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# Biostratigraphical and sequence correlation of the Cenomanian successions in Mangyshlak (W. Kazakhstan) and Crimea (Ukraine) with those in southern England

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## Abstract

Cenomanian successions in southern England (UK), Crimea (Ukraine) and Mangyshlak (Western Kazakhstan) are briefly described and the evidence for biostratigraphical correlation, based on ammonites and inoceramid bivalves is reviewed in the light of new discoveries. Our conclusions differ significantly from those of previous authors in that: i) we date the base of the Cenomanian in Crimea as early *M. dixoni* Zone age, rather than *M. mantelli* Zone age, and ii) most of the supposed Middle Cenomanian in Mangyshlak is more correctly placed within the Lower Cenomanian *M. dixoni* Zone. Sedimentological evidence from the Crimea and Mangyshlak is used to construct a sequence stratigraphical interpretation for each of these regions. The sequences thus identified are correlated by ammonite and inoceramid biostratigraphy with those described previously (1-6) from the Anglo-Paris Basin. The Crimean succession is very similar in both facies development and the distribution and extent of hiatuses to the marly chalk succession of the northern Anglo-Paris Basin, and sequences 3-6 are identified. In the shallower water sandy and marly successions in Mangyshlak sequences 1, 2, 3, 5 and 6 are identified. 4 is missing within a major hiatus which extends across Mangyshlak.

**Key words**: Cenomanian, Europe, Kazakhstan, biostratigraphy, sequences.

## Résumé

Des successions cénomaniennes dans le sud de l'Angleterre (UK), en Crimée (Ukraine) et dans le Mangyshlak (Kazakhstan occidental) sont brièvement décrites et les critères de corrélation biostratigraphique basés sur les ammonites et les bivalves inocéramidés sont réexaminés à la lumière de nouvelles découvertes. Nos conclusions diffèrent de façon significative de celles des auteurs précédents sur les points suivants: i) l'âge de la base du Cénomanien en Crimée est celui de la Zone à *M. dixoni* inférieure plutôt que de la Zone à *M. mantelli*, et ii) la majeure partie du Cénomanien moyen supposé du Mangyshlak est placée plus exactement dans la Zone à *M. dixoni* du Cénomanien inférieur. Des critères sédimentologiques observés en Crimée et dans le Mangyshlak sont utilisés pour établir une interprétation stratigraphique séquentielle dans chacune de ces régions. Les séquences ainsi identifiées sont corrélées sur base des ammonites et des inocéramidés avec celles décrites précédemment (1-6) dans le Bassin anglo-parisien. La succession en Crimée est très semblable à la fois dans le développement des facies ainsi que la distribution et l'extension des hiatus, à la succession de craie marneuse de la partie nord du Bassin anglo-parisien; les séquences 3-6 ont été identifiées. Dans les successions gréseuses et marneuses, d'eau moins profonde du Mangyshlak, les séquences 1, 2, 3, 5 et 6 ont été reconnues. 4 est absent et se place dans un important hiatus présent dans le Mangyshlak.

