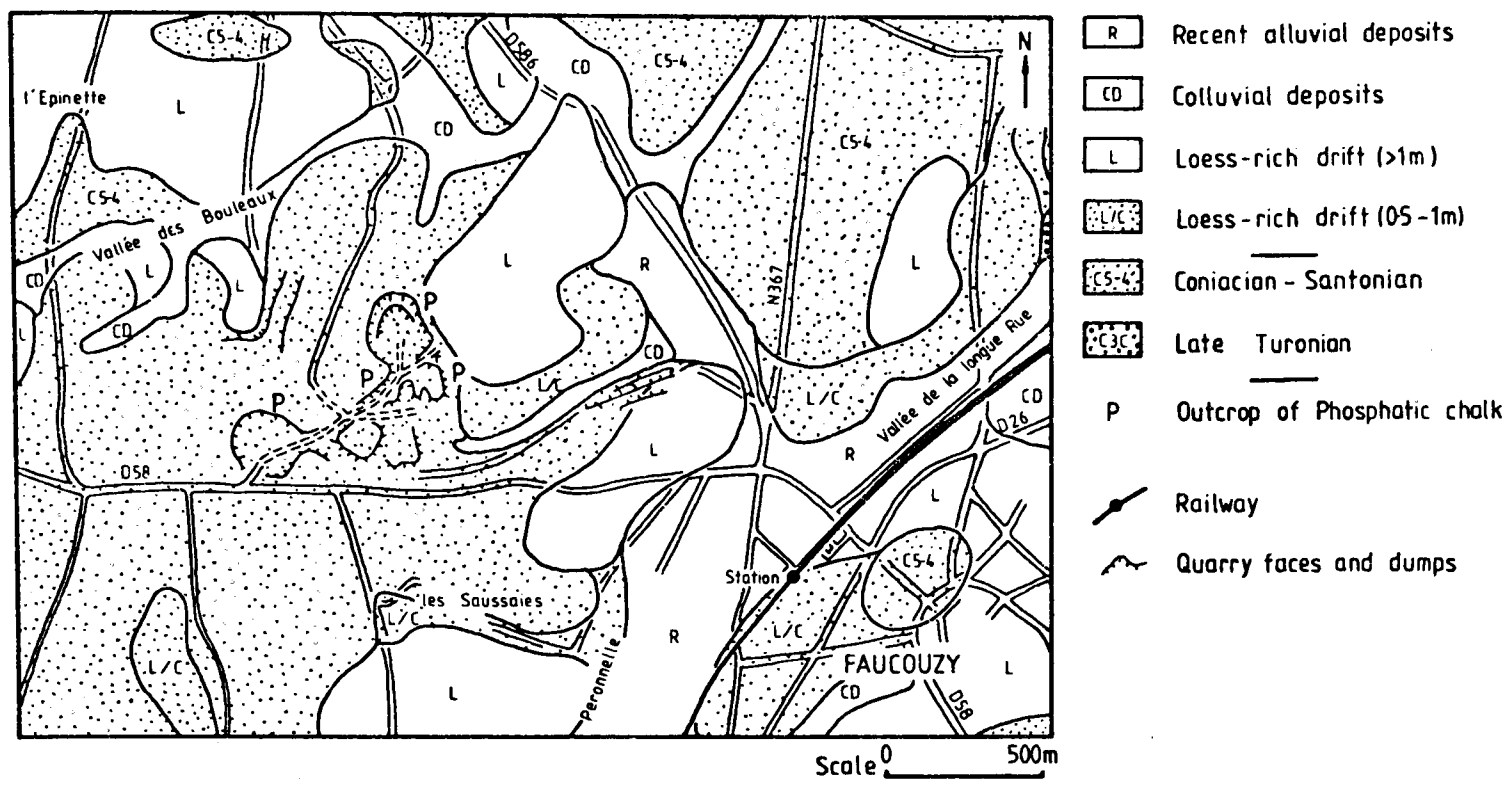


Fig. 2.88 Geological and location map of Faucouzy quarry. Geology from Mathieu et al. (1971).

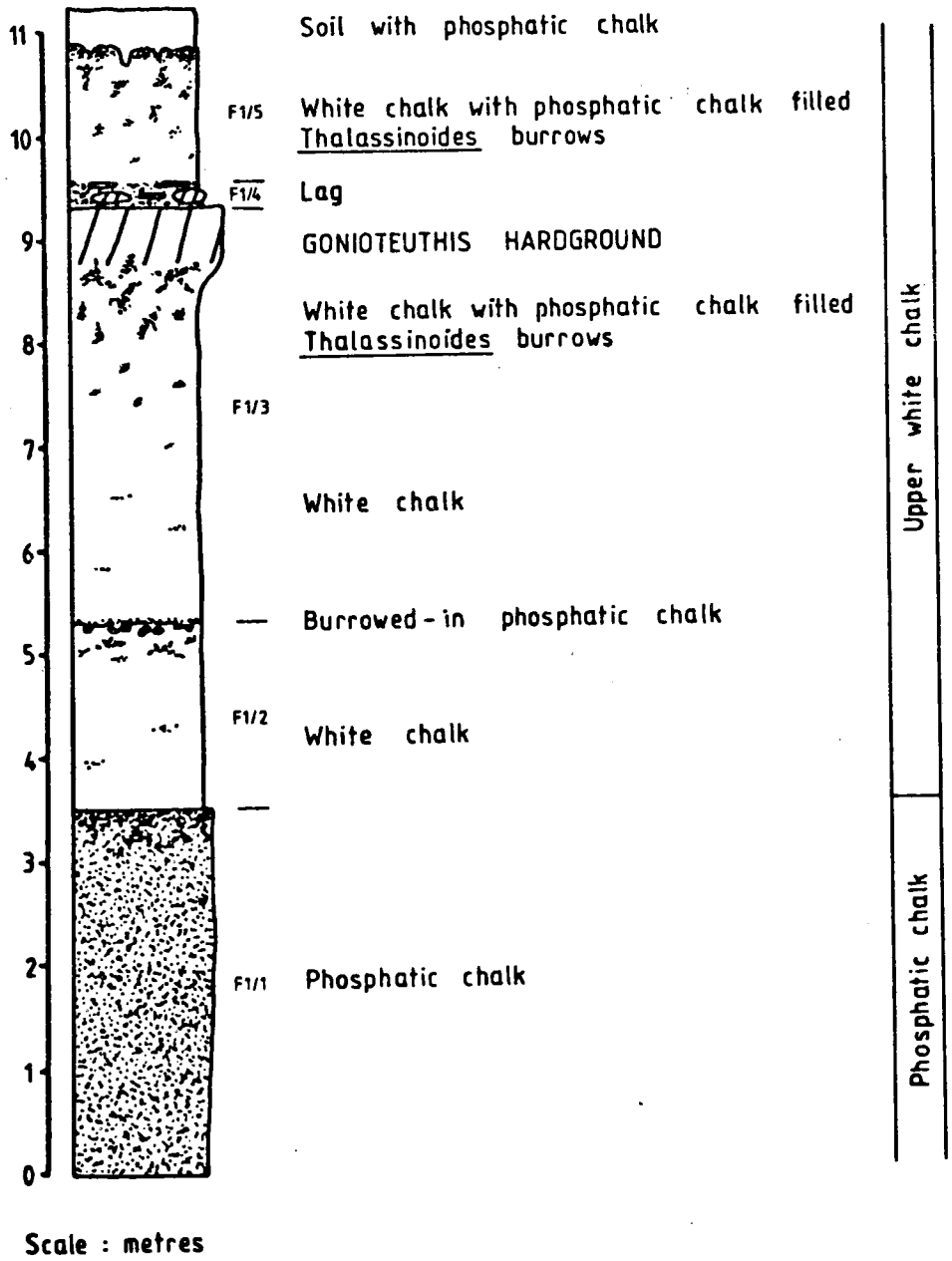


Fig. 2.89 Lithostratigraphy of the SW section, NE quarry Faucouzy (Section 1).

intraclasts increases towards the top of the bed reaching a maximum ~5 cm below the top where 0.2 - 1.0 cm intraclasts and fragments of thin-shelled oyster are abundant. The uppermost 5 cm of the bed contains fewer large intraclasts and very little micrite, this richly phosphatic summit (Fig. 2.90) being burrowed down into the phosphorite below. The top of the bed is sharp and planar (Fig. 2.90) and phosphate is virtually absent in the overlying soft white chalk. Scattered



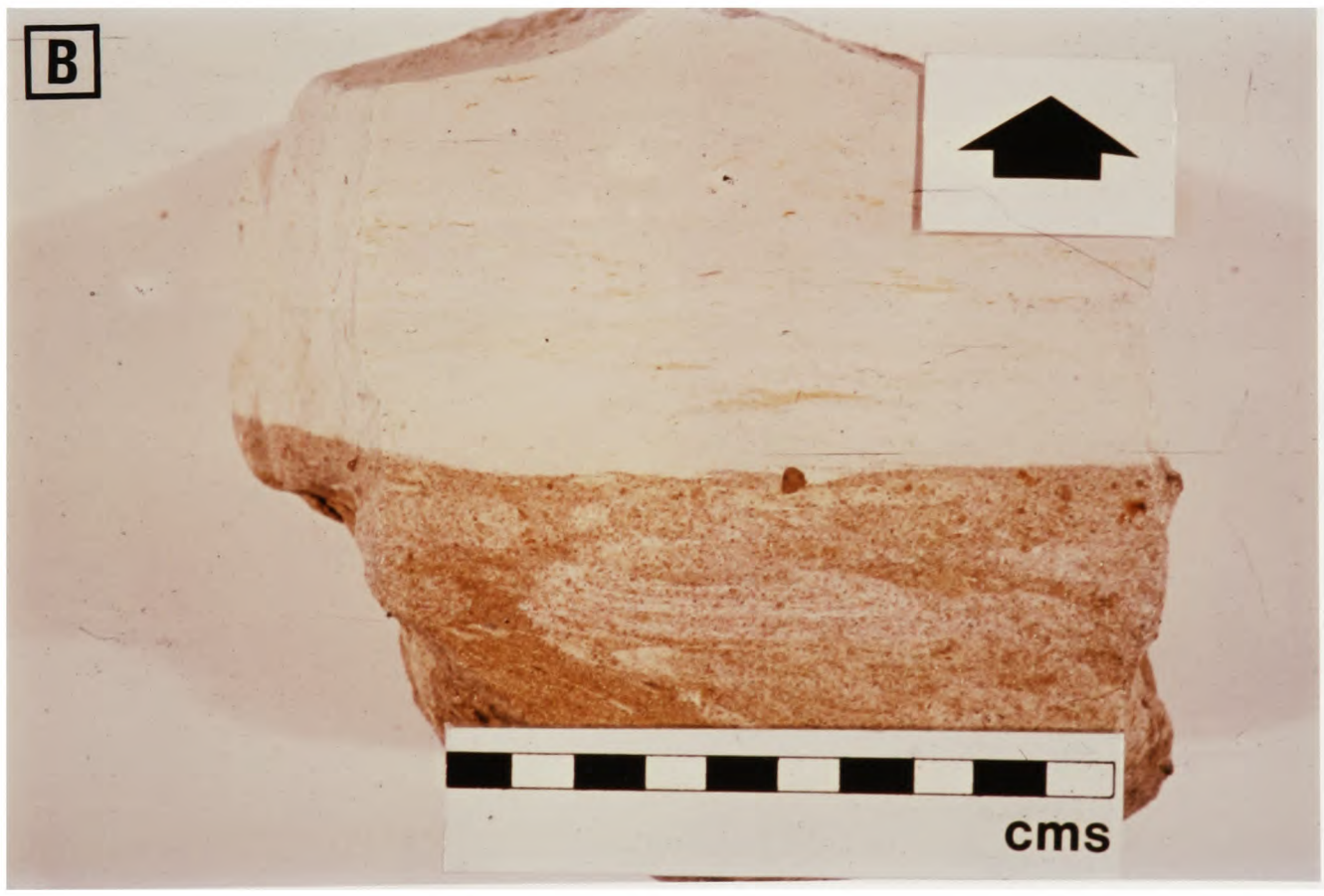


Fig. 2.90 Junction of the phosphatic chalk and the overlying soft white chalk, SW section, NE quarry Faucouzy.
A. General view showing the increased proportion of pelletal phosphate in the uppermost 5 - 10 cm of the phosphatic chalk. This rich phosphorite has been carried down into the underlying sediment by a Thalassinoides burrow system.
B. Close-up of the contact.

large (1 - 2 cm) Thalassinoides burrows mix the two contrasting sediment types but other bioturbation is totally absent. Rinsing wet polished faces of slabbed specimens with acetone reveals that the basal sediment of the overlying white chalk (bed F1/2) contains ~20% small (0.5 - 5.0 mm) rounded - subangular white chalk intraclasts, as well as the limonite-stained phosphatic chalk wisps and abundant thin-shelled oyster debris that occur throughout the bed. The top of the bed is marked by a prominent level of burrowed-in yellow-brown phosphorite overlain by 4 m of soft white chalks similar to those below (bed F1/3), the top of which is taken at a hardground surface - the Faucouzy Gonioteuthis Hardground. This is penetrated by a phosphatic-chalk filled Thalassinoides system which carries phosphorite into the upper portion of the bed. The limonite-stained hardground-sediment contains several percent of pelletal phosphate and phosphatized intraclasts. It is penetrated by an idiomorphic Thalassinoides system with limonitic walls that has been subsequently infilled by a Chondrites-burrowed, phosphatic white chalk similar to the hardground sediment but containing a higher proportion of 1 - 2 cm, rounded - subangular, bored phosphatized intraclasts and fragments of oyster. A later stenomorphic Thalassinoides system with strongly-phosphatized walls has reexcavated the earlier system and has been infilled with a soft, poorly phosphatic chalk. Manganese oxides are concentrated along fracture planes in the more intensely lithified portions of the hardground. The hardground top shows appreciable lateral variation; in some areas it consists of a bed of phosphatized intraclasts that has been cemented by patches of lithified white chalk and is penetrated by large numbers of phosphate-skin coated stenomorphic Thalassinoides to form an open network of cemented intraclasts and soft phosphatic-chalk filled void space. Elsewhere, the intraclasts are in closer contact and are cemented by phosphatized white chalk and iridescent phosphate veneers. Following cementation, they have been intensely bored by several generations of polychaete worm. These borings have phosphatized walls, are lined with shiny phosphate skins and are infilled by a soft poorly phosphatic chalk. The entrances to the borings have been sealed-off by the induration and mineralization of a surface plug of this sediment that has been further coated by a final continuous blanket of iridescent phosphate veneers, a process which is commonly accompanied by encrustation with

'Terebella' phosphatica. In other areas, the hardground top is difficult to delimit, but is overlain by numerous 0.5 - 5.0 cm diameter phosphatized intraclasts that commonly contain soft-sediment filled worm and bivalve borings, and portions of stenomorphic Thalassinoides systems, the surfaces of which have been sealed by surface-inwards cementation and mineralization of the fill. Some nodules exhibit phosphatized and phosphate-skin coated flat faces that may be attributed to synsedimentary fracturing of the hardground surface; others are covered by reticulate scratch marks. The fauna associated with the intraclasts is dominated by Gonioteuthis ex gr. quadrata and phosphatized fragments of ventriculitid sponge, but also includes elasmobranch teeth, cidarid spines and encrustation of the nodules by pycnodonteine oysters, octacoral holdfasts and 'T'. phosphatica.

The overlying 10 cm thick phosphatic chalk (bed F1/4) contains numerous large intraclasts at its base, and 1 - 5 mm phosphatized intraclasts, oyster debris and a high proportion of micrite throughout. The bed is strongly bioturbated by a number of indistinct burrow types that include meniscus-filled varieties. White chalk intraclasts up to 1 cm across (but more commonly 2 - 5 mm in diameter) become more prominent upwards. The top of the unit is sharp and planar and thus similar to the junction seen lower in the section. Small (1 - 3 mm) white chalk intraclasts are again present in the basal portion of the $1\frac{1}{2}$ m thick overlying white chalk (bed F1/5). This final bed contains an increasing abundance of phosphatic-chalk filled Thalassinoides towards its top, indicating the former presence of a further level of phosphatic chalk that has been subsequently removed by erosion.

A section taken 100 m NE (Section 2; Fig. 2.91) of that described previously does not include the Faucouzy Gonioteuthis Hardground, since its southerly dip ($\sim 5^{\circ}$) causes it to leave the exposed faces ~20 m NE of Section 1. The uppermost 70 cm of the rich phosphatic chalk is exposed at the base of the section, but the remainder of the succession consists predominantly of soft white chalks with scattered thin-shelled oysters and poorly-phosphatic chalk filled burrows and winnows, particularly towards the base. A slightly richer horizon of phosphate occurs 3.10 m above the base of the white chalk, and a 40 cm thick bed of poorly phosphatic chalk containing abundant oyster and fish debris lies 6.70 m above.



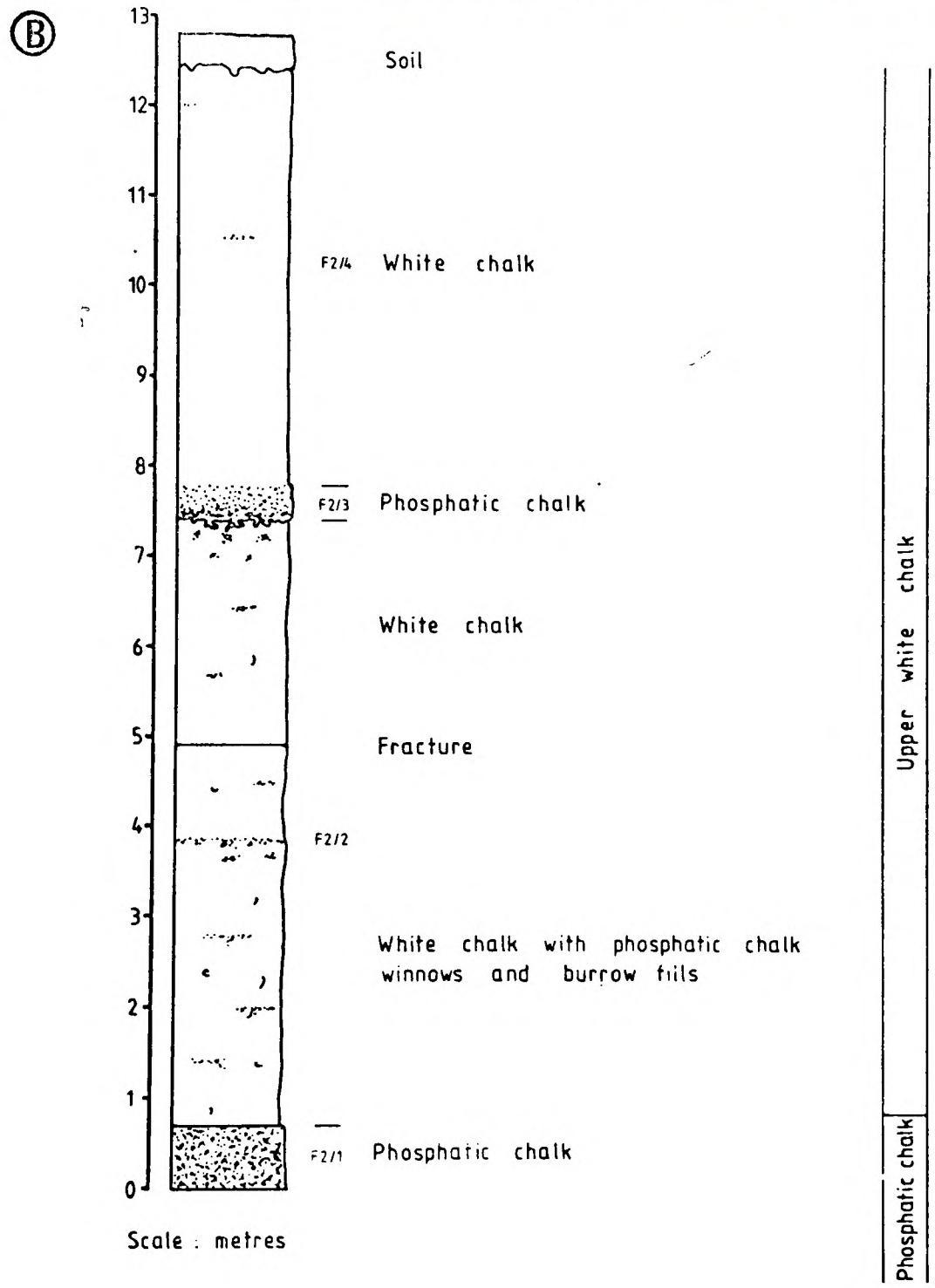


Fig. 2.91 Lithostratigraphy of the northern section (100 m NE of Section 1), NE quarry Faucouzy. A. General view of the exposure. The second phosphatic chalk (F2/3) is clearly visible in the face (arrowed). The scale (circled) is 1.75 m high. B. Sediment log.

A third section (Section 3; Fig. 2.92) taken at the NE corner of the quarry complex is badly obscured, but exposes 2 m of phosphatic chalk 8.50 m from the base of the section.