**Mots-clefs**: Cénomanien, Europe, Kazakhstan, biostratigraphie, séquences.

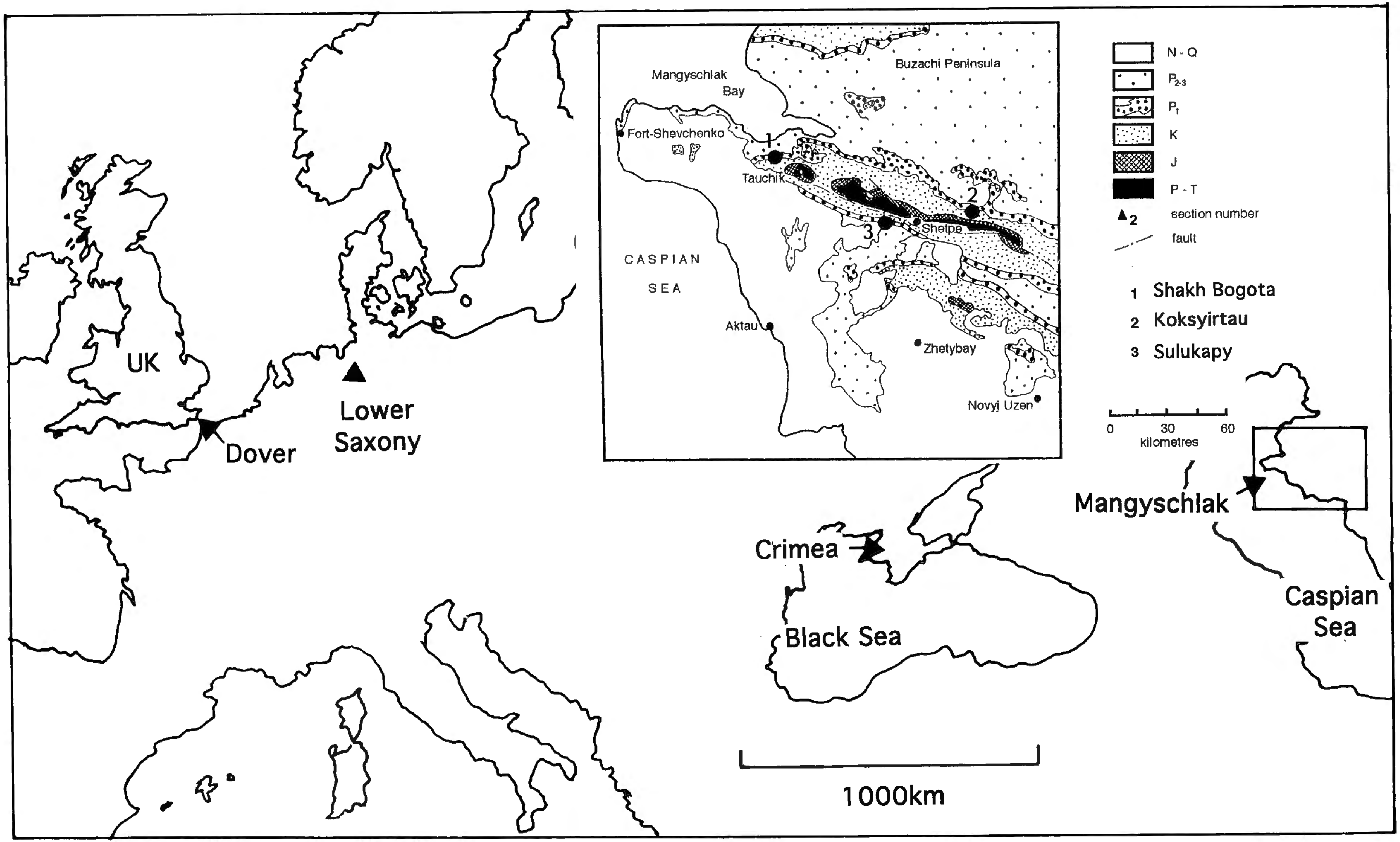
## Резюме

Сеноманские отложения на юге Англии, в Крыму (Украина) и на полуострове Мангышлак (Западный Казахстан) кратко описаны, и данные биостратиграфической корреляции, опирающиеся на аммонитов и иноцерамид, заново изучены в свете новых открытий. Наши заключения значительно отличаются от заключений предыдущих авторов по следующим пунктам: i) основание Сеномана в Крыму относится к нижней части зоны *M. dixoni*, а не к зоне *M. mantelli*, и ii) большая часть предполагаемого среднего Сеномана на полуострове Мангышлак на самом деле находится в зоне *M. dixoni* нижнего Сеномана. Седиментологические признаки пород, наблюдаемых в Крыму и на полуострове Мангышлак, используются для установления стратиграфических секвенций в разрезах каждого из этих районов. Секвенции, идентифицированные таким образом, сопоставляются на основе аммонитов и иноцерамид с секвенциями, описанными ранее (1 - 6) в англо-парижском бассейне. Последовательность отложений в Крыму очень похожа на последовательность карбонатных отложений северной части англо-парижского бассейна, как с точки зрения фациальной изменчивости, так и положения и объемов перерывов. Были идентифицированы секвенции 3 - 6. В мелководных мергелистых и песчаных отложениях на Мангышлаке установлены секвенции 1, 2, 3, 5 и 6. 4 попадает внутрь главного перерыва, развитого на всем полуострове Мангышлак.

**Ключевые слова**: Сеноман, Европа, Казахстан, биостратиграфия, секвенции

## Introduction

The Cenomanian Stage affords one of the best opportunities for development of ultra-high resolution stratigraphy in the Mesozoic, because it contains an ammonite fauna of widespread distribution which enables correlation with a resolution of nearly 0.3 Ma and displays a strong decimetre-scale rhythmicity which provides the basis for an orbitally-tuned timescale (GALE, 1989a, 1995; GALE *et al.*, in press.). Furthermore, the overall (''first order'') sea-level rise which occurs throughout the Cenomanian (HAQ *et al.* 1988) is expressed in shallow marine successions as a series of progressively onlapping


Mangyschlak
Bay
Buzachi Peninsula
Fort-Shevchenko
Tauchik
Shetpe
CASPIAN
SEA
Aktau
Zhetybay
Novyj Uzen
N - Q
$P_{2-3}$
$P_1$
K
J
P - T
section number
fault
1 Shakh Bogota
2 Koksyirtau
3 Sulukapy
0 30 60
kilometres
UK
Dover
Lower
Saxony
Mangyschlak
Crimea
Black Sea
Caspian
Sea
1000km

sequences of which 6 have been identified in western Europe (ROBASZYNSKI *et al.*, 1992, 1998; OWEN, 1996) and Tunisia, north Africa (ROBASZYNSKI *et al.*, 1993). These sequences have a mean duration of 0.8 m.y. and represent eustatic sea-level rises. A $\delta^{13}$ C curve through the Cenomanian contains a number of distinctive positive excursions which aid correlation with successions lacking a good biostratigraphical record (JENKYNS *et al.*, 1994).

In this paper, we describe in outline the lithological and faunal successions of selected Cenomanian localities in southern England, Crimea and Mangyshlak (Fig. 1). The localities are separated by very considerable distances; Crimea is 2,600 km east of southern England, and Mangyshlak is 1,300 km east of the Crimea. Our descriptions are based both on the available literature and our own observations, which provides a personal overview of the successions, although our experience of the Mangyshlak sections was limited to a week. We review the evidence for biostratigraphical correlation between the 3 regions, on the basis of material described and figured in the literature and new specimens which we have collected ourselves and figure here. Lastly, we use sedimentological data to identify the Cenomanian sequences described in western Europe by OWEN (1996) and ROBASZYNSKI *et al.* (1998) in the Crimea and the Mangyshlak Hills.

## South-east England, Anglo-Paris Basin

The Anglo-Paris Basin is situated in northern France and southern England, and during the Cenomanian was surrounded by the Cornubian, Armorican and London-Brabant Massifs and the Massif Central (ROBASZYNSKI *et al.*, 1998). In these marginal areas the sea was shallow, and thin, frequently condensed clastic deposits accumulated (e.g. JUIGNET, 1974; KENNEDY, 1970). In the deeper northern part of the Anglo-Paris Basin, a more complete succession of marly chalks was deposited. Our account here is based upon the section between Dover and Folkestone, Kent, UK (JUKES-BROWNE & HILL, 1903; KENNEDY, 1969; GALE, 1989b; JENKYNS *et al.* 1994; Fig. 2 herein) with faunal and other data drawn from correlative sections in Sussex and the Isle of Wight.

### LITHOLOGY AND GENERAL FEATURES

In south-east England, the Cenomanian Stage is represented by 50-70 metres of variably marly chalks (Lower Chalk Formation) and the basal 1-7 metres of the overlying White Chalk Formation (Fig. 2). At the base of the Lower Chalk a thin transgressive unit containing quartz sand and glaucony is generally present. There is an overall decrease in clay content up through the Lower Chalk succession, from 20-40% near the base to <5% in the White Chalk. The Lower Chalk is conspicuously rhythmic on a decimetre-scale in many sections, and beds of more carbonate-rich fine grained calcisphere-foraminiferal packstone or wackestone alternate with marlier wackestones. The rhythmic couplets can be correlated between sections and have been used as the basis for an orbital timescale (GALE, 1990, 1995). Ammonites are common in the Lower and Middle Cenomanian but rather scarce in the Upper Cenomanian (KENNEDY, 1969). Inoceramid bivalves are common throughout. The carbon and oxygen isotope stratigraphy of the Cenomanian has been described by JENKYNS *et al.* (1994).