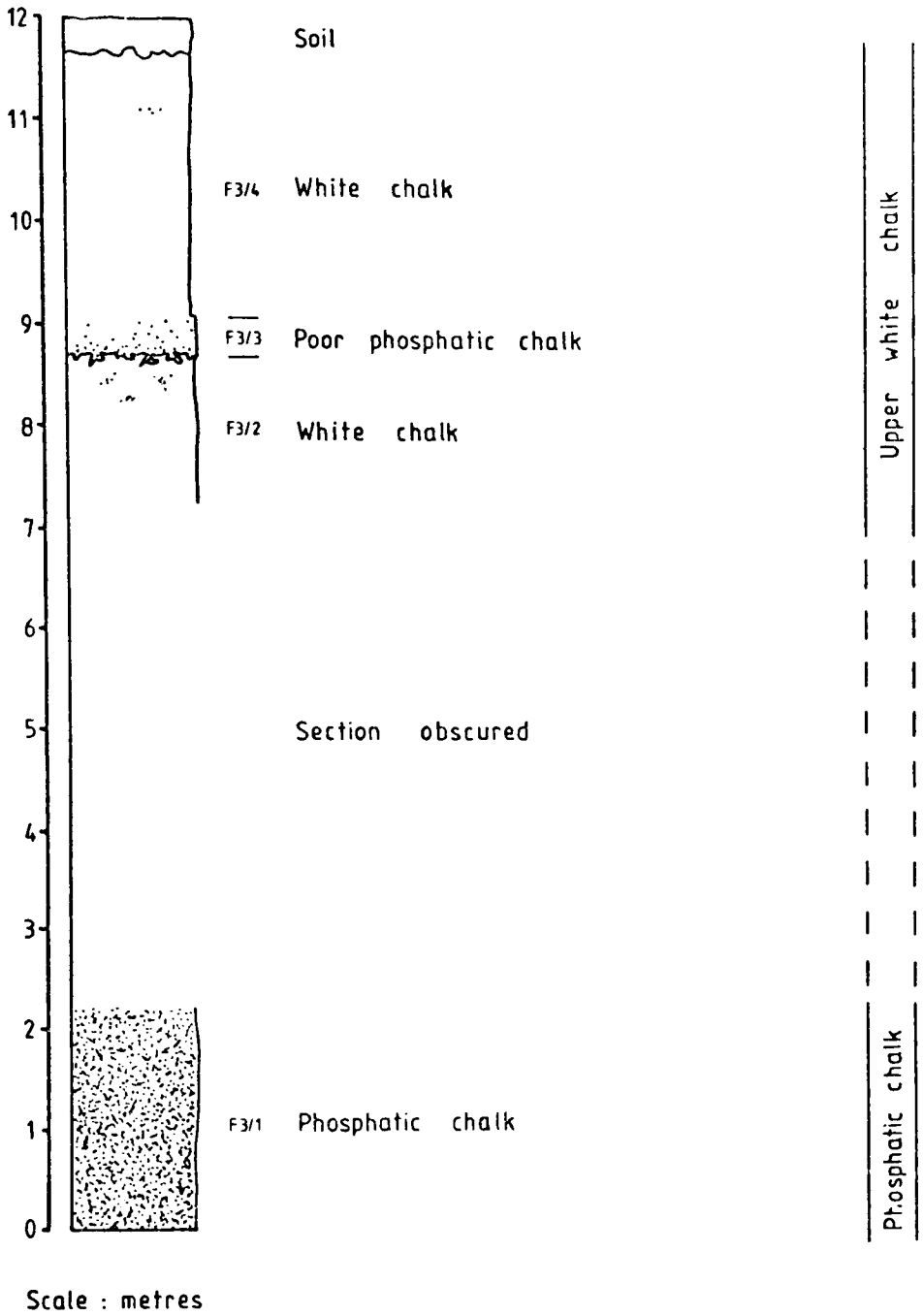
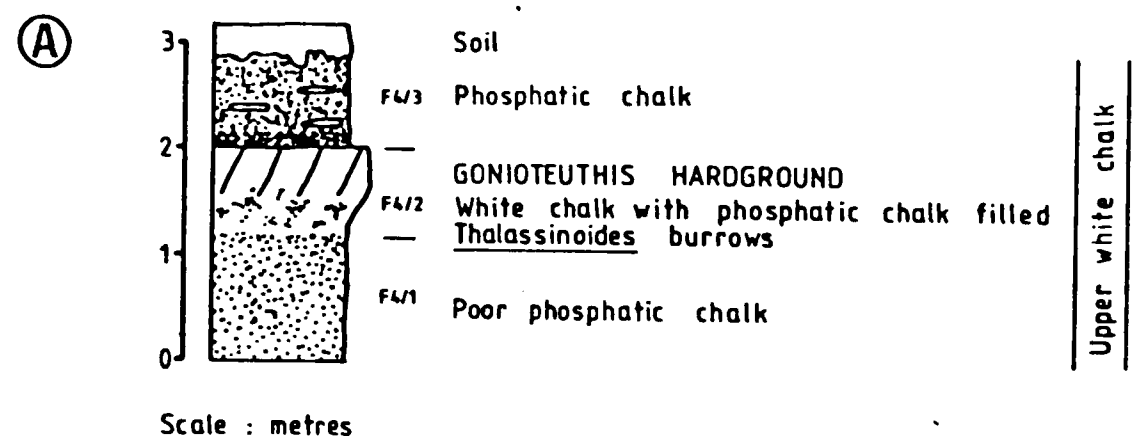


Fig. 2.92 Lithostratigraphy of the NE section, NE quarry Faucouzy (Section 3).

The final exposure (Section 4; Fig. 2.93) lies in the SE corner of the NE quarry. The 3 m section may be divided into three units - a basal 1.30 m of poorly-phosphatic chalk (bed F4/1) overlain by 70 cm of white chalk with pelletal phosphate (bed F4/2) containing numerous idiomorphic phosphatic-chalk filled Thalassinoides burrows at its base (and penetrating into the underlying bed). This passes up into a southerly dipping, well lithified, limonite-stained hardground containing prominent stenomorphed (Fig. 2.94A) Thalassinoides - the Faucouzy Gonioteuthis Hardground. Above this there is 85 cm of phosphatic chalk with abundant Gonioteuthis guards and phosphatized intraclasts. The hardground surface shows similar lateral variation to that seen in Section 1, including planar, intraclastic and 'Terebella' phosphatica encrusted varieties. However, the dominant morphology is of 15 cm of poorly sorted, 0.5 - 5.0 cm, rounded - subangular, phosphatized and



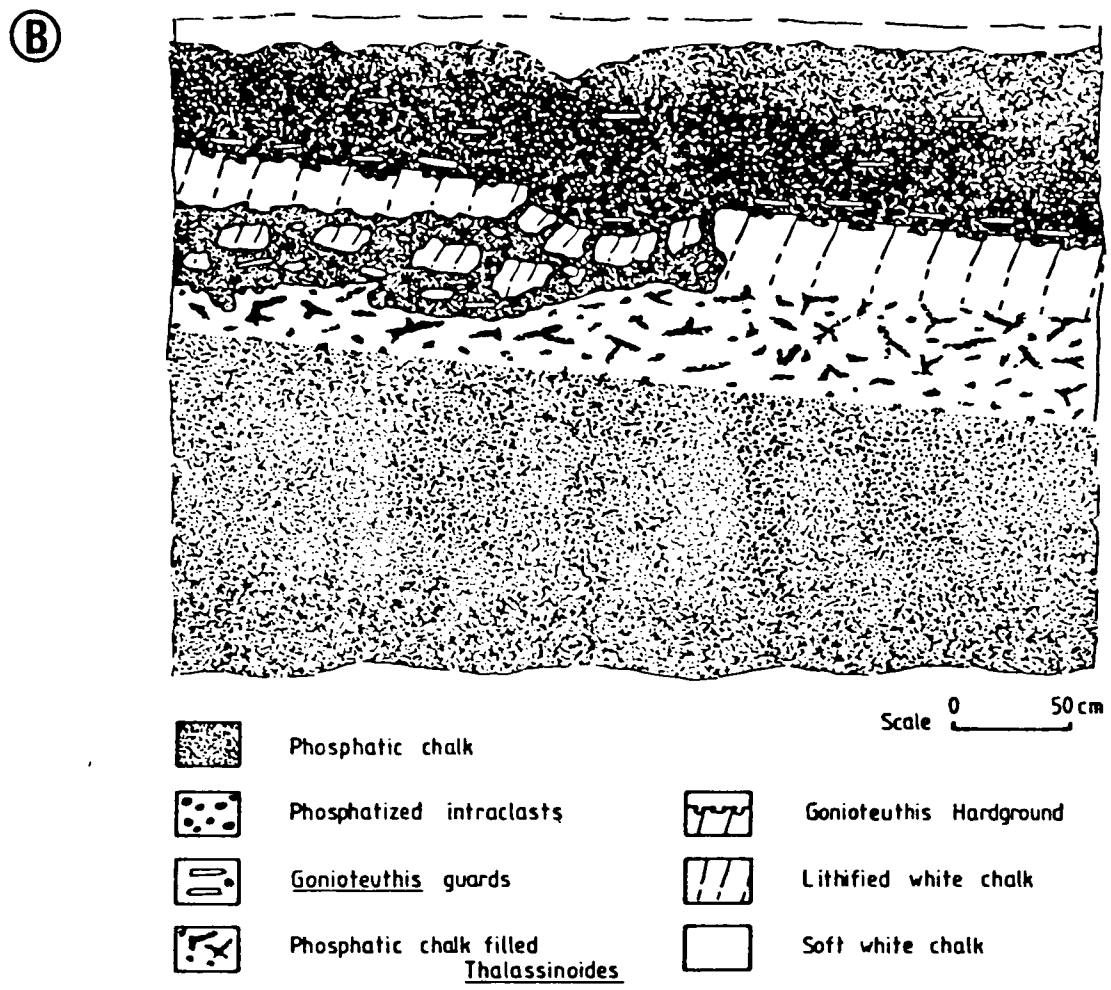


Fig. 2.93 Lithostratigraphy of the SE exposure, NE quarry Faucouzy.
A. Sediment log.
B. Lateral relationships.
(Section 4).

shiny phosphate-skin coated bored intraclasts associated with numerous Gonioteuthis, oyster fragments and cidarid spines, which has been cemented on top of the original hardground surface (Fig. 2.94B) and is overlain by a continuous iridescent phosphate patina. Laterally the cementation and skin are absent, and the bed forms a basal lag to the overlying unit (bed F4/3), which contains Gonioteuthis and phosphatized intraclasts throughout. In one area (Fig. 2.93B) the hardground top has been dislocated and displaced slightly vertically. A biological rather than mechanical mechanism for this breakup is suggested by a number of lines of evidence:

(1) Although the phosphatized, skin-coated top has been displaced slightly vertically, the isolated blocks maintain their relative positions and orientations.

(2) Below the top, isolated blocks show no evidence of disorientation or displacement.

(3) The portion of hardground below the collapsed area contains an abnormally

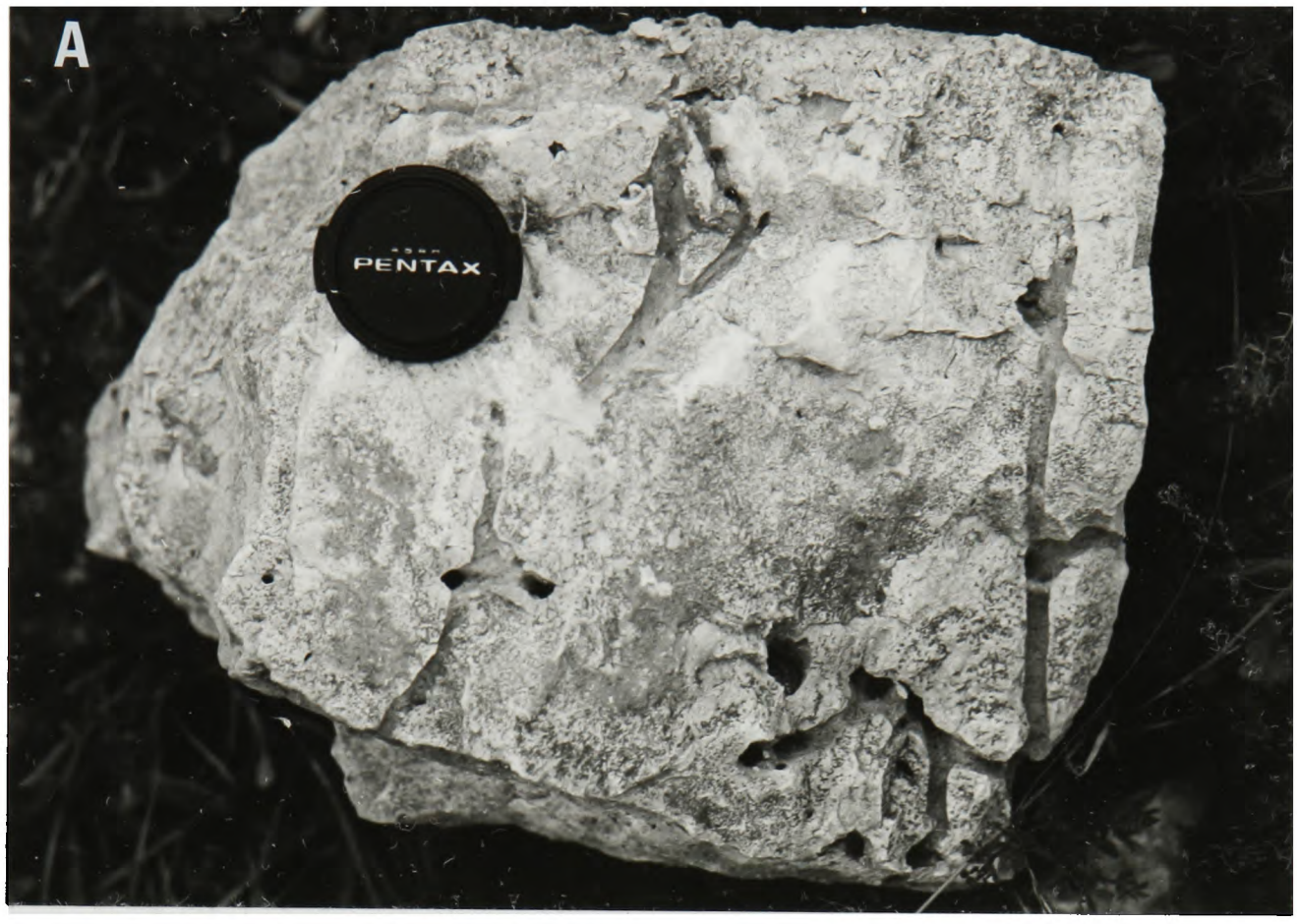




Fig. 2.94 Sediment types of the SE exposure, NE quarry Faucouzy.
A. Stenomorphic Thalassinoides (T. paradoxica) in the Faucouzy Gonioteuthis Hardground.
B. The thick intraclastic pebble bed that overlies the hardground. The lens cap is 5 cm in diameter.

high concentration of phosphatic-chalk filled idiomorphic Thalassinoides burrows.

(4) The intraclasts within the phosphatic chalk matrix are concentrated in burrows rather than physical sedimentological structures.

Consequently, the structures may be explained as a result of the activities of burrowing organisms, predominantly the Thalassinoides-producing crustaceans, penetrating and spreading laterally below the lithified top of the hardground causing it to be undermined and collapse into the burrow riddled sediment below. Subsequent infilling of both collapsed and complete burrows with the overlying phosphorite has resulted in the feature as it is seen today.

A correlation of the exposures is shown in Fig. 2.95. The elevation and southerly dip of the 'Gonioteuthis hardground' at its two exposures, the nature of the hardground surface and the high concentration of intraclasts and Gonioteuthis guards in the overlying phosphatic chalk, are consistent with the two exposures being of the same hardground - the Faucouzy Gonioteuthis Hardground. The phosphatic

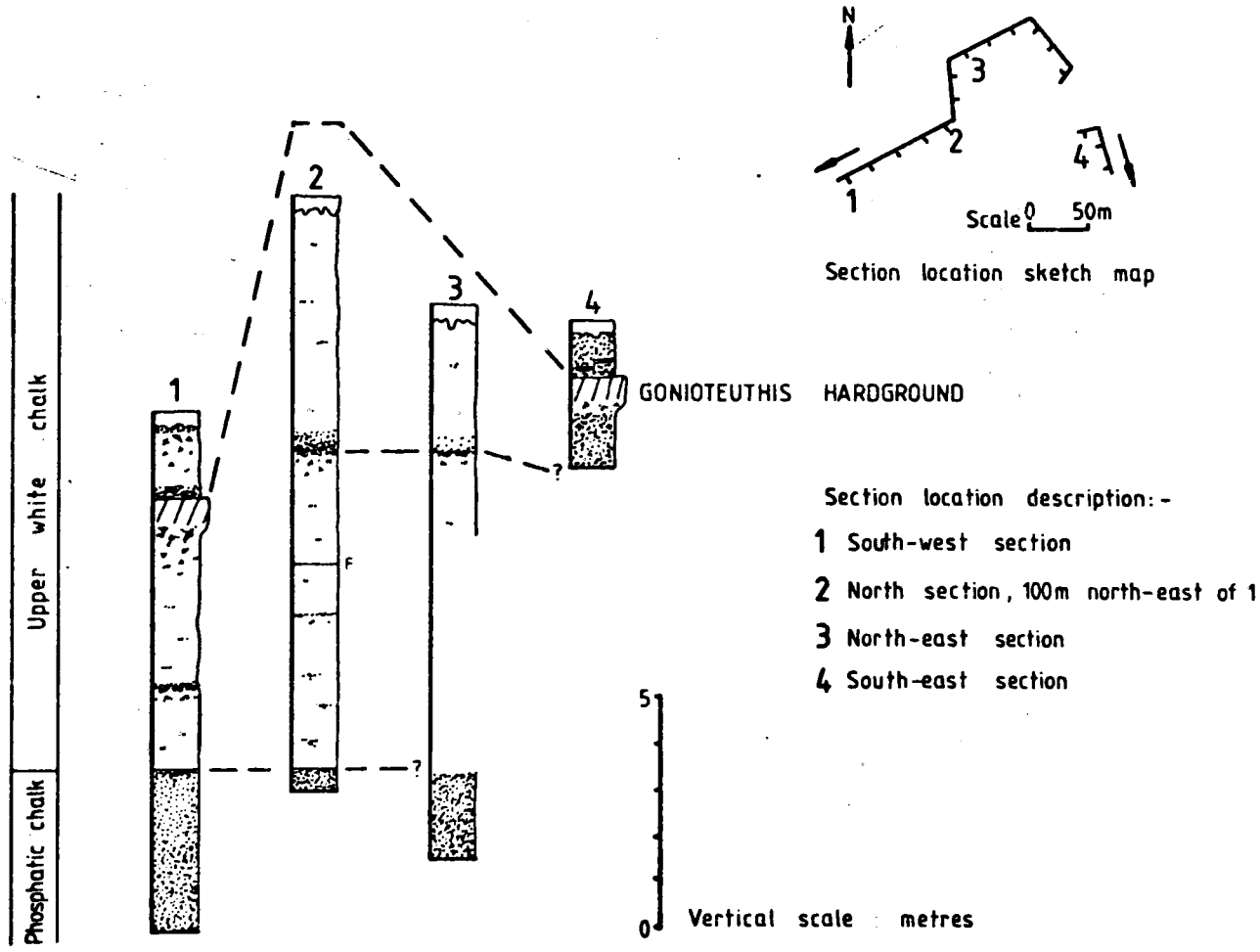


Fig. 2.95 Lithostratigraphical correlation diagram of Faucouzy quarry (Aisne).

chalk below the hardground in Section 4 may be the lateral equivalent of the phosphatic chalk beds exposed in the western quarry and the beds in Sections 2 and 3 in the NE quarry, but this hypothesis cannot be confirmed without further expos-

ure.

The Faucouzy phosphorite has been dated as Santonian by Mathieu et al., (1971), Delattre et al. (1973) and Desvries et al. (1974) who record Gonioteuthis granulata and Lopha semiplana from the deposit. This is supported by the foraminiferal evidence which indicates a middle Santonian Biozone e age for the phosphorite and Biozone d and g age for the underlying and overlying white chalk respectively (Monciardini in Mathieu et al., 1971; Desvries et al., 1974). G. granulata was recovered by me from the phosphatic chalk in the western quarry and the basal rich phosphorite in the NE quarry but the belemnites that overlie the Faucouzy Gonioteuthis Hardground are G. ex gr. quadrata although the material is too poorly preserved for a more exact identification. These suggest an early Campanian age for the youngest phosphatic chalk in the quarry.

2.9.3 Correlation between Ribemont and Faucouzy

The phosphorites of the Ribemont - Faucouzy region have a number of features in common. At both localities the succession consists essentially of several thin beds of Santonian phosphatic chalk intercalated within a dominantly white chalk sequence, at the summit of which is a strongly lithified and mineralized upper hardground. On top of this there rests a Campanian phosphorite containing G. ex gr. quadrata and Belemnitella praecursor. Although the latter belemnite has not been recorded from Faucouzy, it is only a minority element in the fauna and would not be expected in the limited material recovered from that site.

It is suggested, therefore, that the Ribemont Gonioteuthis Hardground, the Faucouzy Gonioteuthis Hardground and similar hardgrounds recorded elsewhere in the vicinity (Rabelle, 1893, 1902; Gosselet, 1901b) are exposures of the same, although not necessarily laterally continuous, hardground.

2.10 Villers-devant-le-Thour and St Martin-du-Tertre

The phosphatic chalk exposures at Villers-devant-le-Thour (Ardennes) which is situated 27 km north of Reims and 68 km SE of St Quentin, and St Martin-du-

Tertre (Yonne), 2½ km NW of Sens and 60 km WSW of Troyes, are isolated occurrences of the phosphatic chalk lithofacies in areas that lie outside the main phosphorite-bearing region and contain considerable expanses of Santonian to Campanian outcrop (Fig. 2.2; Map 1).