### LOWER CENOMANIAN

The basal Cenomanian rests with sharp disconformity upon the Late Albian Gault Clay, the disconformity representing a gap of about 1-2 Ma (GALE *et al.*, 1996). The basal few metres comprise the **Glauconitic Marl Member,** a sandy glauconitic marl which locally (e.g. Isle of Wight; KENNEDY, 1969, 1971) yields abundant phosphatised ammonites of the *Neostlingoceras carcitanense* Subzone. The lower part of the overlying **Chalk Marl Member** (marly chalks) contains ammonites characteristic of the overlying *Sharpeiceras schlueteri* Subzone (GALE, 1995) associated with an acme of large *Inoceramus crippsi crippsi* Mantell (GALE, 1989b, 1995). In more condensed successions, like those developed at Eastbourne in Sussex and on the Isle of Wight, unphosphatised fossils of this assemblage are incorporated in the matrix of the Glauconitic Marl, which contains a rich phosphatised fauna of the *carcitanense* Subzone (KENNEDY 1969, 1971; WRIGHT *et al.*,1984). The highest part of the *M. mantelli* Zone is poorly fossiliferous at Folkestone, but to the west (Sussex, Isle of Wight) includes abundant *Mantelliceras saxbii* (Sharpe) and comprises the *M. saxbii* Subzone (KENNEDY, 1969; GALE, 1995).

The upper boundary of the *M. mantelli* Zone coincides approximately with a burrowed erosion surface at Folkestone and elsewhere in the northern Anglo-Paris Basin (GALE, 1989b; ROBASZYNSKI *et al.*, 1998). The surface is overlain by coarse chalks containing mineralised intraclasts which locally yield indigenous, unmineralised specimens of the ammonite *M. dixoni* Spath. The first appearance of this species in southern England is coincident with the first appearance of *Inoceramus virgatus* (Schlueter) which occurs in great abundance in the lower part of the *M. dixoni* Zone. Five metres above the base of the zone, there is a marked increase in carbonate, and a group of 5 closely spaced limestones (B11-15) contain an acme of *I. virgatus* and numerous ammonites. The higher part of the *M. dixoni* Zone yields few age-diagnostic ammonites in the Anglo-Paris Basin, and there is a gap of some 10 metres above the highest *Mantelliceras* and beneath the lowest *Cunningtoniceras* (GALE, 1995).