2.10.1 Villers-devant-le-Thour (Ardennes)

The village of Villers-devant-le-Thour lies on a narrow tract of NW - SE trending Santonian chalk between broad expanses of Coniacian chalks to the north and east and early Campanian to the south and west (Guérin et al., 1977; Mathieu et al., 1975). The locality was mentioned by De Grossouvre (1901, p126) as a Campanian site and by Broquet (1973) as a phosphatic chalk locality, but it has only recently been dated (Guérin et al., 1977). Two quarry sections in the area expose phosphatic chalks (Fig. 2.96). The larger lies within a small wood on the

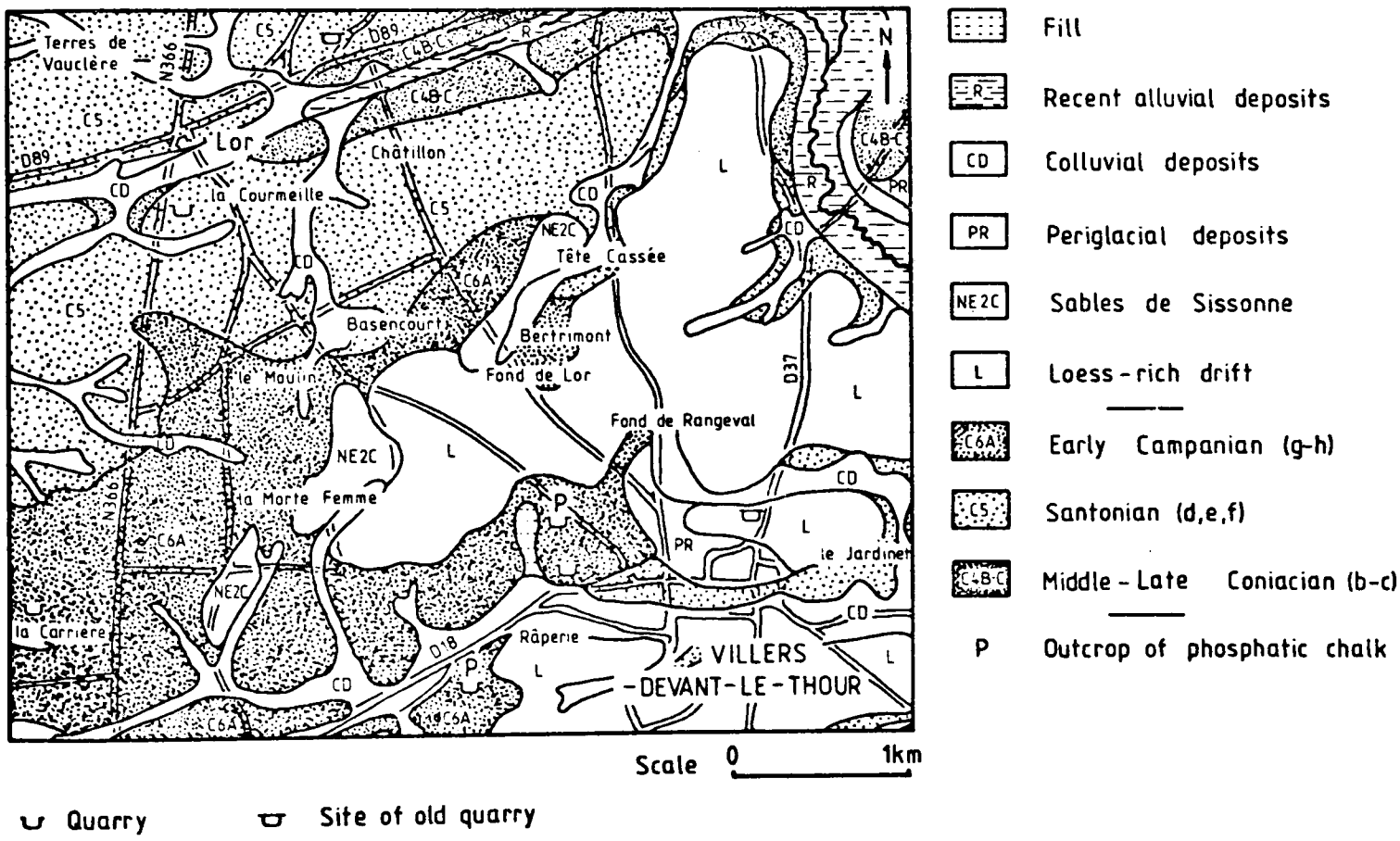


Fig. 2.96 Geological map of the Villers-devant-le-Thour area. Geology modified from Guérin et al. (1977).

south side of the D18, 1500 m WSW of Villers-devant-le-Thour village and 1000 m NE of the hamlet of Le Tremblot: x 725,35 y 201,50 z 100 (1g.923E 55g.003). The smaller, a farm pit, lies on the west side of the unclassified road that joins Villers-devant-le-Thour and Lor, 750 m NW of the former: x 725,86 y 202,39 z 115 (1g.931E 55g.011). Both sites lie within the early Campanian outcrop, but are

within close proximity of the mapped boundary with the Santonian (Guérin et al., 1977).

The larger quarry at Le Tremblot exposes an ~100 m long section of predominantly white chalks. At the western end of the quarry the base of the section (Section 1; Fig. 2.97) consists of 6 m of barren white chalk (bed V1/1) with rare

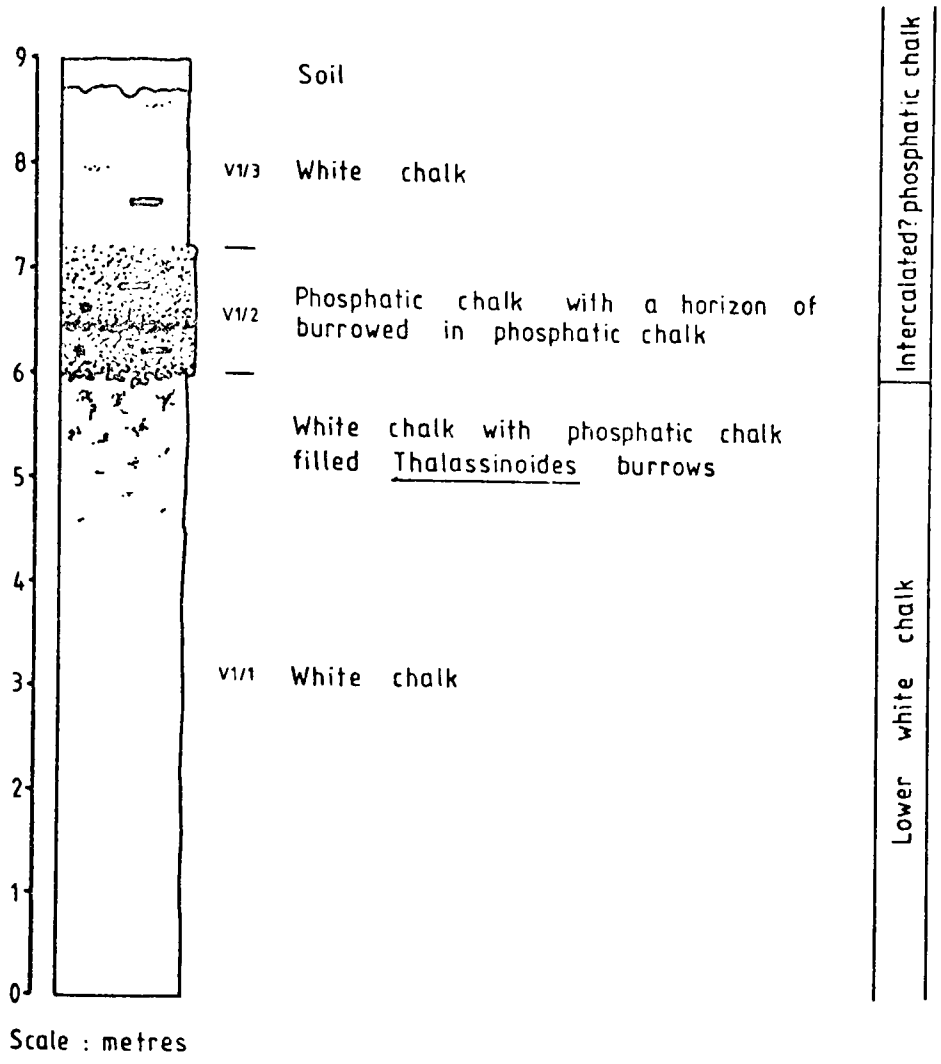


Fig. 2.97 Lithostratigraphy of the western section Le Tremblot quarry, Villers-devant-le-Thour (Section 1).

patches of oyster debris and pyrite-filled 5 mm wide horizontal burrows. The upper 1.50 m of this bed contains phosphatic-chalk filled idiomorphic Thalassinoides burrows that increase in size and abundance towards the summit, where the phosphorite fill (which originates from the overlying 1.20 m of phosphatic chalk, bed V1/2) is particularly rich in phosphatized intraclasts. The base of the phosphatic chalk also contains a high proportion of 0.5 - 5.0 mm diameter, heavily bored, chocolate-brown phosphatized intraclasts and a fauna that includes Gonioteuthis ex gr. quadrata, thin-shelled (?)Gryphaeostrea, Pycnodonte and Chlamys, all of which occur throughout the bed. The proportion of intraclasts decreases rapidly above the basal lag, and the remaining sediment consists of a phosphatic chalk rich in fish and oyster debris, with scattered goethitic nodules. A burrowed-in chocolate-brown, richly phosphatic chalk occurs 45 cm above the base. The bed passes up via a transitional boundary into the 1.50 m of overlying soft white

filled burrows and winnows.

Laterally, at the eastern end of the quarry (Section 2; Fig. 2.98), there is only 2.90 m of barren white chalk exposed, despite the base of the section being at the same topographical elevation as that of the previous section. This is the result of partial truncation of the bed by the overlying phosphatic chalk. The basal 60 cm of the deep chocolate-brown phosphorite contains a very high proportion of 0.1 - 10 cm , deep to pale chocolate-brown, dull surfaced, heavily scratched and bored, strongly to weakly phosphatized, white (or poorly phosphatic) chalk intraclasts (Fig. 2.99), commonly with goethitic (pyrite, goethite, lepidocrocite and limonite) cores and associated with numerous Gonioteuthis guards. The borings



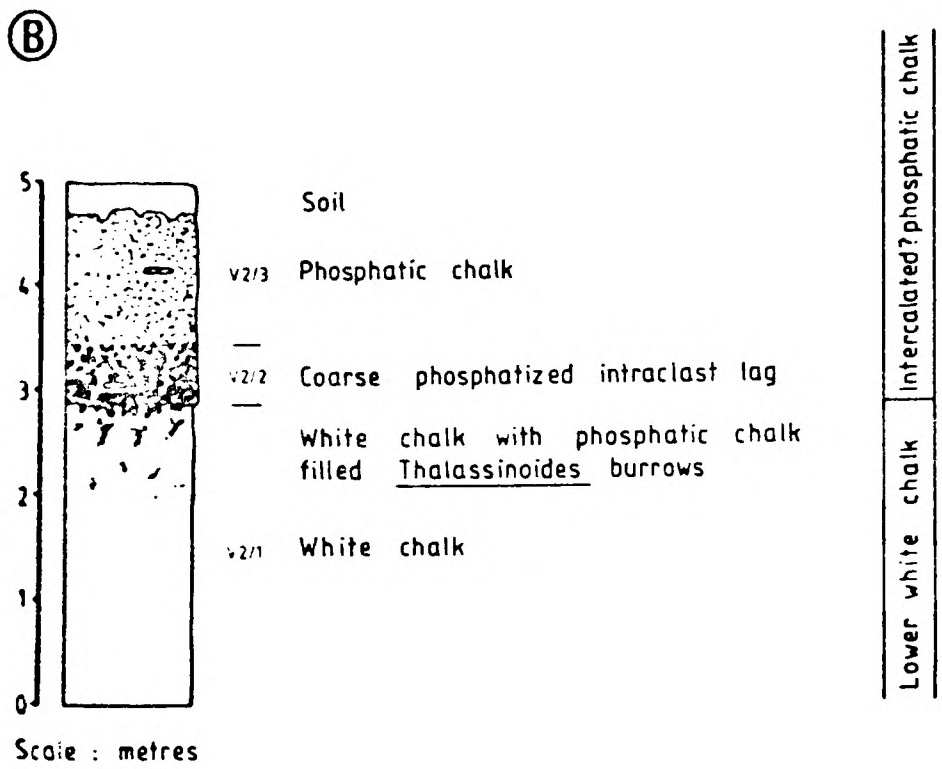


Fig. 2.98 Lithostratigraphy of the eastern section Le Tremblot quarry, Villers-devant-le-Thour (Section 2).
A. General view of the exposure.
B. Sediment log.
Base of V2/2 in (A) indicated by the dashed line.

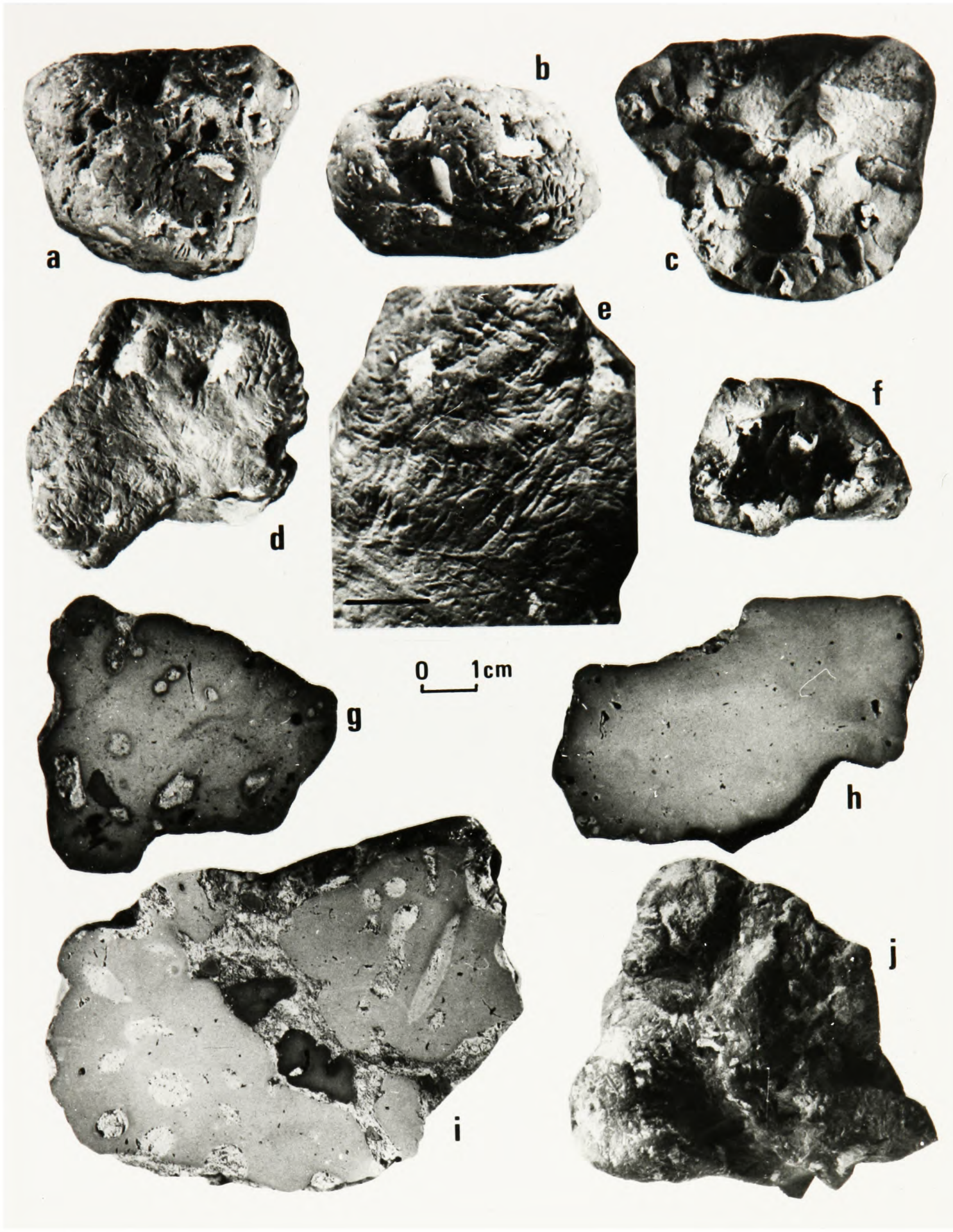


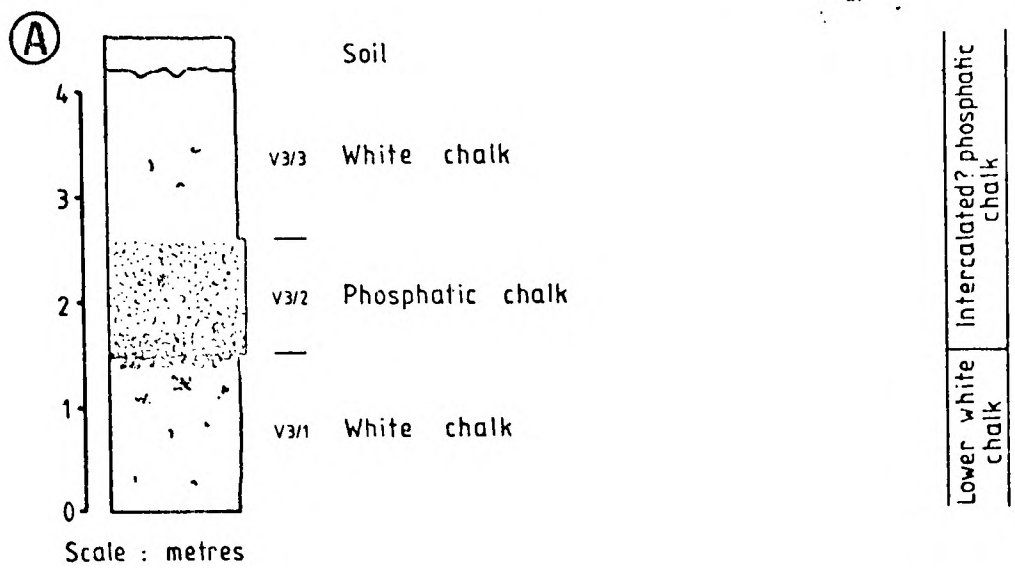
Fig. 2.99 Phosphatized intraclasts from bed V2/2, le Tremblot, Villers-devant-le-Thour. a-b. External morphology of two typical intraclasts. c. Broken intraclast displaying flask-shaped bivalve crypts. d. Gnathichnus covered surface of a slab-like intraclast. e. Close-up of the Gnathichnus trace (scale-bar = 1 cm). f. A broken intraclast with a finger-like goethitic core. g. Polished surface of a broken intraclast. h. Polished surface of a lightly-bored white chalk intraclast. i. A large bored intraclast penetrated by a phosphatic chalk and phosphatized intraclast filled stenomorphic Thalassinoides burrow. Polished surface. j. Stenomorphic Thalassinoides producing a Y-shaped sculpture on the surface of an intraclast.

are of two main varieties: the most frequent are 3 - 7 mm wide flask-shaped crypts that commonly exhibit a fine surface sculpture, particularly at the termination of the bores, and may be attributed to pholadid bivalves; the second type consists of 0.1 - 1.0 mm wide, subvertical, slightly-sinuous borings that penetrate the outer centimetre of the nodules and were probably produced by polychaete worms. Larger ~1 cm tubes also penetrate some of the larger nodules, but these are regarded as the remnants of the Thalassinoides system that developed in the sediment prior to intraclast formation. The majority of upper surfaces, and commonly the entire intraclast, are covered in large numbers of pentaradiate scratch marks referable to the ichnospecies Gnathichnus pentax Bromley, which has been interpreted as an echinoid browsing trace (Bromley, 1975). These scratch marks are particularly pronounced in the areas around the entrances to the bivalve borings. Some of the intraclasts are encrusted by pycnodonteine oysters. It is noteworthy that the majority of bivalve crypts have been truncated, many remaining as shallow dish-shaped surface depressions in the surface of the intraclasts, indicating that significant erosion has occurred subsequent to the earlier generations of boring, while the common occurrence of concave faces on the smaller intraclasts in the bed suggests that bioerosion was an important process in their breakdown. The rounded to subangular morphology of the majority of smaller intraclasts demonstrates, however, that mechanical abrasion was also significant. Soft sediment trace-fossils within the interiors of the intraclasts include Chondrites and meniscus-fill varieties.

Intraclasts have been carried down into the upper portions of the idiomorphic Thalassinoides system that penetrates the underlying white chalk, but show a marked reduction in their size and number in the 1.20 m of phosphatic chalk that overlies the bed. This phosphorite (bed V2/3) is similar to its lateral equivalent in the western section, containing a high proportion of fish debris, thin-shelled oyster and G. ex gr. quadrata. Its top is not seen.

The small farm pit, NW of Villers-devant-le-Thour, exposes (in the middle of the 4.20 m section) 1.10 m of highly bioturbated, yellow-brown phosphatic chalk (Section 3; Fig. 2.100, bed V3/2) containing abundant thin-shelled (?)Gryphaeostrea and fish debris. The bed, which also contains occasional 5 cm goethitic nodules

and fragments of inoceramid and pectinid, is under- and overlain by soft white chalks (beds V3/1; V3/3), has a burrowed base and transitional top, and contains numerous 3 mm white chalk intraclasts.