### MIDDLE CENOMANIAN

The base of the Middle Cenomanian is taken at the lowest

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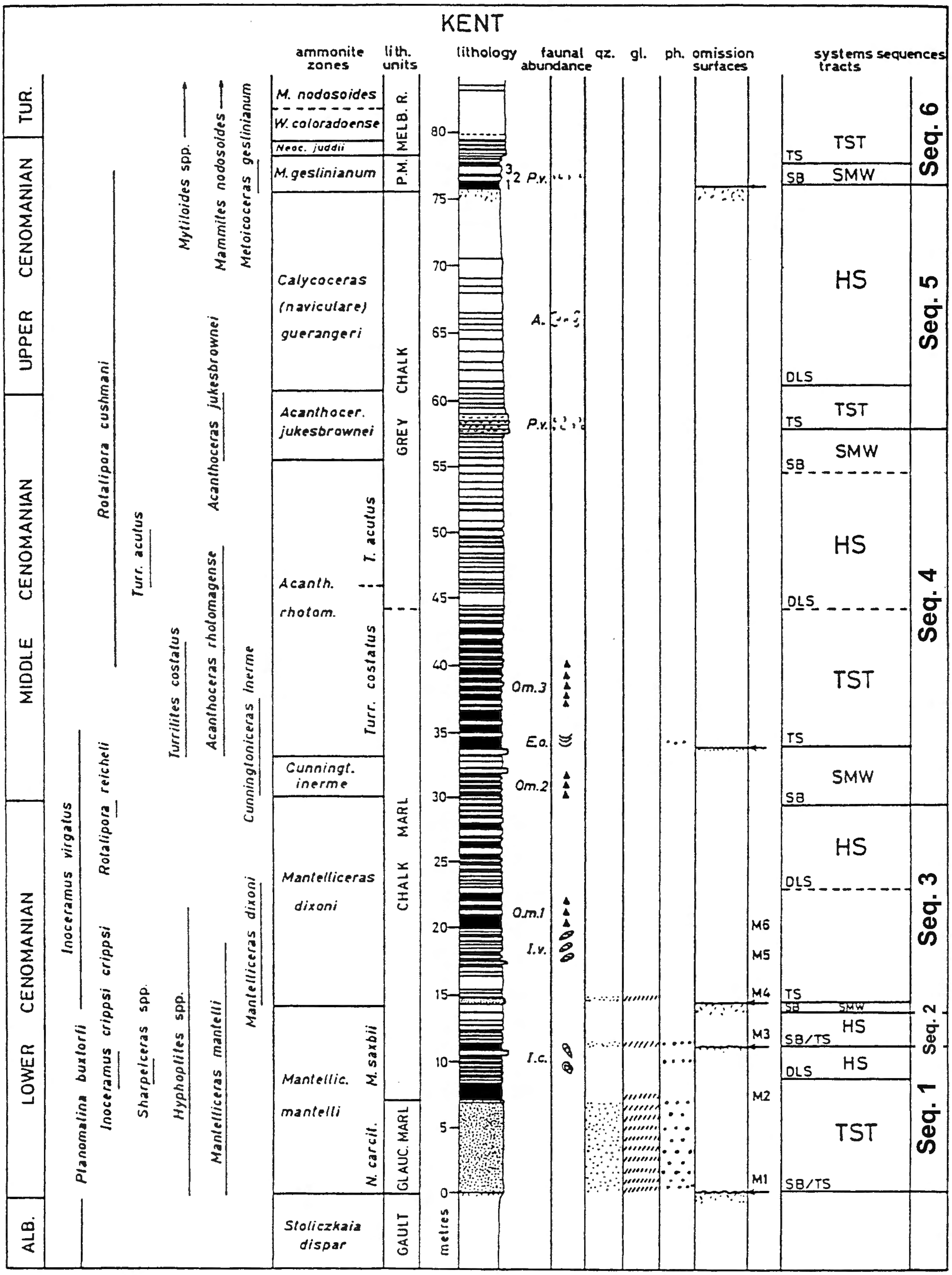
Text-figure 1 — Map to show positions of Dover, UK, Crimea and Mangyshlak. Inset map shows locations in Mangyshlak.


KENT
ammonite zones
lith. units
lithology
faunal abundance
qz.
gl.
ph.
omission surfaces
systems tracts
sequences
TUR.
UPPER CENOMANIAN
MIDDLE CENOMANIAN
LOWER CENOMANIAN
ALB.
Planomalina buxtorfi
Inoceramus virgatus
Inoceramus crippsi crippsi
Rotalipora reicheli
Rotalipora cushmani
Sharpeiceras spp.
Turr. acutus
Hyphoplites spp.
Turrilites costatus
Mytiloides spp.
Mantelliceras mantelli
Acanthoceras rhotomagense
Acanthoceras jukesbrownei
Mammites nodosoides
Mantelliceras dixoni
Cunningtoniceras inerme
Metoicoceras geslinianum
M. nodosoides
W. coloradoense
Neoc. juddii
M. geslinianum
Calycoceras (naviculare) guerangeri
Acanthocer. jukesbrownei
Acanth. rhotom.
T. acutus
Turr. costatus
Cunningt. inerme
Mantelliceras dixoni
Mantellic. mantelli
M. saxbii
N. carcit.
Stoliczkaia dispar
MELB. R.
P.M.
GREY CHALK
CHALK MARL
GLAUC. MARL
GAULT
metres
P.v.
A.
Om.3
E.o.
Om.2
Om.1
I.v.
I.c.
M6
M5
M4
M3
M2
M1
TST
SMW
HS
DLS
TS
SB
SB/TS
Seq. 6
Seq. 5
Seq. 4
Seq. 3
Seq. 2
Seq. 1

occurrence of *Cunningtoniceras inerme* (Pervinquière) which first occurs in a marly interval (PAUL *et al.*, 1994; Couplet B37). This species is common at Folkestone and at Southerham in Sussex. The lowest *Acanthoceras rhotomagense* (Brongniart), marking the base of the eponymous zone, appear in a hard limestone 4 metres higher. The top of this limestone (couplet B43) is a burrowed/erosional surface, and is overlain by a dark marly bed containing abundant calcitic bivalves and brachiopods called the "Cast Bed."

The "Cast Bed", so-called because of the local abundance of composite moulds of aragonitic gastropods (GALE, 1989b), contains rare specimens of the belemnite *Actinocamax primus* (Arkhangelsky) (PAUL *et al.*, 1994). Four metres above, a group of thin limestones contain abundant *Sciponoceras baculoides* (Mantell) and the rhynchonellid *Orbirhynchia mantelliana* (d'Orbigny) together with diverse ammonites of the *Turrilites costatus* Subzone (KENNEDY, 1969). A correlative abundance of *Sciponoceras* and *Orbirhynchia* is present in northern Germany (MEYER, 1990) and in the Crimea (MARCINOWSKI, 1980; see below). A basinwide increase in carbonate a short distance above the acme of *O. mantelliana* marks the base of the **Grey Chalk Member**. This boundary is approximately coincident with the base of the *Turrilites acutus* Subzone.
The marls and marly chalks of the *A. rhotomagense* Zone are very conspicuously rhythmic in southern England and the couplets (20-40 cm thick) represent the precession cycle (mode at 20 K.y.), with bundles reflecting the short eccentricity cycle (100 K.y.; GALE, 1989a). Bundles and couplets can be correlated precisely with the Selbukhra section in the Crimea (see below).

The base of the *A. jukesbrownei* Zone is taken at the first occurrence of the species. 2 metres above the base of the zone, 3 thin dark marl beds containing the oyster *Pycnodonte* are present, overlain by 2-4 metres of massive, coarse, calcisphere-rich chalk containing laminated structures (probably burrow-fills) and large *Acanthoceras jukesbrownei* (Spath) (KENNEDY, 1969). The stratigraphy of these beds is constant across the northern Anglo-Paris Basin (GALE, 1995, fig. 12), and precisely correlative beds are found in northern Germany and the Crimea (see below).

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Text-figure 2 — Succession in the Cenomanian Lower Chalk Formation between Dover and Folkestone (Kent, UK) to show main lithological horizons, biostratigraphy and sequence stratigraphy. Modified after ROBASZYNSKI *et al.* (1998, fig. 6). M1-6 refer to marker beds described by GALE (1989b). *I.c .= Inoceramus crippsi, I.v. = Inoceramus virgatus, O.m. = Orbirhynchia mantelliana, P.v. = Pycnodonte vesicularis, A. = Amphidonte* sp.