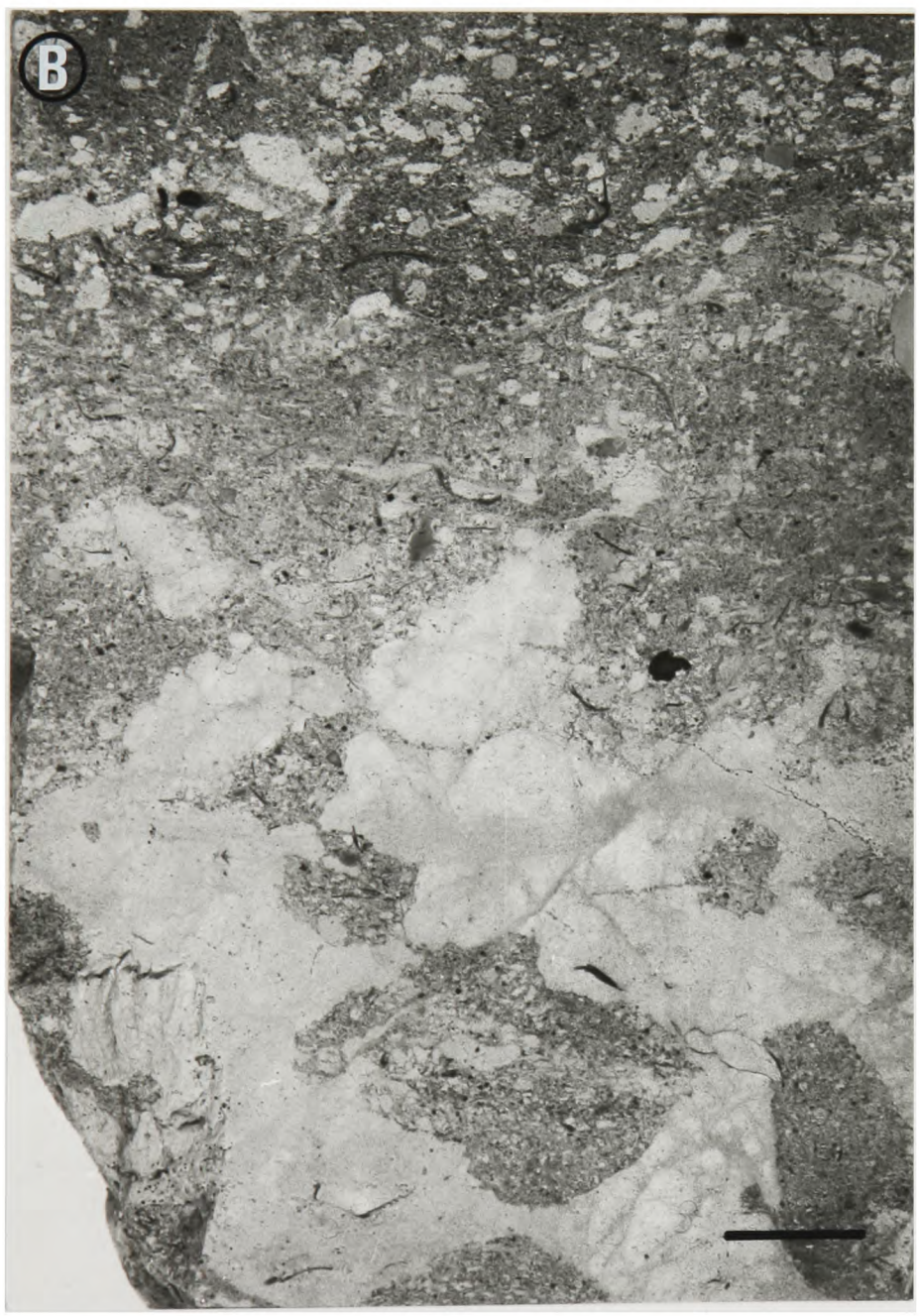


Fig. 2.100 The farm pit section, Villers-devant-le-Thour (Section 3).
A. Sediment log.
B. Contact between the phosphatic chalk and the underlying soft white chalk. Scale bar = 2 cm.

A lithostratigraphical correlation of the sections is shown in Fig. 2.101. It is apparent that the phosphatic chalk is both thicker and richer in the area where it has truncated the greatest thickness of white chalk. The correlation with the NW section (Section 3) is tentative.

The Le Tremblot exposure has been dated as early Campanian Biozone g by

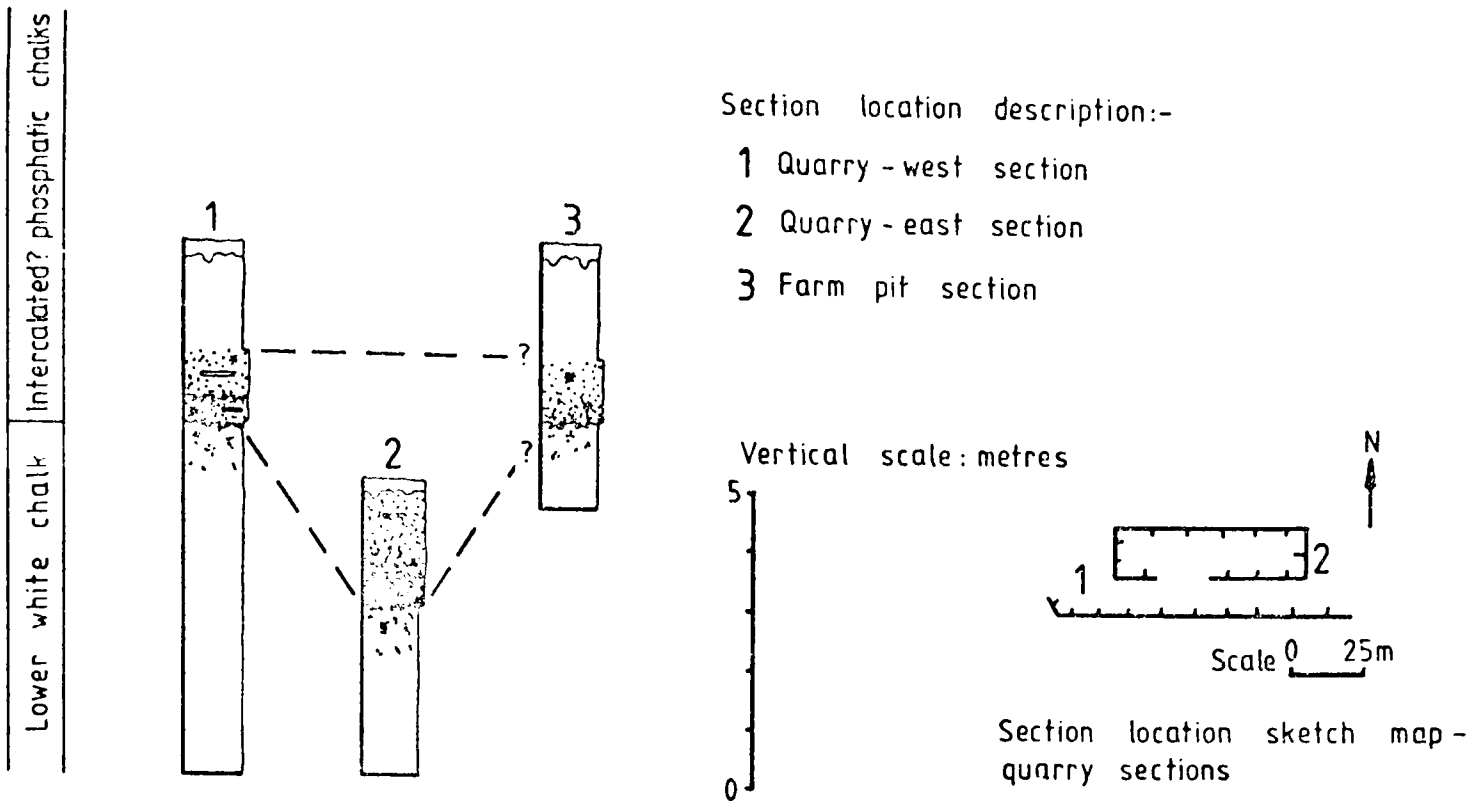


Fig. 2.101 Lithostratigraphical correlation diagram of the Villers-devant-le-Thour exposures.

Monciardini (in Guérin et al., 1977) and the farm pit exposure as early Campanian Biozone h by the same author, on foraminiferal evidence. These results are not inconsistent with the presence of G. ex gr. quadrata of a form transitional between G. q. quadrata and G. q. gracilis in the basal phosphorite at Le Tremblot (see Chapter 4), although the belemnites perhaps suggest a slightly younger age for the phosphorite than that indicated by the microfauna.

2.10.2 St Martin-du-Tertre (Yonne)

The village of St Martin-du-Tertre lies on the NW outskirts of Sens, $2\frac{1}{2}$ km from the centre of the town. Sens is situated at the confluence of the river Yonne and river Vanne and although the bulk of the Cretaceous in the region is obscured by several metres of Tertiary and Quaternary sediments (Fig. 2.102), the river cliffs provide excellent continuous exposure of late Turonian Holaster planus Zone to late Campanian Belemnitella mucronata Zone chalks (Bouiller et al., 1971), more than 200 m of section. Consequently, the area was chosen as the type for the Senonian Stage (D'Orbigny, 1842)(see Chapter 1).

Pelletal phosphate was first recognised in the chalks of the region in 1895 (Cayeux, 1897) but it was not realised that the deposits were of economic potential until 1910 (Hure 1910, 1912; Negre, 1912b, 1913, 1964; Raguin, 1926) when the section situated below the St Martin-du-Tertre church: x 668,85 y 056,83 y 104

(1°.027E 53°.561) described by Cayeux (1897) was traced southwards into richer phosphatic chalks (Hure, 1910). Here, the section consisted of a strongly-lithified phosphatized and phosphate skin coated basal hardground displaying prominent manganese staining, overlain by 15 - 25 cm of phosphatic chalk rich in phosphatized intraclasts and containing up to 18% P_2O_5. This basal lag was overlain by 2.15 m of yellow phosphatic chalk with 14 - 18% P_2O_5 and scattered phosphatized and glauconitized intraclasts. Weathering of the phosphorite, which could be traced ~50 m along the face, had caused a secondary enrichment of the upper part of the bed. A horizontal shaft sunk into this unit: x 668,77 y 056,39 z 104 (1°.027E 53°.561), exposed up to 3 m of phosphorite but ran across a (?)faulted wall of barren white chalk 15 m into the face, and was subsequently abandoned. The majority of the phosphatic chalk was extracted from a complex of vertical

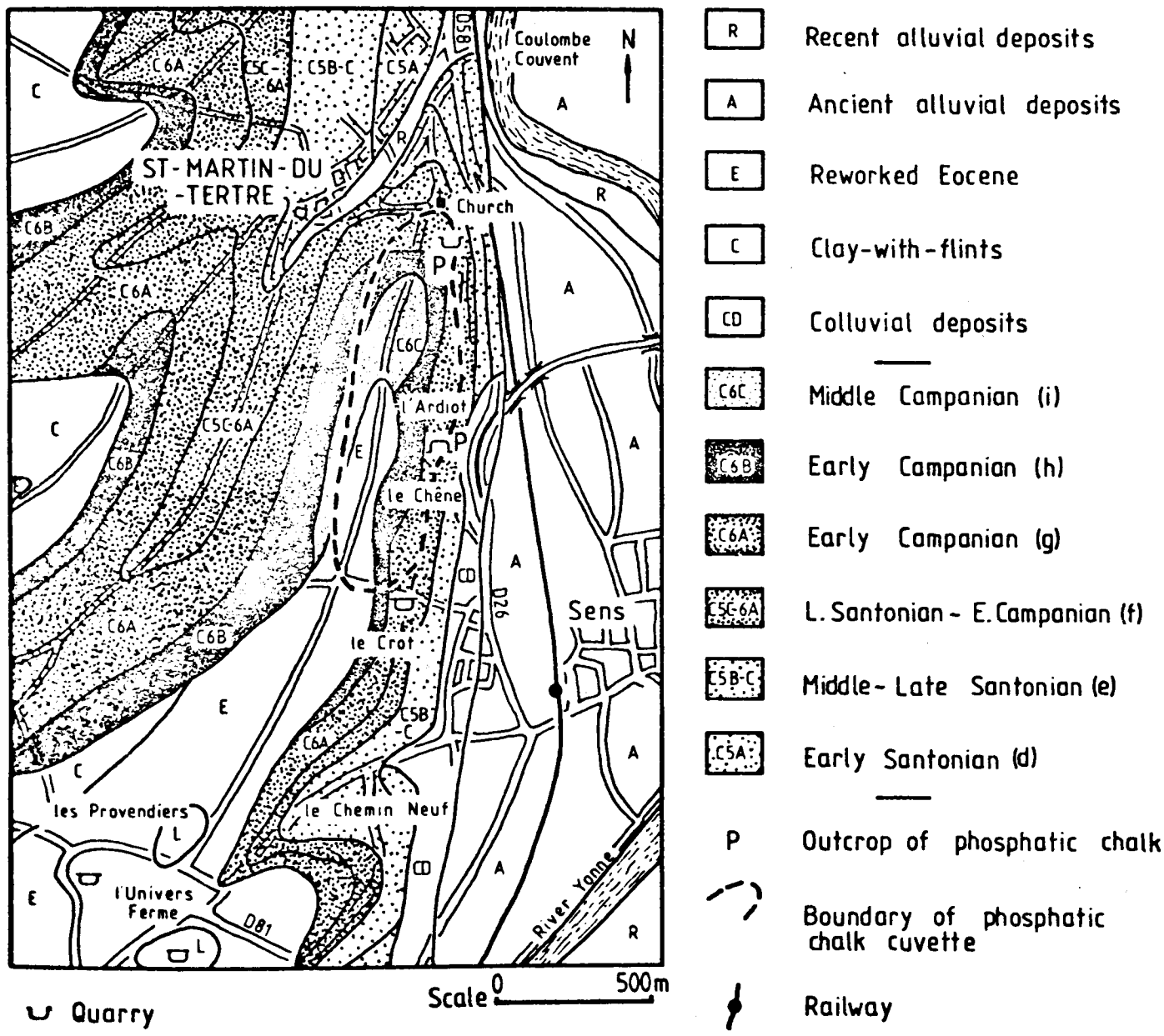


Fig. 2.102 Geological map of the St Martin-du-Tertre phosphatic chalk deposit. Based on Negre (1913, 1964) and Bouiller et al. (1971).

shafts and subterranean workings in the area 500 m SW of the original site, where a NW - SE elongated, 1250 m long 250 m wide and up to 5 m thick, lens of phosphorite

containing up to 20% P_2O_5 was worked between 1912 and 1934, by which time the remaining phosphatic chalk was of too low a grade to be economic (Negre, 1964).

The fauna recorded from the phosphorite includes Gonioteuthis ex gr. quadrata, Offaster pilula, Echinocorys, Stereocidaris sceptifera, rhynchonellids, Kingena lima Defrance, Pycnodonte vesicularis, Gryphaeostrea canaliculata, Serpula, Plicatula, Bourgeticrinus ellipticus d'Orbigny, Porosphaera globosa Von Hagenow, Trochus, Avicula, Inoceramus, Platyceramus, sponges and elasmobranch teeth. This suggests an early Campanian Offaster pilula Zone age for the deposit. This is confirmed by the occurrence of Marsupites testudinarius and G. ex gr. quadrata in the white chalks above and below the phosphorite respectively, and the presence of a Biozone g foraminiferal assemblage within the phosphorite (Bouiller et al., 1971).

2.11 Southern England

Coniacian to Campanian chalks are exposed over considerable expanses of southern England, particularly in Dorset, Hampshire, West and East Sussex, Kent, Wiltshire, Berkshire, Buckinghamshire and the Isle of Wight (see review in Rawson et al., 1978), but phosphatic chalks of this age are only recorded from six localities: Taplow (Bucks), Winterbourne (Berks), Boxford (Berks), Lavant (West Sussex), Whitecliff Ledge (Isle of Wight) and Downend (Hants). All but the last of these localities, which is the subject of a recent paper by Gale (1980), have not been examined for many years and only two (Taplow and Winterbourne) have been described in detail. Reexamination of all six sites by me and detailed description of the first five (see below), two of which (Winterbourne and Boxford) have been recently (1978) reexcavated by the Nature Conservancy Council, allows close comparison with French examples of the lithofacies.

2.11.1 Taplow (Bucks) SU 906 819

The village of Taplow lies between the B3026 and B476, 1 km north of the A4 on the east bank of the river Thames and on the NE outskirts of Maidenhead (Berks),

and 21 km ENE of Reading (Berks). A single exposure of phosphatic chalk occurs in a disused chalk quarry, South Lodge Pit (Fig. 2.103), at an elevation of ~35 m OD, near South Lodge at the SW corner of the grounds of Taplow Court and on the north side of the unclassified road that joins the B476 to the quayside. The quarry lies in an area of late Coniacian to early Santonian M. coranguinum Zone chalk (Jukes-Browne and Hill, 1904) but exposure is limited to a small number of scattered outcrops, the remainder of the chalk being obscured by Tertiary (Reading Beds) and drift.

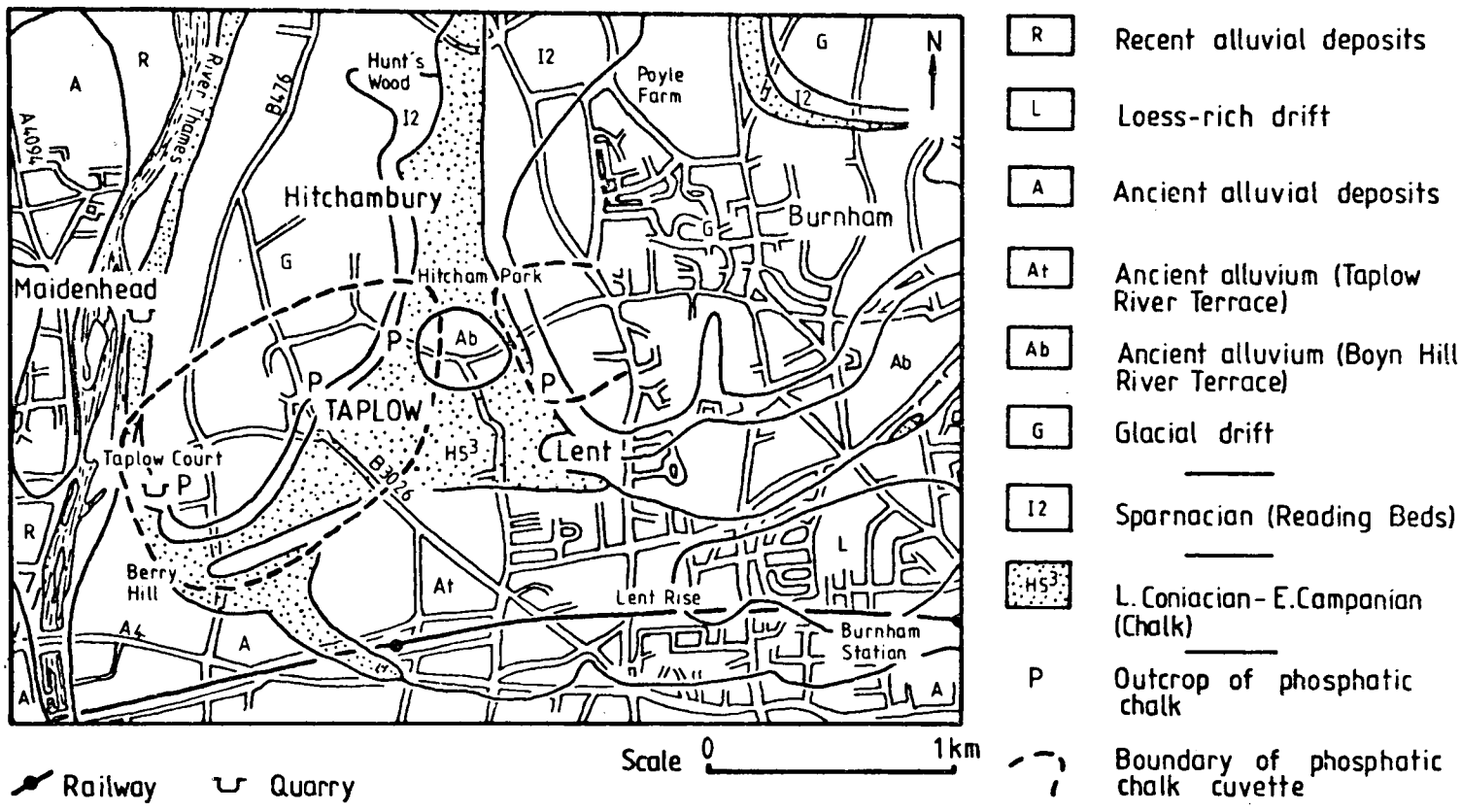


Fig. 2.103 Geological map of the Taplow phosphatic chalk cuvette. Based on the maps of the Ordnance and Geological Surveys and Hawkins (1948).

The abnormal nature of the Taplow chalk was first recorded by Whitaker (1889, p77) and was shortly afterwards recognised as a phosphatic chalk and described in detail by Strahan (1891, 1892, 1895) and later authors (Jukes-Browne and Hill, 1905; Sherlock et al., 1927; Hawkins, 1948). The microfauna of the locality has been described by Chapman (1892) and a secondary phosphorite (with > 30% P_2O_5) filled solution pipe by De Mercey (1896). The section was examined most recently by Willcox (1953a).

The quarry exposes an ~70 m long, heavily overgrown and talus-obscured face running WNW - ESE; the beds dipping at 4 - 5° ESE. The site originally (Strahan, 1891; White and Treacher, 1905) exposed an ~18 m thick section that could conveniantly be divided into five lithostratigraphical units: a lower white

chalk, a lower phosphatic chalk, an intermediate white chalk, an upper phosphatic chalk and an upper white chalk (Fig. 2.104). At the present time (1979) the lower white chalk is almost totally obscured, and the upper white chalk is predominantly inaccessible, but the remainder of the section (albeit severely weathered and salt-impregnated) is still adequately exposed.

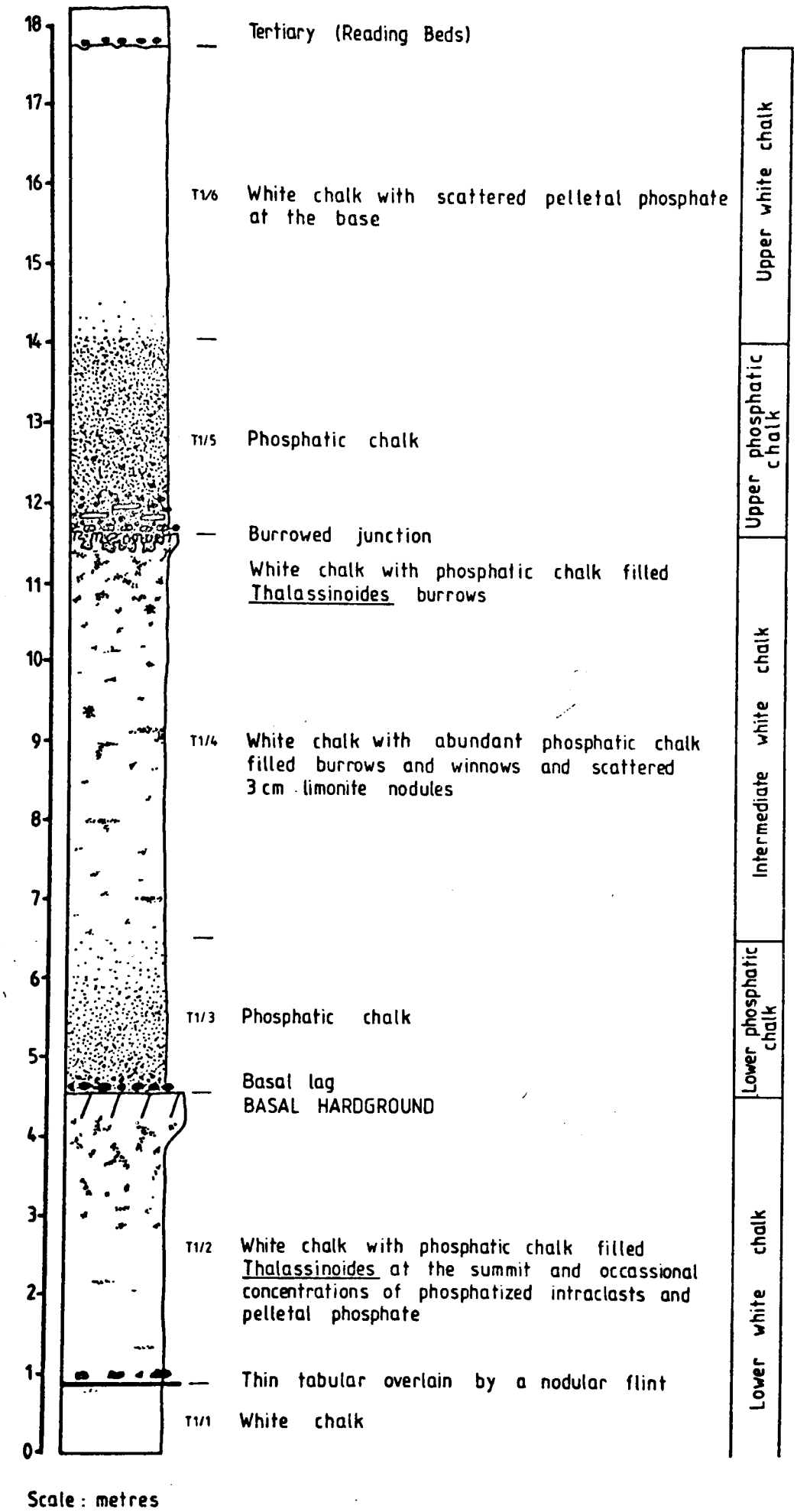


Fig. 2.104 Lithostratigraphy of South Lodge Pit, Taplow. Based on personal observation but incorporating data from Strahan (1891), White and Treacher (1905) and Hawkins (1948).

The lowest bed (T1/1) consisted (White and Treacher, 1905) of 90 cm of soft white chalk containing scattered pelletal phosphate at its summit. The base of the overlying 3.65 m thick white chalk (T1/2) was marked by a thin tabular flint, closely overlain by a line of burrow flints. This chalk contained phosphatic-chalk filled winnows and phosphatized intraclasts throughout and was penetrated by a phosphorite filled Thalassinoides system in its upper portion. The white chalk becomes progressively lithified in its upper 60 cm, to form a well-developed basal hardground to the overlying phosphatic chalk. The lithified sediment contains pelletal phosphate and phosphatized and glauconitized intraclasts, particularly at its top, which in some areas consists of a bed of intraclasts up to 4 cm across cemented by a lithified micrite and overlain by shiny phosphate skins. The hard-ground sediment also contains a number of small (0.5 - 3.0 cm) goethitic nodules, calcite-spar filled voids and a dense network of fractures and weakly-developed stylolites that have been injected with phosphatic chalk and act as foci for manganese oxide precipitation. The iridescent phosphate veneer that covers the surface of the hardground coats, and is encrusted by, the pycnodonteine oysters and serpulids that adhere the surface. The skins also seal-off the entrances to the Thalassinoides systems that are commonly plugged with phosphatized sediment.

The basal hardground is overlain by 1.95 m of phosphatic chalk (bed T1/3) containing $\sim$12% P_2O_5, and having a well-developed, 3 - 15 cm thick basal lag with 15% P_2O_5, composed of phosphatized and glauconitized intraclasts and phosphatized internal moulds of Micraster cf. coranguinum and ventriculitid sponges. Intra-clasts are generally of three types:

(1) subangular - rounded phosphatized and shiny phosphate skin coated intraclasts of phosphatic chalk up to 10 cm across, larger examples being penetrated by stenomorphic Thalassinoides burrows indicating that they were lithified prior to their reworking,

(2) smaller, angular - subangular phosphatized, and occasionally shiny phosphate veneered intraclasts up to 5 cm across and

(3) subangular - rounded, heavily-bored glauconitized and occasionally phosphatized intraclasts up to 1 cm across.

Bioclasts predominantly consist of comminuted Platyceramus, fragments of

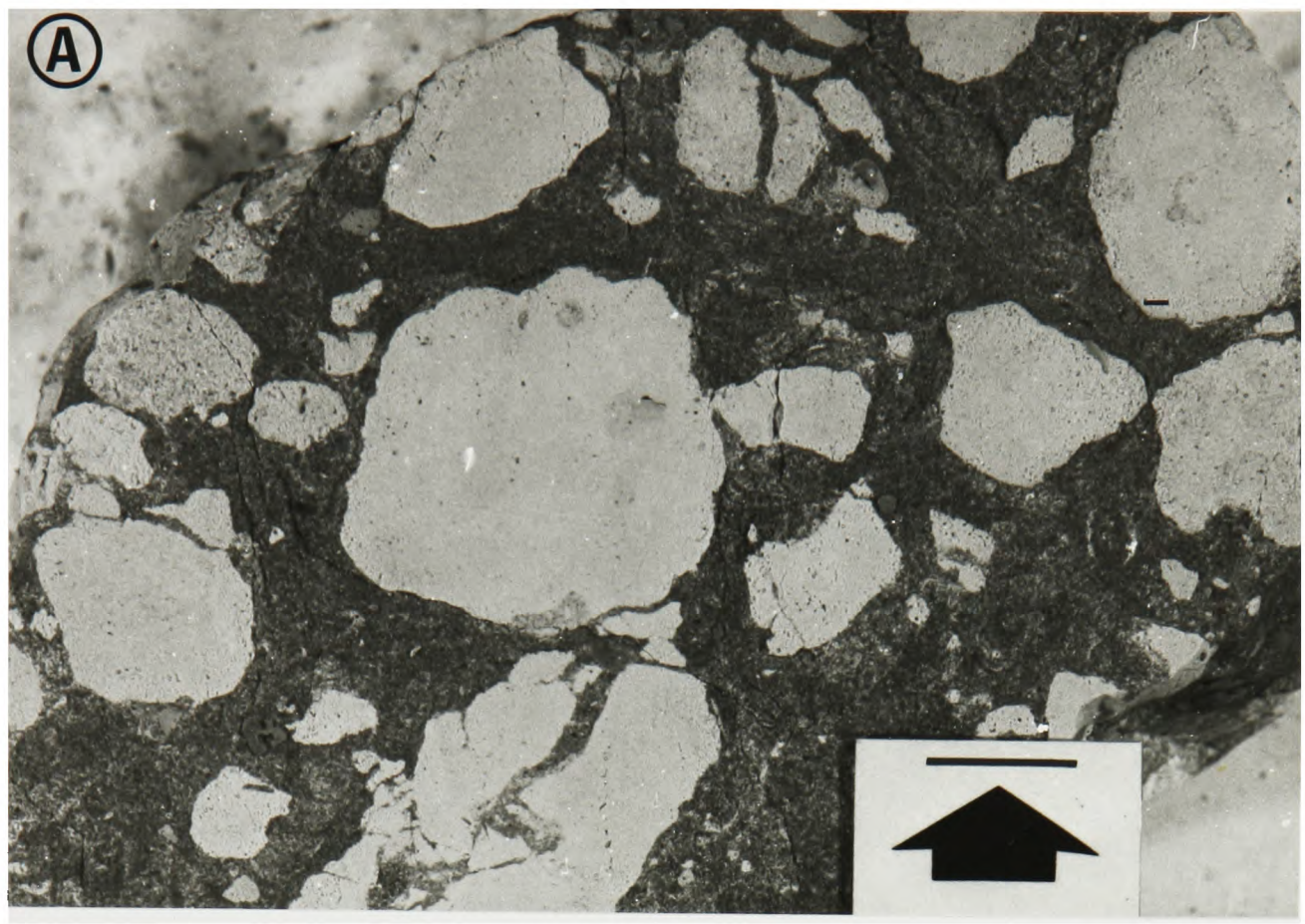
echinoid tests and oyster shell, and elasmobranch teeth. The basal lag infills the upper portions of the phosphatic-chalk filled Thalassinoides system. Intraclasts are less common in the overlying phosphatic chalk, which contains laterally impersistent levels of burrowed-out white chalk in its lower 60 cm and passes up via a 75 cm transitional zone into the overlying 4.95 m of white chalk (bed T1/4).

The intermediate white chalk contains abundant burrowed-in phosphatic chalk, disseminated pelletal phosphate and 3 cm limonitic nodules throughout, and a well-developed phosphatic-chalk filled Thalassinoides at its summit. The top of the unit is taken at the upper surface of the weakly-lithified, burrowed-out white chalk (Fig. 2.105) that occurs at the top of the burrow system. A combination of early-diagenetic lithification, isolation and dislocation of white chalk nodules by burrowing, late-diagenetic fracturing, and the formation of compactional microfaults, has produced a complex pseudo-conglomerate similar to that figured by Gosselet (1893c, p154) from Fresnoy-le-Grand. The nodules in the pseudo-conglomerate are generally unmineralized, although the uppermost examples show a weak limonitic stain.

The overlying 2.45 m of phosphatic chalk (bed T1/5) contains 9 - 13% P_2O_5, a higher proportion of small (<1 cm) phosphatized and glauconitized intraclasts and oyster fragments, and smaller but more diverse foraminiferans than the lower phosphatic chalk. The phosphorite contains few well-mineralized intraclasts larger than 1 cm but abundant Gonioteuthis granulata, the majority of which are badly fractured and weathered (although Willcox (1953a) collected >100 complete guards from this level).

The upper phosphatic chalk passes up via a transitional top into the overlying 3.65 m of white chalk (bed T1/6), the summit of which has been hardened and manganese stained by Tertiary weathering. Scattered pelletal phosphate and phosphatic-chalk filled burrows occur in the lower 1 m.

A shaft sunk into the hillside above the pit in 1891 (Strahan, 1891) gave a section consisting of 1.20 m of lower phosphatic chalk, 3.65 m of intermediate white chalk, 4.00 m of upper phosphatic chalk passing via a 60 cm transitional top into 5.50 m of upper white chalk overlain by 2.90 m of Tertiary strata (Reading Beds). These measurements demonstrate attenuation of the intermediate



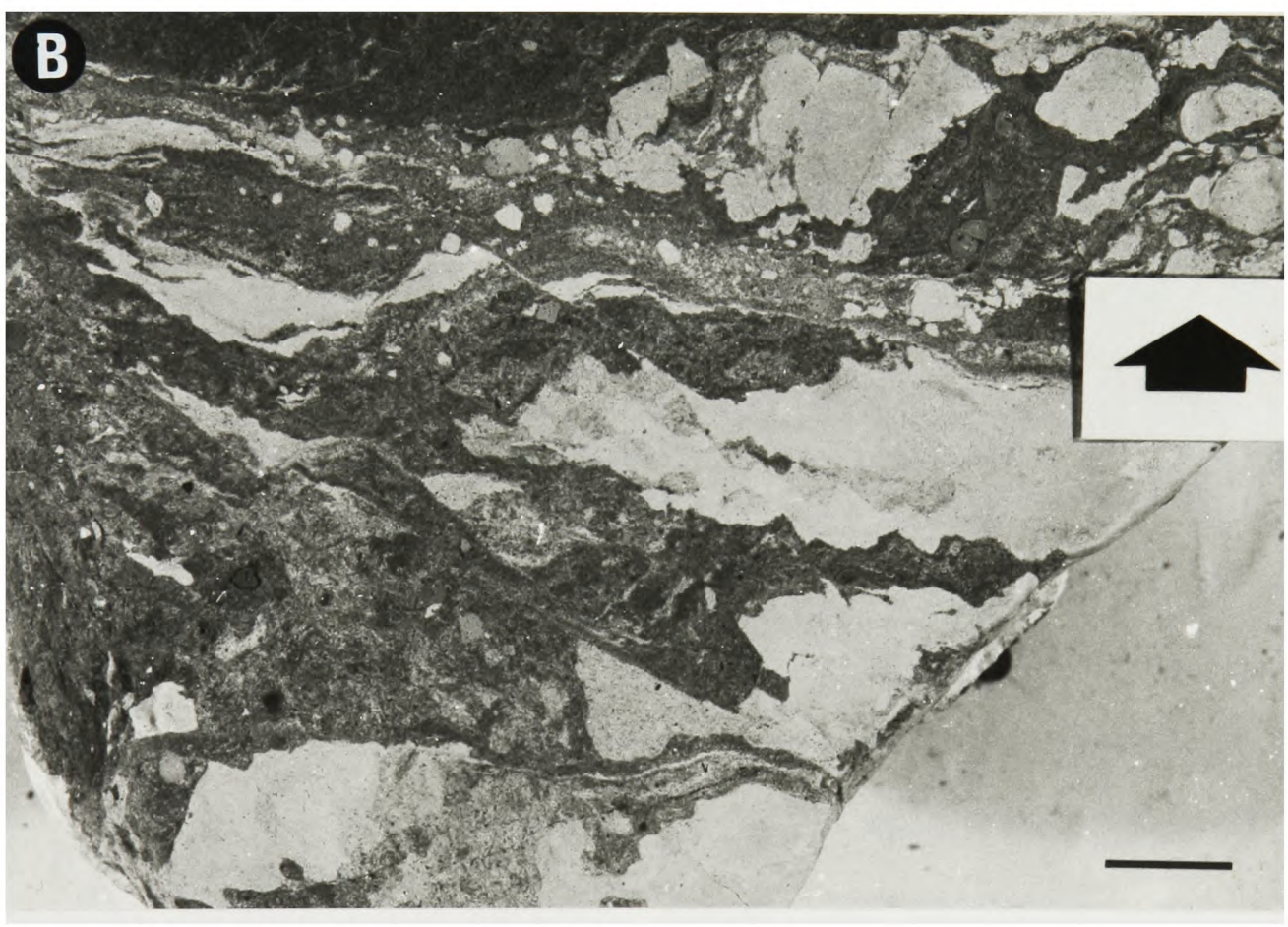


Fig. 2.105 Junction between the intermediate white chalk and the upper phosphatic chalk, Taplow. A. Upper 20 cm of the burrowed junction illustrating the burrowed-out (pseudo-conglomeratic) texture of the white chalk. B. Lower 30 cm with compactional microfaults (dashed lines). Scale bars = 2 cm.

white chalk and thickening of the upper phosphatic chalk to the NE. Later work (Strahan, 1895; Hawkins, 1948) determined that the minimum extent of the phosphatic chalk cuvette was 1800 x 900 m, elongated SW - NE (Fig. 2.103). White and Treacher (1905) suggested that the limited extent of the deposit could be attributed to intra-Cretaceous folding but subsequent borehole data (Willcox, 1953a) has demonstrated that the Chalk Rock is unfolded in the region and that the severe attenuation that occurs in the Taplow section (see below) must be attributed to a primary erosional cuvette structure similar to those described from France.

The Taplow phosphatic chalk was originally (Whitaker, 1889) refered to the Margate Chalk or M. testudinarius Zone because of the occurrence of 'Belemnitella quadrata' and the scarcity of flints. The record of 'B. quadrata' led French geologists (e.g. De Lapparent, 1893 p.1208; Cayeux, 1939) to incorrectly refer the phosphorite to the Campanian. Reidentification of the belemnite (Jukes-Browne and Hill, 1904) as Gonioteuthis granulata demonstrated that the deposit was older than Campanian and detailed macrofaunal collecting (White and Treacher, 1905) proved the occurrence of M. coranguinum, U. socialis and M. testudinarius Zone sediments. Later records of Offaster pilula (Willcox, 1953a) indicated the presence of that zone at the summit of the section.

The fauna of the lower white chalk includes Conulus albogalerus, Echinocorys, Micraster coranguinum, M. coranguinum latior Rowe, Bourgueticrinus ellipticus and small (6 - 12 mm) Porosphaera globularis Phillips which, in the absence of other diagnostic fauna, indicate a late M. coranguinum Zone age for the unit. The oldest lower phosphatic chalk contains abundant Lopha semiplana, Actinocamax verus and Uintacrinus socialis, the remaining fauna including Kingena lima, Porosphaera, rhynchonellids, Terebratulina striata, Scalpellum, Micraster coranguinum, cidarid spines and plates and fragments of Echinocorys and Conulus, indicating the middle Santonian U. socialis Zone. Uintacrinus socialis disappears at the lowest occurrence of Marsupites testudinarius, 70 cm from the base of the lower phosphatic chalk, the remainder of which is relatively unfossiliferous as is the bulk of the intermediate white chalk which contains M. coranguinum and Echinocorys elevata a typical M. testudinarius Zone form. The lower 1 m of upper phosphatic chalk has yielded Gonioteuthis granulata, Micraster coranguinum, Echinocorys elevata and

other forms of Echinocorys, Marsupites testudinarius, 'Ostrea' boucheroni Coquand and 'O.' incurva Nilsson as well as elasmobranch teeth, comminuted Platyceramus and cidarid debris. This fauna also indicates the M. testudinarius Zone. Offaster pilula has been recorded (Willcox, 1953a) from 2 m above the base of the upper phosphatic chalk. The upper white chalk contains Gonioteuthis (?)granulataquadrata, Echinocorys, Gryphaeostrea canaliculata striata and Offaster pilula, indicating that the upper portion of the upper phosphatic chalk and the upper white chalk are referable to the early Campanian O. pilula Zone.

In conclusion, the biostratigraphy of the deposit demonstrates a complete (albeit severely attenuated) early Santonian to early Campanian succession. The top of the Chalk Rock lies 58 m below the top of the basal hardground (Willcox, 1953a), but elsewhere in the region, near Henley-on-Thames and Beaconsfield (Jukes-Browne and White, 1908; Sherlock et al., 1922), the top of the M. coranguinum Zone occurs 85 m above the Chalk Rock. This attenuation is even more marked in the overlying beds: the U. socialis Zone is only 70 cm thick and the M. testudinarius Zone 7.40 m, compared to a minimum thickness of 30 m for the two zones on the Kent coast and in the Hampshire Basin (Jukes-Browne and Hill, 1904).

2.11.2 Winterbourne (Berks) SU 448 723

The village of Winterbourne lies on the unclassified road that runs N - S to link the B4494 with the B4000, 5 km NNW of Newbury (Berks). A small farm quarry, recently reexcavated by the Nature Conservancy Council, is situated 100 m SW of Lower Farm, 400 m NNW of Winterbourne church and west of the track that joins Winterbourne Manor to Lower Farm (Fig. 2.106). The site is located at a height of 120 m OD in a region of predominantly late Coniacian to early Santonian M. coranguinum Zone chalk (White, 1907). The phosphatic nature of the section was first recognised by White and Treacher (1906) who undertook a detailed study of the area (White and Treacher, 1906; White, 1907).

Reexcavation of this SSSI (Site of Special Scientific Interest) in June 1978 exposed a 6 x 20 m long section that now provides the best exposure at the site since the turn of the century (Fig. 2.107). The lowest chalk (bed W1/1) was seen

quarry during the reexcavation. The sediment consists of a soft white chalk with

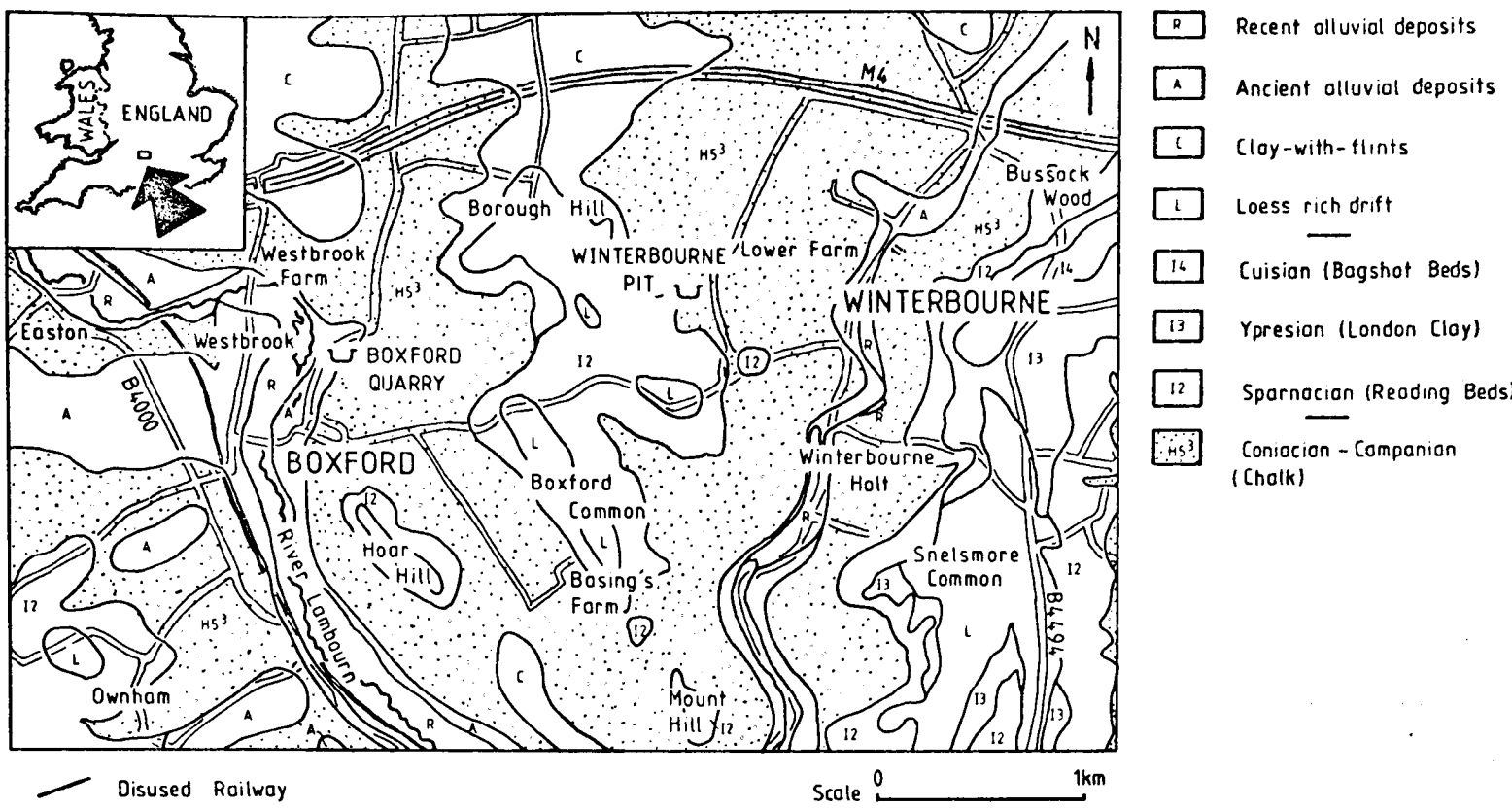


Fig. 2.106 Geological and location sketch map of Winterbourne pit and Boxford quarry. Based on the maps of the Ordnance and Geological Surveys.

scattered pelletal phosphate and rare small (< 1 cm) phosphatized and/or glauconitized intraclasts, the top of the bed being taken at the upper surface of a poorly-lithified hardground - the Winterbourne Lower Glauconitic Hardground. The hardground surface is indistinct, hummocky and discontinuous, but is clearly visible in the face. A horizon of superficially-phosphatized, 0.5 - 3.0 cm intraclasts with glauconitized cores and associated with a higher concentration of

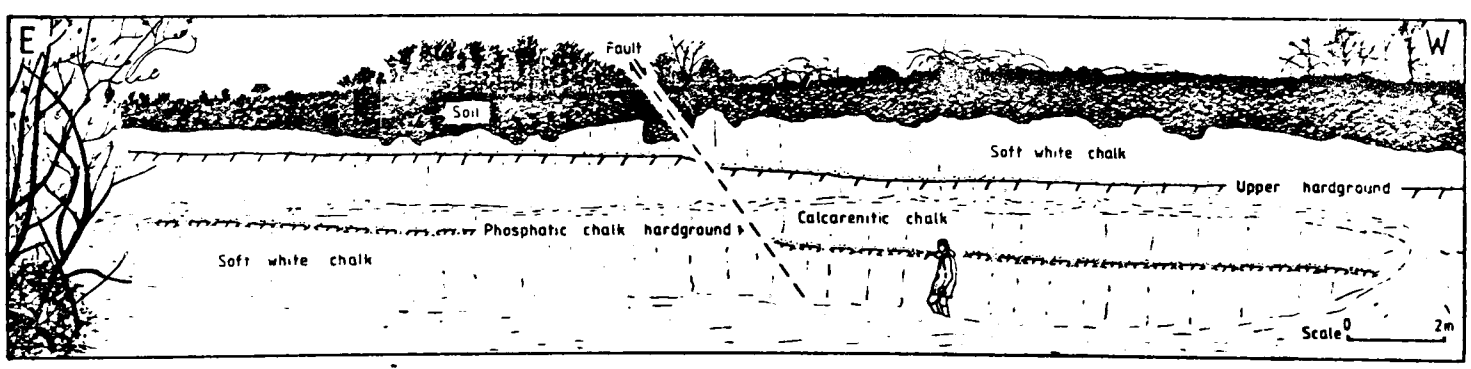


Fig. 2.107 Sketch of the reexcavated face of Winterbourne pit in June 1978.

pelletal phosphate occur on top of the hardground surface. This is overlain by 60 cm of white chalk (bed W1/2) with pelletal phosphate that is topped by a second glauconitic hardground - the Winterbourne Upper Glauconitic Hardground, identical in morphology to, but with a higher concentration of intraclasts than the lower. The upper hardground is overlain by 1.50 m of soft white chalk with pelletal

phosphate (bed W1/3) and scattered glauconitized/phosphatized intraclasts up to 1 cm across. The size and abundance of these intraclasts and the percentage of pelletal phosphate (phosphatized intraclasts, faecal pellets and fish debris) increase towards the summit of the unit where the chalk is penetrated by grey, pelletal-phosphate rich, calcarenitic-chalk filled Thalassinoides burrows originating from the overlying bed. The top of the bed is marked by a discontinuous, ~8 cm thick, irregularly-lithified surface - the Winterbourne Phosphatic Chalk Hardground. The hardground surface is weakly-glauconitized and limonite stained and bears pycnodonteine oysters and Gnathichnus-like scratch marks on lithified bosses up to 10 cm high that must have remained exposed when the bulk of the hardground was mantled in soft sediment. The lithified portions of the hardground are separated by the dense Thalassinoides system that penetrates the surface. The level is characterised by large numbers of ventriculitid and other sponges preserved as limonite-stained internal/external moulds in the indurated sediment of the hardground.

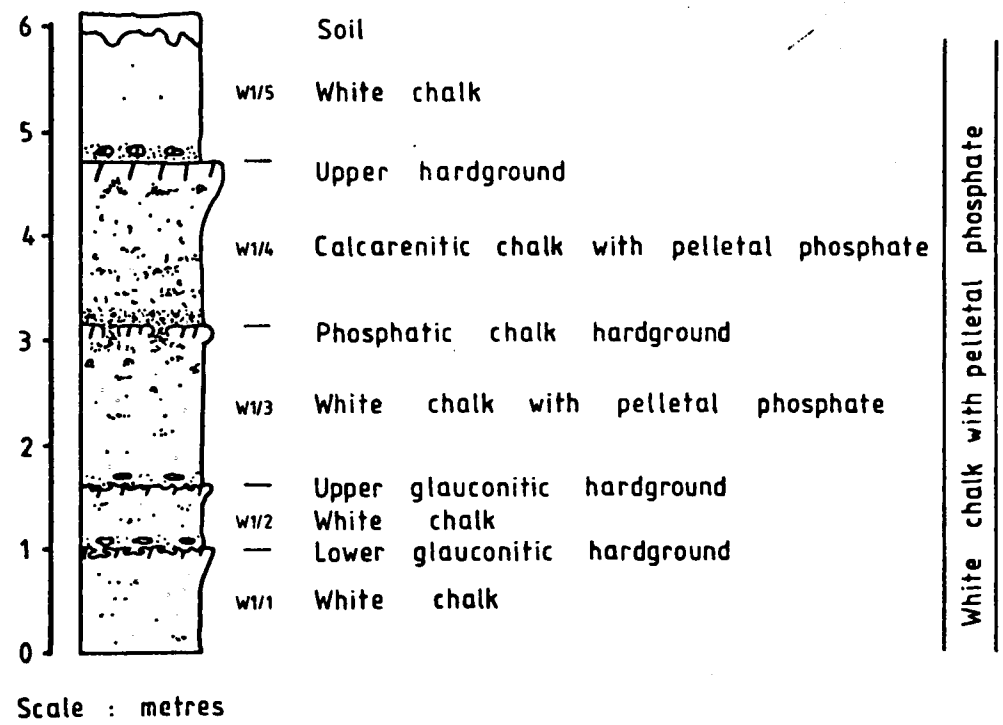


Fig. 2.108 Lithostratigraphy of Winterbourne pit.

The overlying 1.55 m of grey-white, calcarenitic chalk contains a high proportion of oyster and inoceramid debris and numerous phosphatized/glauconitized intraclasts up to 2 cm across and smaller, subangular phosphatized intraclasts. This bed (W1/4) contains a large percentage of pelletal phosphate in the lower 10 cm and scattered pelletal phosphate throughout. The top is taken at the surface of the 15 - 23 cm thick, strongly-lithified Winterbourne Upper Hardground. The

hardground sediment is limonite stained, weakly-glauconitized and phosphatized in some areas, and contains glauconitic intraclasts with phosphatized surfaces up to 10 cm across, angular - subangular phosphatized intraclasts up to 1.5 cm across, and small (<1 cm) goethitic nodules. Most of the larger intraclasts are welded into the body of the hardground by the lithified white chalk matrix but other younger examples, lie above its hummocky, well-defined, lightly-phosphatized upper surface that is encrusted by Pycnodonte, Spondylus and Plicatula. Composite moulds of ventriculitid sponges commonly occur within the hardground and dendritic manganese oxide coats most of the fracture surfaces.

The Winterbourne Upper Hardground is overlain by 1.25 m of white chalk (bed W1/5) composed of a 15 cm thick basal unit with pelletal phosphate (particularly phosphatized faecal pellets up to 1 mm across), subangular - rounded phosphatized intraclasts, scattered grains of glauconite and occasional subangular - well-rounded 0.5 mm quartz grains. The overlying 30 cm contains scattered phosphatized intraclasts, but above this, the chalk becomes fine-grained and phosphate-free. However, this highest chalk contains numerous 0.25 - 0.50 mm specks of iron and manganese oxides, is extensively limonite-stained and its fauna, particularly the Echinocorys, badly corroded. These and the underlying weathering effects are a result of the proximity to the directly overlying basal Tertiary unconformity with its pockets of iron-rich Reading Beds.

The late Santonian M. testudinarius Zone age of the chalk below the phosphatic chalk hardground is indicated by the presence of Marsupites testudinarius, which becomes abundant in the uppermost 30 - 60 cm of chalk overlying the Winterbourne Upper Glauconitic Hardground, where it is associated with Pycnodonte vesicularis, Spondylus spinosus (J. Sowerby), comminuted Platyceramus and composite moulds of ventriculitid sponges. M. testudinarius remains common in the lower 20 cm of the bed immediately overlying the Winterbourne Phosphatic Chalk Hardground, where it occurs with P. vesicularis, 'Ostrea' boucheroni and other oysters. Above this, the crinoid is scarce, but Actinocamax verus and Gonioteuthis granulata appear.

The disappearance of M. testudinarius 75 cm above the Winterbourne Phosphatic Chalk Hardground marks the top of that zone, the remainder of the bed being assigned to the early Campanian Echinocorys depressula Subzone, Offaster pilula

Zone. Echinocorys elevata is common immediately above the hardground and Spondylus latus (J. Sowerby). teredine bivalve siphonal tubes, ventriculitid sponges and elasmobranch teeth occur throughout the overlying bed. Micraster coranguinum rostratus is common in the upper levels of the bed, beyond the apparent range of M. testudinarius, although it is predominantly a M. testudinarius Zone form (Stokes, 1977).

Gonioteuthis granulata, Echinocorys tectiformis, Offaster pilula and ventriculitid sponges occur cemented into the lithified sediment of the Winterbourne Upper Hardground and become abundant in the overlying chalk indicating a correlation with the E. tectiformis belt (basal E. depressula Subzone, O.pilula Zone) of Hampshire (Brydone, 1912). The fauna from above the upper hardground has been severely etched and MnO stained by Tertiary weathering, so the majority of Echinocorys tests disintegrate on extraction, while most of the Gonioteuthis guards have lost their pseudoalveoli. The Riedel-Quotient of the Gonioteuthis at this level ranges from 4.5 - 6.0 (White and Treacher, 1906) so the 'population' as a whole must be referable to G. granulataquadrata (Stolley) or G. ex gr. quadrata (Ernst, 1964). The high concentration of fauna that overlies the upper hardground is restricted to the lower 30 cm of the overlying bed, above which no diagnostic fauna has been recorded.

Mapping of the region indicates that the phosphate-bearing chalks and the underlying poorly or non-phosphatic middle Santonian U. socialis Zone chalks lie in a synclinal or faulted structure beneath the horizontally bedded Tertiary cover of Borough and Basford Hills (White and Treacher, 1906 fig. 3). The U. socialis Zone chalk contains little phosphate and no hardgrounds so it cannot be regarded as the lower unit of a phosphatic chalk sequence. This, together with the known structure and the interpreted structural setting of Boxford quarry (see below) nearby suggests that the formation and preservation of the Winterbourne outlier results from intra-Upper Cretaceous tectonic movement. The occurrence of Coniacian tectonism at Boxford indicates that the area has been tectonically active several times during the late Cretaceous, and that the stratigraphical attenuation observed at both Winterbourne and Boxford allows younger chalks to be preserved beneath the Tertiary unconformity in the area.

2.11.3 Boxford (Berks) SU 431 719

The village of Boxford lies on the banks of the river Lambourne, 250 m east of the B4000, 6 km NW of Newbury (Berks). A chalk quarry, recently reexcavated by the Nature Conservancy Council, is situated 300 m NNE of Boxford church on the east side of the unclassified road that links the village of Leckhampstead (Fig. 2.106). The site is located at a height of 93 m OD in an area of exclusively late Coniacian to early Santonian M. coranguinum Zone chalk (White, 1907). The section was first described by White and Treacher (1906) and White (1907) but the faces were badly degraded at that time. The quarry was subsequently reopened and by 1924 exposed a section (Hawkins, 1924 fig. 34) similar to that seen today. The quarry was the second SSSI in the area to be reexcavated, and now provides an excellent and easily accessible exposure of the entire section (Fig. 2.109).

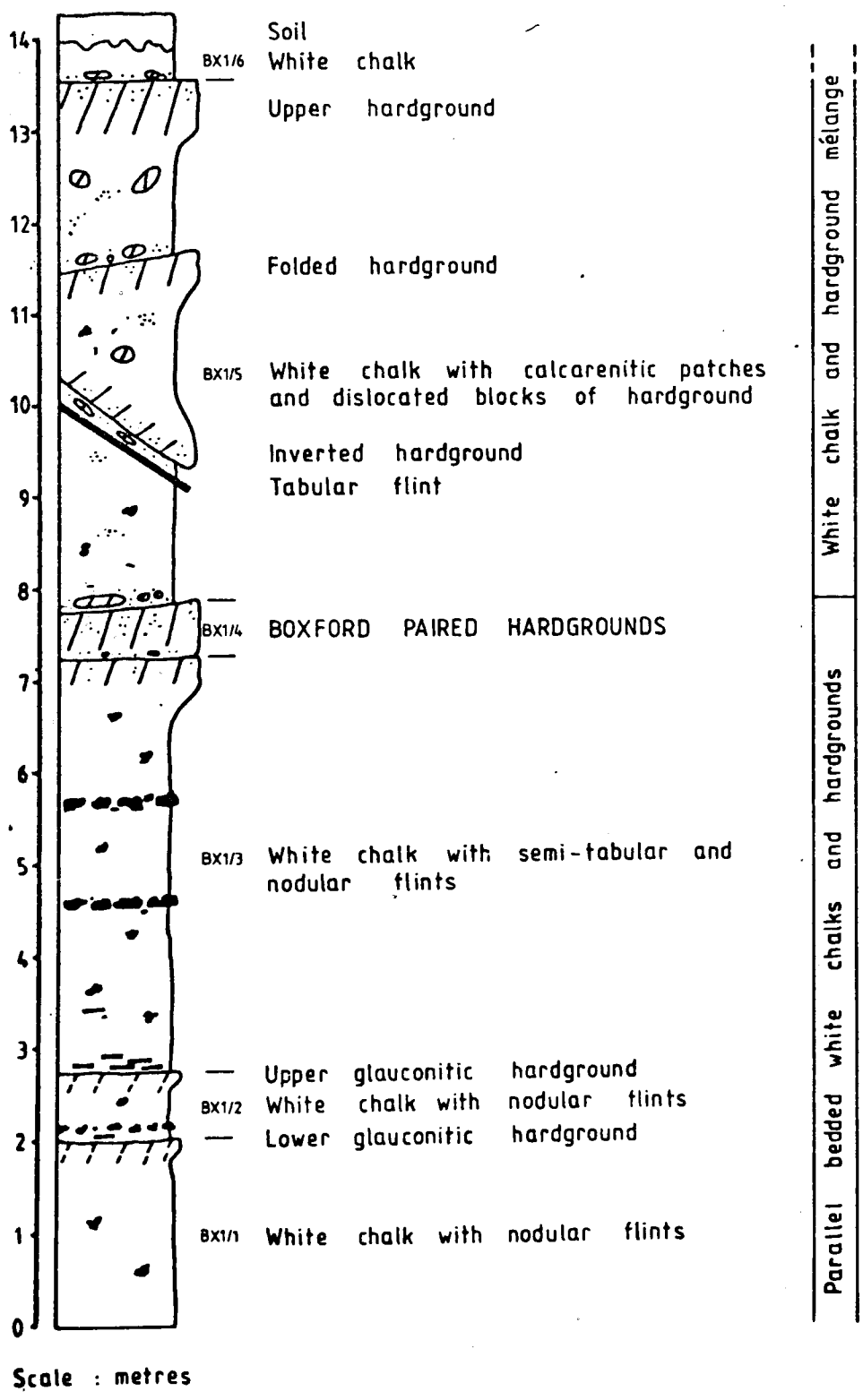


Fig. 2.109 Lithostratigraphy of Boxford quarry.

The oldest beds are exposed in a near-strike section at the northern end of the quarry. The base of the section consists of 2 m of soft white chalk (bed BX1/1) with scattered nodular flints and comminuted inoceramid debris throughout (Fig. 2.109), the top is taken at the weakly-glauconitized surface of a poorly-indurated hardground - the Boxford Lower Glauconitic Hardground. The hardground is overlain by 75 cm of white chalk (bed BX1/2) with scattered flints and inoceramid debris and a line of small nodular flints 15 cm above the base. The top of the bed is marked by a similarly-mineralized hardground - the Boxford Upper Glauconitic Hardground, which is followed by a white chalk containing numerous fragments of Platyceramus up to 10 cm across. The remainder of this bed (BX1/3) consists of $\sim 3\frac{1}{2}$ m of soft white chalk with scattered nodular flints throughout and two well-developed lines of semi-tabular flint, 1.80 and 2.90 m above the base respectively. The top of the bed is not seen in the northern section but the flint lines may be traced southwards into the main southern face where, in a dip section (Fig. 2.110), they are inclined at an angle of $\sim 25^{\circ}$ in a direction of 160° (SSE) and consequently disappear rapidly below the floor of the quarry (Fig. 2.111). The top of the bed



Fig. 2.110 The Boxford Paired Hardgrounds and underlying semi-tabular flint line (indicated) dipping below the floor of the quarry.

is here marked by a strongly-lithified, poorly-glauconitized hardground surface containing occasional bivalve borings. This hardground is closely (30 - 50 cm)

overlain by a second , with a planar surafce coated by a light-brown phosphate veneer and penetrated by soft white-chalk filled stenomorphic Thalassinoides burrows. The walls of these burrows have been glauconitized, and are commonly coated with phosphate skins to a depth of 10 cm below the hardground surface. These two hardgrounds are the most prominent feature of the quarry and they are here named the Boxford Paired Hardgrounds (BPH). The cemented sediment of the hardgrounds includes angular - subangular, 0.1 - 1.0 cm glauconitized intraclasts and a small proportion of pelletal phosphate and phosphatized intraclasts. Occasional voids are filled with calcite spar and 'pyrolusite' has been precipitated within the extensive fracture system that penetrates the hardgrounds. The upper hardground surface exhibits bivalve and worm borings and large indeterminate cavities, probably the relics of an eroded Thalassinoides system (cf. Bromley, 1975a fig. 18.10c), all of which have been infilled by a complex of phosphate veneers interlayered with phosphatized micrite. These complexes are cut by worm borings lined with phosphatized sediment that have been subsequently infilled with soft white chalk. The uppermost phosphate crust generally consists of a fine, discontinuous, filigree surface which is probably a secondary feature because weathering has corroded the surface of both hardgrounds over much of the exposure.

The two surfaces of the BPH are 50 cm apart and separated by soft white chalk at the southern end of the exposure (Fig. 2.111) but converge to 30 cm at the top of the northern end of the main face, where the base of the upper is welded onto the top of the lower to form a double hardground. Both hardgrounds and much of the surrounding chalk has been strongly limonite-stained in the form of Liesegang rings, which give the chalk a finely-laminated appearance (although it clearly

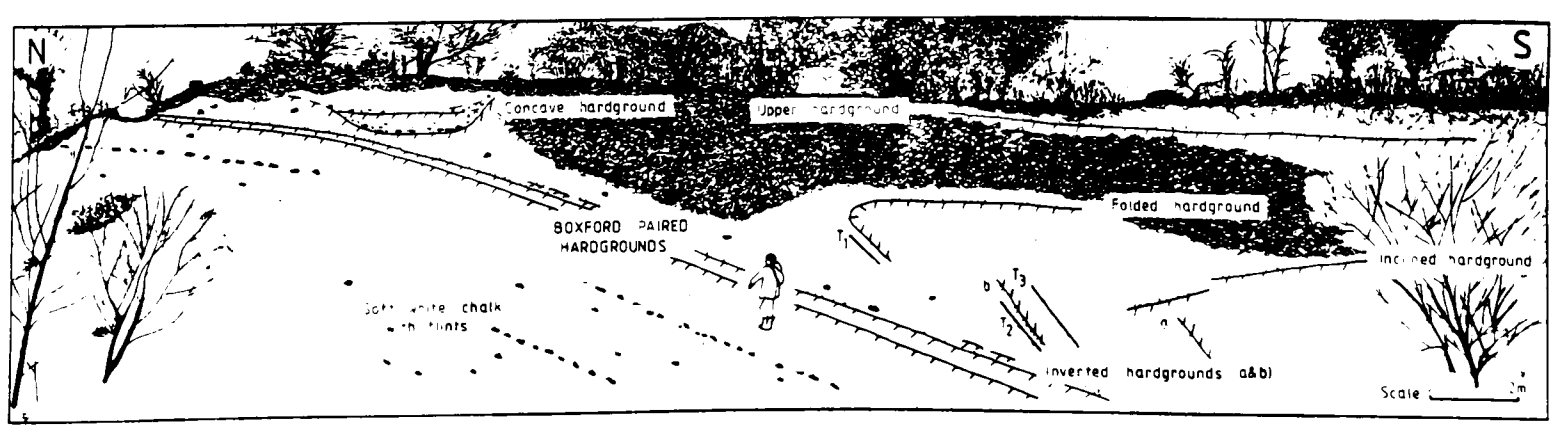


Fig. 2.111 Sketch of the reexcavated main face of Boxford quarry in June 1978.

does not reflect bedding). This prominent discolouration and lamination is interpreted as a weathering effect, probably resulting from the breakdown of primary pyrite within the hardground sediment coupled with a secondary concentration of iron leached from the overlying Tertiary deposits. Except for the convergence of their surfaces, the BPH are concordent with the bedding of the underlying soft white chalk (as inferred from the dip of the semi-tabular flints, which are generally good bedding indicators e.g. Håkansson et al., 1974; Hancock, 1975; Kennedy and Garrison, 1975) but above this, the section becomes more complex and the bedding discordant.

Above the BPH and occupying the major portion of the main face is a deposit here refered to as a mélange (the term is used descriptively French: mixture; no genetic connotations are implied) since it contains numerous blocks and fragments of dislocated hardground in a variety of orientations set in a matrix of calcarenitic chalk. The sizes of the hardground pieces vary from <1 cm to >10 cm across, the way-up of the larger blocks being determined by their mineralized (predominantly glauconitized) upper surfaces. Scattered nodular flints and three prominent tabular flints, apparently parallel to the (albeit disturbed) bedding, are present. The BPH are directly overlain by 30 cm (and smaller) slabs of glauconitized hardground in a few places (Fig. 2.111) but elsewhere hardground fragments are not found until some distance above the BPH. Although small fragments occur throughout the mélange there are five groups of large hardground blocks within the face, the:

(1) inverted hardgrounds, (2) inclined hardground, (3) folded hardground,

(4) concave hardground, (5) upper hardground.

The inverted hardgrounds (a and b in Fig. 2.111) are situated at the southern end of the face just above the BPH. They consist of two 1 - 2 m blocks of overturned hardground surrounded by soft chalk. The northern end of the two blocks is associated with two tabular flints (T2 and T3 in Fig. 2.111) which occur in the soft chalk immediately underlying and overlying the block. These flints may have formed along shear planes produced during the emplacement of the block or they may reflect primary bedding in soft white chalk that remained attached to the hardground during dislocation. Whatever the cause of the discontinuity that the

tabulars indicate, flint formation almost certainly postdates movement of the hardgroud blocks.

Above, and slightly south, of the inverted hardgrounds, a single continuous $2\frac{1}{2}$ m long stretch of hardground dips northwards towards the BPH. This inclined hardground is probably the southern portion of the hardground indicated by Hawkins (1924 fig. 34) although he incorrectly interpreted it as a faulted continuation of another block (the folded hardground?). The southern termination of the inclined hardground is obscured by talus but to the north it abruptly passes into soft chalk.

North and upslope, but at a similar height above the BPH, a third hardground runs horizontally across the face for a distance of $2\frac{1}{2}$ m. Its southern end terminates abruptly but its northern end is downturned with a dip of 130° in a direction of 150° (SSE) before also terminating against soft sediment. The folded portion of the hardground is overlain by a tabular flint (T1 in Fig. 2.111), in a similar position and probably with a comparable history to the tabulars associated with the inverted hardgrounds.

Perhaps the most complex hardground association occurs at the northern end of the main face. Here, a hardground with a glauconitized surface curves concavely upwards over a visible distance of 4 m, to form a small basin with both ends passing out of the top of the quarry. In the deeper part of the bow this hardground is overlain by a soft chalk containing abundant pelletal phosphate (phosphatized faecal pellets, intraclasts and internal moulds of globigerinid foraminiferans with occasional fish debris), pelletal glauconite and subangular - angular glauconitized intraclasts up to 5 mm across. These components are concentrated in poorly-defined burrow-fills surrounded by a similar but poorer phosphatic chalk. Large (up to 10 cm), superficially-mineralized, phosphatized and/or glauconitized intraclasts (which occur throughout the whole mélange) are particularly prominent at this level. This is the only exposure of phosphatic chalk similar to that recorded by White and Treacher (1906) although small amounts of phosphatic material are also associated with the BPH and the detached blocks of hardground. The top of the phosphatic chalk is marked by the surface of a second glauconitized hardground surface that partly fills the concavity of the lower. Syndepositional

fracturing of this upper surface is demonstrated by the development of a crevice fauna of pycnodonteine oysters cemented in-place on the walls of the upper parts of the vertical cracks with their hinge lines vertical. Intraclasts and small detached blocks of hardground surface also overlie this second top. The three-dimensional nature of the concave hardground is unknown, its clarification being hampered by the proximity of the hardground to the top of the quarry where hill-cambering and soil-creep may have modified its primary morphology.

The final hardground seen within the bed (BX1/5) occurs at the top of the quarry face, apparently dipping at a few degrees to the south. True-dip may be much greater because in this part of the quarry the face swings back to the west to become a near-strike section. This upper hardground is continuous over a distance of ~6 m and resembles the upper surface of the BPH in detailed morphology. The stenomorphic Thalassinoides that penetrate the lithified sediment are particularly well-displayed and the phosphatized top is overlain by a limonite-stained white chalk containing numerous, large (up to 10 cm) fragments of Platyceramus. Both the concave and the upper hardgrounds are truncated by the quarry top and may therefore be in situ and possibly not dislocated blocks, as is clearly the case with the lower three hardgrounds.

Good specimens of Volviceramus involutus (J. de C. Sowerby) have been recovered from immediately above the Lower and Upper Glauconitic Hardgrounds; Hagenowia rostrata Forbes, Micraster coranguinum, M. cf. bucaillei (Parent), Kingena lima, Plagiostoma, Porosphaera, Bourgueticrinus, bryozoans, serpulids, cidarid and star-fish debris occur in association with abundant oyster and inoceramid fragments in the white chalk above the Boxford Upper Glauconitic Hardground. Fauna recorded from the BPH is restricted to Gibbithyris sp. and teredine bivalve siphonal tubes.

The coarse chalk of the mélange contains abundant Pycnodonte vesicularis and occasional Gryphaeostrea canaliculata, Exogyra sigmoidea Reuss, Chlamys cretosus (Defrance), Micraster coranguinum, Echinocorys sp., elasmobranch teeth, bryozoans, cidarid and inoceramid debris.

The faunal association of the parallel bedded white chalks and hardgrounds (Fig. 2.111) below the BPH and particularly the index fossils V. involutus, H. rostrata and M. cf. bucaillei clearly indicate a late Coniacian age and there-

fore within most interpretations of the lower part of the M. coranguinum Zone, and not high in that zone (i.e. Santonian) as suggested by White and Treacher (1906). Tha association within the mélange and above is poorly diagnostic and little more can be said than that it is either Coniacian or Santonian in age. Inoceramus cf. cordiformis J. de C. Sowerby has been found above the concave hardground and this is a definite low-mid Santonian index so the mélange must be of late Coniacian to mid Santonian age. It was noted that no unduloplicate inocermids (common at several levels within the basal Santonian) were recovered suggesting that there are no beds of early Santonian age at Boxford.

The lack of lateral control on the Boxford structure makes it impossible to determine a unique mechanism for its formation but any model must explain two important properties of the exposure. Firstly, the upper surface of the dipping BPH is parallel to the underlying bedding as indicated by the semi-tabular flints and secondly the sediment above the BPH is clacarenitic and contains numerous detached and deformed blocks of hardground on a variety of scales.

The features displayed at Boxford quarry appear to be of limited lateral extent since mapping (White and Treacher, 1906; White, 1907) has indicated that 500 m to the SSW of Boxford church the chalk is within the late Santonian U. socialis Zone. Blocks of hardground may be traced in the field rubble 300 - 400 m south and north-east of the quarry, on the eastern side of the Boxford - Leckhampstead road. Phosphatic chalk, of similar age, is also known from the western side of that road 500 m NNE of Boxford church.

No phosphatic chalk or well-developed hardgrounds similar to the BPH are known to me from the late Coniacian to early Santonian of southern England. However, there are records of other hardgrounds possibly of similar age in the western part of the London Basin. White (1907) recorded one near Oare, to the north of the Vale of Pewsey and later (White, 1909) listed several pits to the south of Basingstoke with iron-stained hard layers; Hawkins (1942) recorded what he termed the Whitway Rock in the Kingsclere-Whitway area. I have not seen any of these examples and they may indicate that the conditions which formed the Boxford hardgrounds extended some distance at that time; however there is no evidence that they occur in association with disturbed sediments similar to the Boxford deposits.

The observation that the flint lines below the BPH are concordant with the upper surface of the couplet suggests that the inclination of the hardgrounds and underlying beds is due to tectonic disturbance rather than in situ erosion as is the case with the Picardy and Taplow basal hardgrounds. An accretionary origin for the observed dips cannot be entirely discounted but is considered very unlikely in view of the normal nature of the soft white chalk. The convergence of the BPH towards the top of the quarry might be taken to indicate that after the formation of the lower hardground of the couplet (horizontal and parallel to the underlying beds) slight uplift occurred to the NNW, prior to or contemporaneous with the formation of the upper hardground, which caused the observed hardground convergence through up-dip erosion of sediment. However, the convergence is so small (1 in 75) that it is more likely to have been caused by any one of a number of depositional variations during hardground formation. This is supported by the fact that hard-ground convergence of this order is fairly common at other localities. The most likely explanation for the observed tectonic disturbance of the lower beds is that in-situ tilting, controlled by faulting, occurred after its deposition in a horizontal position. It is also possible that the entire lower unit is an olisto-lith and therefore out of situ, perhaps a large basal fragment to the overlying mélange. However, there is no known analogue for the movement of such large blocks in a shelf environment so the lower beds are regarded as being essentially in situ.

The mélange portion of the upper beds is considered to represent a mass flow deposit emplaced in one event following down-slope transit. The recumbent nose of the folded hardground is comparable to similar deformation which results from limited downslope movements of portions of basal hardground in the phosphatic chalk cuvettes of Picardy (Chapter 3). It is suggested, therefore, that the folded hardground was produced by shearing during transit or when the flow came to rest against the southward dipping slope of the BPH. Below the folded hardground, the inclined and inverted hardgrounds resemble the fractured and dislocated pieces of a further recumbent fold. These large fragments of hardground within the mélange suggest that mass movement was from the south and that it terminated against the south dipping surface of the BPH. Debris flows may be initiated through instability arising from oversteepening in channels but the lack of erosional truncation at

the base of the upper beds or significant discordance between the BPH and the underlying chalks indicate a wholly tectonic origin.

The timing of the movement of the lower beds relative to the mélange could have been before, during or after its emplacement. I have found no evidence to firmly settle this point largely because the mélange lacks its own indications of bedding. However, as the interpretation of the mélange requires the previous existence of some topography, movement of the lower beds before or during mélange emplacement is considered most likely.

Following from the above discussion the most likely history of events is considered to be:

(1) Mid to late Coniacian: Two periods of uplift, probably related to basement faulting, caused local planar erosion resulting in the formation of the Glauconitic and Boxford Paired Hardgrounds.

(2) Late Coniacian to mid Santonian : A major faulting episode with faults reaching the seafloor produced an upthrown area to the south of the present quarry. During or immediately after faulting sediment on the upthrown side of the fault became gravitationally unstable. Sediment moved downslope en-mass, filling the downthrown region. Shearing during transit fractured and folded the included hardground(s) to produce the present mélange.

(3) Mid Santonian: Scouring and sediment winnowing over the still regionally high area, which had earlier produced the coarse calcarenitic sediments of the mélange matrix, formed the concave and upper hardgrounds concentrating pelletal phosphate in the former.

The evidence for a tectonic control of the sedimentary structures at Boxford has been presented above. A further question raised by this site is how far the formation of hardgrounds was directly related to tectonism. At several times during the late Cretaceous (early and late Turonian, early Coniacian, late Santonian) there was geographically widespread hardground development but these phases correlate with eustatic falls in sealevel (Cooper, 1977; Hancock, 1975) and do not require local or regional tectonism for their formation. Although hardgrounds may preferentially form over regionally high areas, their occurrence in basinal regions and at the base of both small and large scour channels (Chapter 3) suggests that

local environmental conditions were of equal importance. The Boxford hardgrounds are therefore unlike most known Upper Cretaceous hardgrounds in southern England in that they are geographically restricted and at a stratigraphical level which contains few other hardgrounds. It is suggested therefore that the association with local tectonism is more than fortuitous and that uplift and subsequent erosion of the Boxford area initiated hardground formation.

2.11.4 Lavant (West Sussex) SU 835 098

The area of country known as Lavant lies on either side of the River Lavant, north of the villages of Mid Lavant and East Lavant, 3½ km north of Chichester (West Sussex). A small chalk quarry was located at a height of 75 m OD, 400 m NE of Stoke Clump, 1100 m west of Langford Farm (Fig. 2.112), 2½ km NW of the village of Mid Lavant (Gaster, 1944; Palaeontographical Society, 1954). The quarry has since been abandoned and filled although a depression remains at the site which is now part of the field system; exposure is limited to field rubble.

The locality was recorded as a phosphatic chalk site by Gaster (1944) who gives a short faunal list but no information concerning the lithostratigraphy. A number of facies are represented in blocks recovered by me:

(1) Indurated white chalk containing rounded - subangular phosphatized and glauconitized intraclasts up to 1 cm across and scattered pelletal phosphate

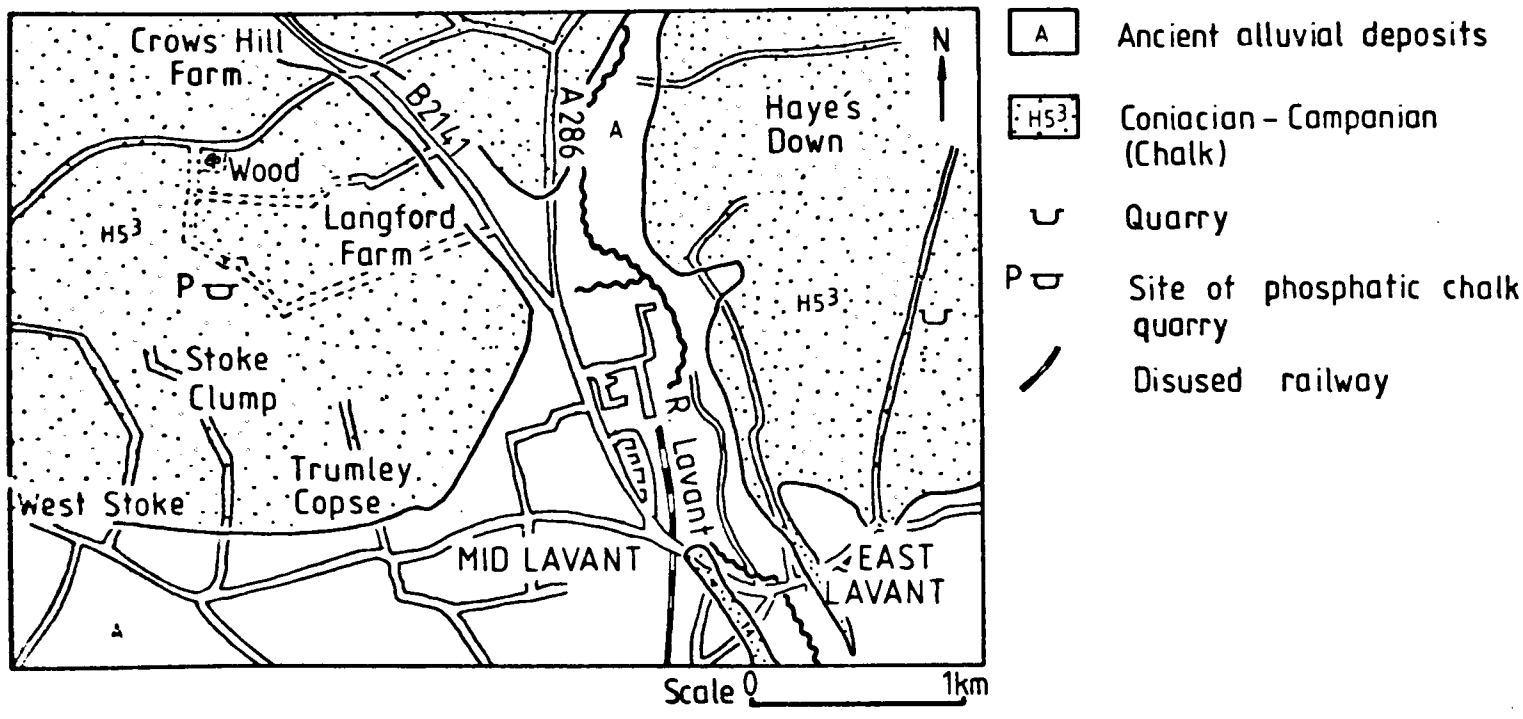


Fig. 2.112 Geological and location sketch map of the Lavant phosphatic chalk site. Based on the maps of the Ordnance and Geological Surveys.

and glauconite. Some specimens exhibit phosphatized and shiny phosphate veneered surfaces, commonly with phosphatized-sediment lined worm borings, the walls of which have also been phosphatized. Voids are occasionally present but they are commonly part-filled with calcite spar.

(2) Occasional bored and phosphatized/glauconitized intraclasts up to 3 cm across and coated with iridescent phosphate patina.

(3) Coarse phosphatic chalk with a lithified micrite matrix. The large component consists of clionid sponge bored, subangular - rounded phosphatized intraclasts up to 1 cm across, glauconitized intraclasts from 0.1 to 1.0 cm across, and bioclastic debris, particularly fragmented scleractinian coral, oyster and inoceramid. Only the walls of the coral have been preserved in calcite the resulting internal cavity being filled with micrite. The micritic matrix contains a high proportion of sand-grade pelletal phosphate so that the lithology is identical to poorly-silicified portions of the Beauval Coral Bed (2.3.2; Fig. 2.17).

(4) Coarse phosphorite containing 10 - 20% angular - subangular, 1 - 5 mm, lightly-phosphatized intraclasts and a similar percentage of pelletal phosphate, the remainder of the rock consisting almost entirely of calcisponge spicules.

(5) Calcisponge-spicule calcarenite of three varieties (see Section 3.5):

(a) grain supported with virtually no matrix,

(b) grain supported but with all void space filled by calcite spar,

(c) micritic matrix supported.

Type (b) forms large (up to 30 cm) blocks of limestone in the field rubble but most examples pass into type (a) at their margins suggesting that they are the result of calcite precipitation caused by weathering processes. All three varieties contain varying amounts of accessory pelletal phosphate and specimens transitional between types (4) and (5) are common.

The facies listed above are ordered in what is interpreted to be their relative stratigraphical positions (i.e. basal hardground overlain by progressively less-phosphatic calcarenites). The majority of blocks recovered, however, are of type (5) or normal soft white chalk, other facies being poorly represented.

The fauna recovered from the locality includes numerous elasmobranch teeth, Offaster pilula, Gryphaeostrea canaliculata striata, Terebratulina rowei and large Serpula ilium J. Sowerby, indicating the early Campanian, abundant O. pilula Subzone of the O. pilula Zone.

The lithologies present are typical of a basal hardground phosphatic chalk sequence although the abundance of calcisponge spicules within all varieties of phosphatic chalk is unique. The coarse nature of the carbonate component and the lack of high-grade phosphorite is very similar to that seen at Hallencourt quarry and in the upper part of the section at Orville, both of which are also of abundant O. pilula Subzone age. Unfortunately exposure is poor and trial pits have revealed no further data concerning the lateral extent of the deposit.

2.11.5 Whitecliff Ledge (Isle of Wight) SZ 639 855

Whitecliff Ledge is situated between Culver Cliff and Whitecliff Bay, 4 km ESE of Shanklin and 2½ km SSW of Bembridge on the east coast of the Isle of Wight. The section between Culver Cliff and Whitecliff Bay displays a complete succession from the early Cenomanian to late Campanian, but the only phosphatic chalk in the sequence occurs in 17½ m of section known as the "flintless area" (Rowe, 1908 p245) which is situated on Whitecliff Ledge, 70 m NE of Hermits Hole (Fig. 2.113).

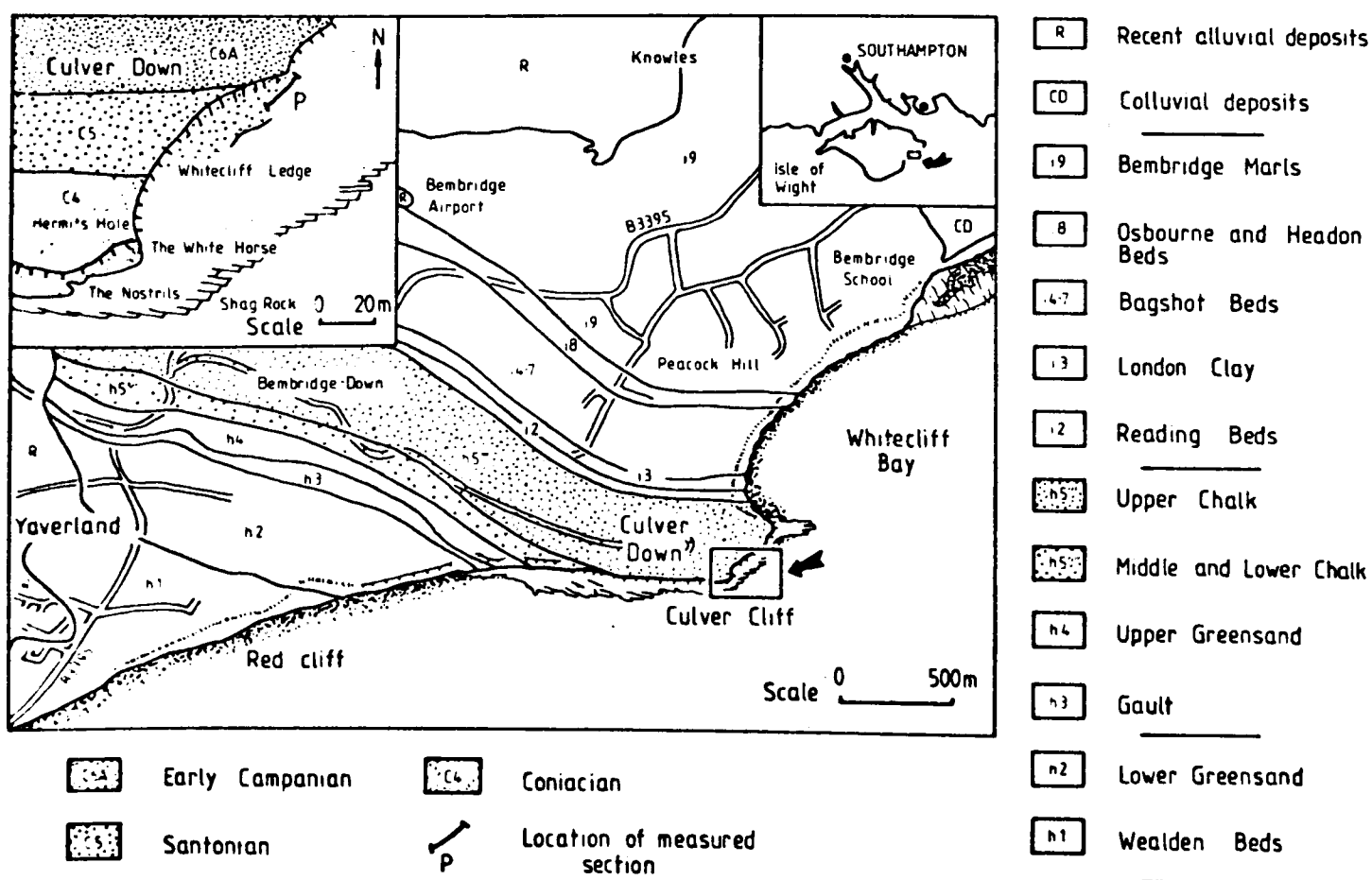


Fig. 2.113 Geological maps of the Culver Down region, Isle of Wight showing the location of the Whitecliff Ledge "flintless unit".

The abnormal nature of this part of the section was first recorded by Whitaker (1865) who recognised the absence of nodular flint in a succession that otherwise contains a flint line every 0.5 - 3.0 m. He also described four glauconitic 'nodule beds' within the "flintless area". These glauconitic 'nodules' were described in more detail by Hill (in Bristow et al., 1889) and refered to by White (1921). The only measured section was provided by Rowe (1908 p.245) and it was only recently recognised (Middlemiss and Bromley, 1962) that the succession contains five and not four 'nodule beds'.

The final nodular flint below the "flintless unit" is overlain by 2.15 m of soft white chalk (bed WC1/1) containing a thin marl seam 75 cm from its base (Fig. 2.114). The top of the bed is the surface of a poorly-lithified, glauconitized hardground - the Whitecliff Ledge First Glauconitic Hardground, which is closely (35 cm) overlain by a second similar hardground surface - the Whitecliff Ledge Second Glauconitic Hardground. Glauconitized intraclasts up to 5 cm across occur above, and are contained within, the lithified sediment of both of these hardgrounds which together correspond to Rowe's (1908 p.245) fourth nodule bed (Rowe inadvertently inverted the details given in his account of this part of the succession). The second glauconitic hardground is overlain by 3.00 m of soft white chalk containing two marl seams, 0.75 and 1.15 m above the base. The uppermost 50 cm of this bed (WC1/3) becomes increasingly indurated and its top is taken at the phosphatized, glauconitized and limonite-stained, convolute surface of a well-developed hardground - the Whitecliff Ledge Phosphatized Hardground (Rowe's third nodule bed). A second less-prominent hardground surface lies 20 cm above the first and is termed the Whitecliff Ledge Third Glauconitic Hardground. Although only poorly-lithified the latter hardground is overlain by 5 cm of sediment containing abundant pelletal glauconite, particularly at the base. The remainder of the overlying bed (WC1/5) is a soft white chalk with four distinct marl seams, marl wisps and a discontinuous tabular flint 2.70 m above the base. A lightly limonite-stained surface - the Whitecliff Ledge Limonitic Hardground, marks the top of the bed. The overlying 1.50 m of white chalk (WC1/6) includes a discontinuous tabular flint 25 cm above the limonitic hardground and a marl seam 75 cm above. The top is taken at the prominent convolute surface of a glauconitized, phosphatized and limonite stained

hardground - the Whitecliff Ledge Lower Phosphatic Chalk Hardground. Lithification penetrates to a depth of 30 cm below the surface where slight hardening is associated with a phosphatic-chalk filled Thalassinoides system. The overlying 10 cm of phosphatic chalk becomes progressively less-phosphatic away from the surface of the hardground and never attains the richness of the phosphorite preserved in the burrow that penetrate it. A similar but less convolute hardground

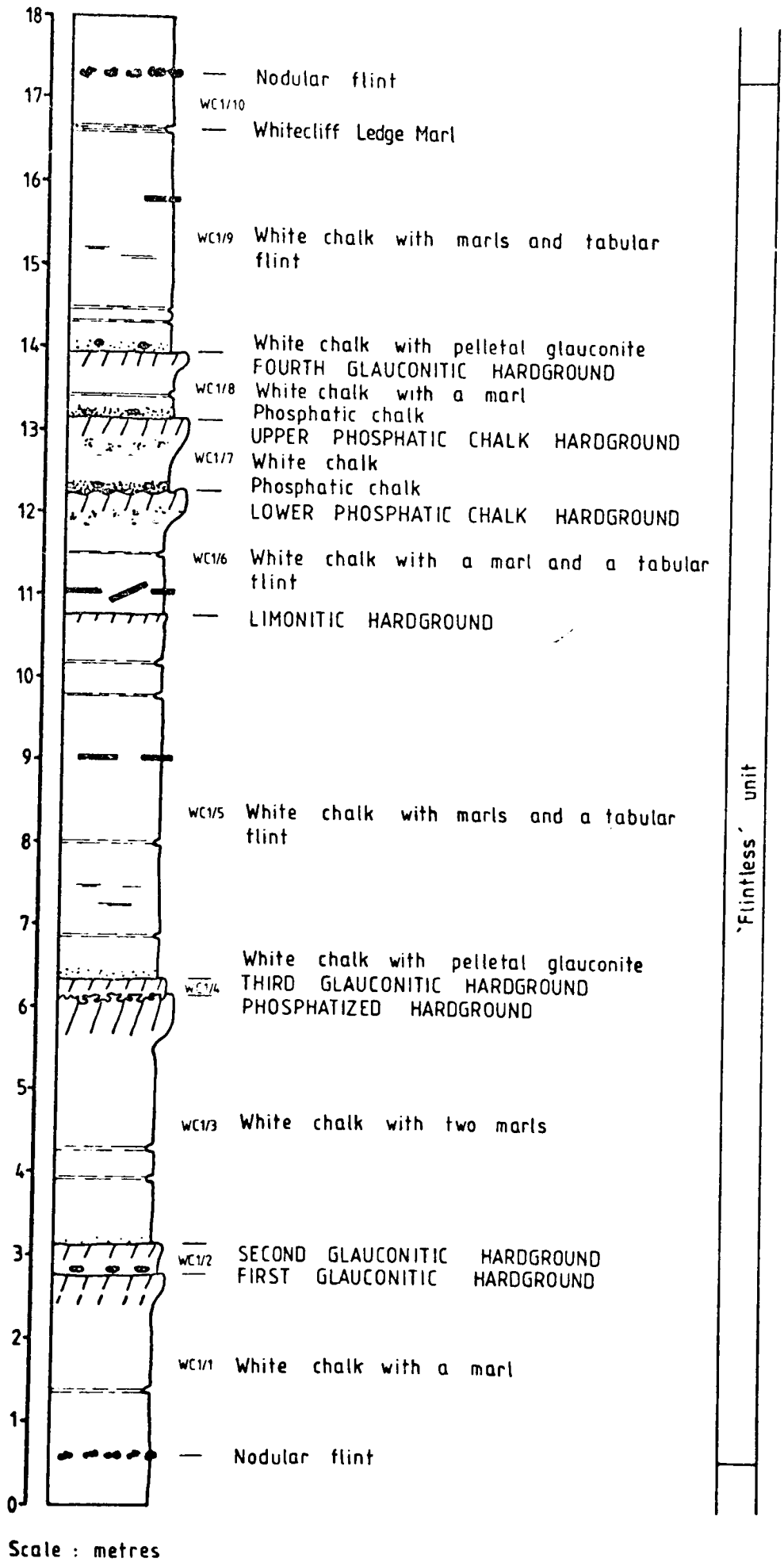


Fig. 2.114 Lithostratigraphy of the "flintless unit" Whitecliff Ledge, Isle of Wight.

surface - the Whitecliff Ledge Upper Phosphatic Chalk Hardground lies 1.90 m above the lower (the two hardgrounds together correspond to Rowe's second nodule bed). Again penetrated by a phosphatic-chalk filled Thalassinoides system, lithification is less pronounced and the pelletal phosphate content lower than in the underlying sequence. A marl seam occurs 25 cm above the top of the upper phosphatic chalk hardground and the surface of the Whitecliff Ledge Fourth Glauconitic Hardground, 80 cm above. The body of this final hardground (Rowe's first nodule bed) encloses dark-green glauconitized intraclasts with pyritic cores. These were described by Hill (in Bristow et al., 1889) who noted the abundance of calcite preserved silici-sponge spicules within the nodules. The glauconitized surface of the hardground is overlain by a pelletal-glauconite rich sediment (attaining greensand-like proportions in thin ($\leqslant 5$ mm) flaser seams) and common Offaster pilula. The termination of the "flintless unit" is marked by a nodular flint 3.35 m above the Whitecliff Ledge Fourth Glauconitic Hardground, although a prominent marl seam - the Whitecliff Ledge Marl, 2.70 m above the base, divides the overlying white chalk into two beds (WC1/9, WC1/10).

Rowe (1908) recorded Marsupites testudinarius from the lithified sediment of the Whitecliff Ledge First Glauconitic Hardground and Gonioteuthis granulata from the Whitecliff Ledge Phosphatized Hardground, placing the M. testudinarius/O. pilula Zone boundary (Santonian/Campanian) midway between these two hardgrounds. Offaster pilula and Echinocorys sp. occur in the sediment immediately overlying the Whitecliff Ledge Third Glauconitic Hardground and O. pilula, Serpula plexus, 'Rhynchonella' plicatilis, Coelosmilia laxa Edwards and Haine, Crateraster quinquelobus Goldfuss and sponges have been recorded (Bristow et al., 1889; Strahan in Jukes-Browne and Hill, 1904; Rowe, 1908; White, 1921) from the uppermost three hardgrounds, indicating that the remainder of the unit may be refered to the early Campanian O.pilula Zone. Unfortunately, insufficient material has been collected from the poorly exposed section overlying the "flintless unit" to fix the O. pilula/G. quadrata Zone boundary, but Rowe (1908) considered that the G. quadrata/B. mucronata Zone boundary is situated $\sim$105 m above the top of the unit.

2.12 Conclusions

2.12.1 Lithostratigraphy

All exposures have a large number of features in common but Beauval quarry (Section 2.3.2) provides the most complete assemblage of features believed to be typical of phosphatic chalk deposits. These features are:

(1) The occurrence of a cuvette cutting into the underlying white chalk (Fig. 2.62) and delimiting the area of phosphorite deposition. This erosional relationship can best be seen at Hallencourt quarry (Fig. 2.64) but other clear examples are recorded from Templeux-la-Fosse (Fig. 2.42), Templeux-le-Guérard (Fig. 2.56), Sénercy (Fig. 2.83) and Ribemont (Fig. 2.87).

(2) The presence of a strongly indurated and mineralized hardground - here termed the basal hardground, at the base of the cuvettes which acts as the lower boundary to the phosphatic chalk unit. This hardground is developed in a winnow coarsened sediment (Chapter 3) of late Coniacian to early Santonian (e.g. Beauval quarry, Hallencourt pit) or late Santonian (e.g. Hallencourt quarry) age (see below).

(3) Demonstrable and commonly visible topography on the basal hardground surface, on a variety of scales, from a few millimetres to several metres.

(4) The occurrence of a distinctive intraclast pebble lag, designated the basal lag, on top of the basal hardground particularly in depressions, which contains a prolific, varied and highly distinctive fauna typified by 'Terebella' phosphatica Leriche (a worm tube) and Diblasus arborescens Parent (an ahermatypic compound scleractinian coral) patch reefs with abundant oysters.

(5) A phosphatic chalk unit up to 17 m thick having a rapidly transitional, sometimes sharp upper limit returning to normal soft white chalk deposition.

(6) Synsedimentary folding and dislocation of the basal hardground after or during the deposition of the overlying phosphorite, and prior to the return of white chalk deposition.

(7) A repetition or repetitions of phosphatic chalk deposition with the same sequence of basal hardground, basal lag and phosphatic chalk. No folding has

been observed or described from later units of phosphatic chalk.

(8) A ubiquitous faunal sequence occurring in the upper part of the youngest phosphatic chalk unit and typified by beds of Offaster pilula and Gonioteuthis quadrata quadrata.

The sedimentological implications of these conclusions will be considered in the next chapter.

2.12.2 Biostratigraphy

The biostratigraphical correlation of the extant exposures is shown in Fig. 2.115. Macrofaunal zonation is hampered by the absence of the zonal crinoids of the middle and late Santonian in the majority of sections, and causes the location of the U. socialis and M. testudinarius Zone boundaries to be somewhat arbitrary. Correlation is, however, considerably improved by the incorporation of echinoid and belemnite (Chapter 5) distributions and the foraminiferal data, which are in general accord with the macrofauna. Except for the atypical Boxford quarry section (Section 2.11.3), all of the deposits are of Santonian mid M. coranguinum Zone to early Campanian O. pilula Zone age, the bulk of the phosphorite being of post-U. socialis Zone age.

The age of the oldest phosphatic chalk varies considerably from site to site, and although all basal hardgrounds are overlain by post-Coniacian basal lags, only the stratigraphically lowest contain Actinocamax verus and Gonioteuthis granulata. In the upper portion of many of the youngest phosphorite, however, a distinct faunal sequence may be discerned. A bed of belemnites occurs just below the highest phosphatic chalk; Gonioteuthis quadrata quadrata with rare Belemnitella ex gr. praecursor. This band overlies, but is separated from, a bed of Offaster pilula. The occurrence of Echinocorys truncata (Griffith and Brydone) from below and within the latter bed indicates that it corresponds to the lower belt of O. pilula, Subzone of abundant O. pilula (Brydone, 1914). Rare Echinocorys cincta (Brydone) occur above the Offaster Beds indicating that the age of the youngest phosphatic chalk is probably within the E. cincta level of Brydone (1914). Tabatabaï (1977) dates this final period of phosphatization as being within Bio-

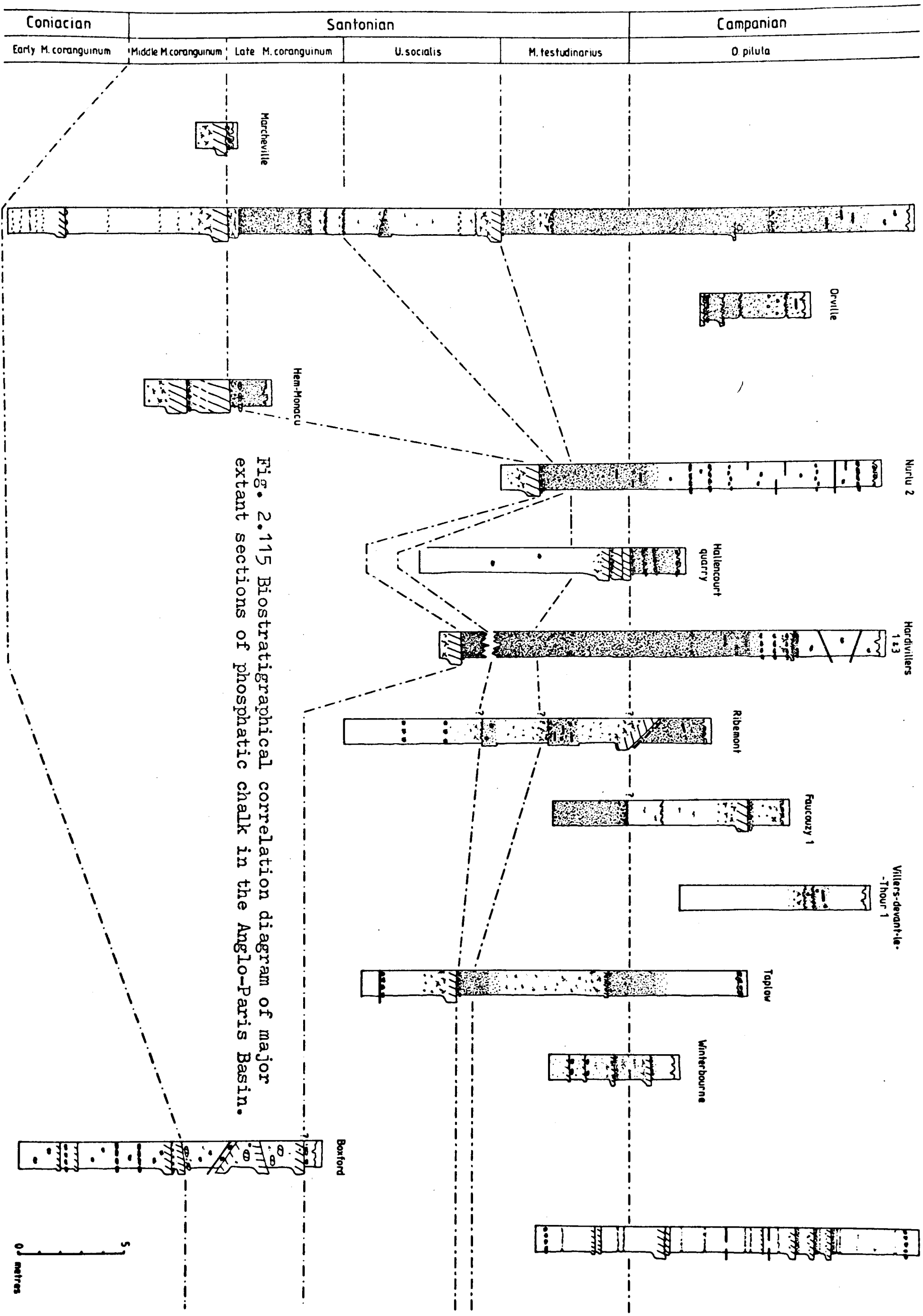


Fig. 2.115 Biostratigraphical correlation diagram of major extant sections of phosphatic chalk in the Anglo-Paris Basin.

zone h at most sites.

Comparisons of the thicknesses of the zones and biozones in soft white chalk and phosphatic chalk lithofacies are given in Tables 2.1 and 2.2. In northern France (Table 2.1) the data demonstrate that phosphatic chalks show varying degrees of attenuation and lie within regions where the associated white chalks of comparable age are also thinner. This trend is demonstrated by comparing the thickness of Biozones e, f and g in phosphatic chalks (Group A), white chalks in the same region (Group B) and white chalks elsewhere in the Anglo-Paris Basin (Group C). Thus Biozone e is thicker at Beauval in a phosphatic chalk facies than in the vicinity of Roye in a white chalk facies; similarly Biozone g is a comparable thickness at Beauval, Albert and Roye, yet is only 25 - 30% of the thickness of the chalk of that age in the Yonne (Group C). This relationship is also seen when the phosphorites are compared with the Chalk of the south-east coast of England (Table 2.2). Clearly other sections show more pronounced attenuation than Beauval but two important conclusions can be reached from these data:

(1) the environmental changes that resulted in the accumulation of phosphatic chalks caused corresponding reductions in the thickness of white chalks in the same area, and

(2) although most Santonian to early Campanian white chalks contain some pelletal phosphate, the percentage is several orders of magnitude too small (Chapter 3) to produce a phosphatic chalk by removal of the micritic component alone, at least by the attenuation observed in these deposits. Thus, winnowing alone is insufficient to derive a phosphorite from a white chalk.

Palaeobiological aspects of the biostratigraphy will be discussed in Chapter 5.

	Locality	Coniacian			Santonian			Campanian		
		a	b	c	d	e	f	g	h	i
A	Beauval*1 (Somme)				>16	8	2	11	>7	
	Nurlu*1 (Somme)				>3	2	1	3	>10	
	Hardivillers*2 (Oise)				>2	4	1	6	>8	
B	Hallencourt*2 (Somme)	>40	20	25	20	10	8	pc	pc	
	Albert*3 (Somme)		15	25	30	10	10	10	pc	
	St Just-en-Chaussée*4 (Oise)	10	10	25	———	35	———	nd	nd	
	Roye*5 (Somme)				>15	6	10	10	15	>10
C	Sens*6 (Yonne)	40	30	20	20	30	20	30	30	>10
	Chéroy*7 (Yonne)	40	30	20	20	30	20	40	40	40

TABLE 2.1 Comparison of the thicknesses of foraminiferal biozones between phosphatic chalks (Group A), soft white chalks in the vicinity of phosphatic chalk cuvettes (Group B) and soft white chalks from basinal areas (Group C). Data sources: *1 zonation from Tabatabai' (1977 fig.21), thicknesses from my measurements; *2 Mennessier et al. (1974); *3 Mennesier et al. (1976); *4 Blondeau et al. (1978); *5 Mennessier et al. (1978); *6 Bouiller et al. (1971); *7 Menillet et al. (1974); pc = phosphatic chalk facies only; nd = no thickness data provided. Thicknesses are estimated maxima given to the nearest metre.

	Locality	Coniacian	Santonian		Campanian	
		M. coranguinum	U. socialis	M. testudinarius	O. pilula	G. quadrata
A	Taplow*1 (Bucks)	>5	1	7	>5	
	Beauval*1 (Somme)	>16	7	6	>13	
	Nurlu*1 (Somme)	>3	1	3	>11	
	Hardivillers*1 (Oise)	>1	2	4	>12	
B	Sussex*2	74	9	20	32	>30
	Kent*3	85	21	>15		
	White Nothe*4 (Dorset)	52	25	10	42	>18
	Scratchells Bay*5 (Isle of Wight)		19	21	39	60

TABLE 2.2 Comparison of zonal thicknesses between phosphatic chalks (Group A) and soft white chalks (Group B). Data sources: *1 Authors measurements; *2 Rowe (1900); *3 Gaster (1924); Rowe (1900); *4 Rowe (1901) and Brydone (1914); *5 Brydone (1914). Thicknesses are given to the nearest metre.