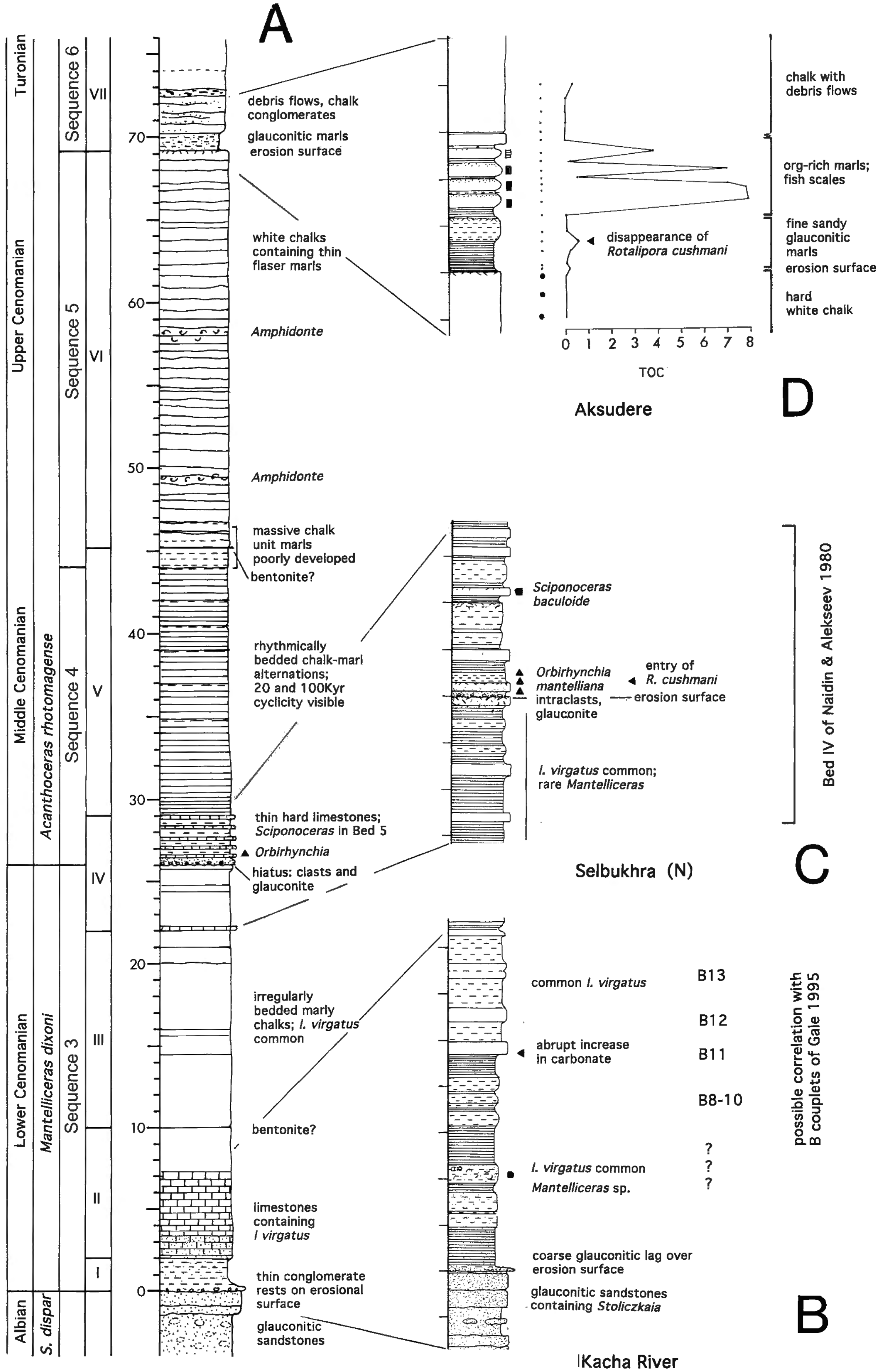
UPPER CENOMANIAN

The Upper Cenomanian contains few poorly preserved ammonites in the chalk facies of the Anglo-Paris Basin (KENNEDY, 1969) and the contact between the Middle Cenomanian *A. jukesbrownei* Zone and the Upper Cenomanian *C. guerangeri* Zone cannot be accurately placed. The *C. guerangeri* Zone at Folkestone is a clay-poor, pale grey to white chalk which contains two levels containing abundant small oysters, *Amphidonte obliquatum* (Pulteney), in the middle part. The same oyster horizons are found in northern Germany (ERNST & REHFELD, 1997; KAPLAN, *in press*) and the Crimea (see below). The top of the *C. guerangeri* Zone is ubiquitously marked by the sub-plenus erosion surface (JEFFERIES, 1962, 1963), overlain by the rhythmically bedded marly chalks of the **Plenus Marls Member** (*M. geslinianum* Zone) which are 2-10 metres in thickness. JEFFERIES (1962, 1963) was able to trace each of 8 beds within the Plenus Marls throughout the expanded succession in the Anglo-Paris Basin. Features of the Plenus Marls important for correlation into eastern Europe and central Asia include the abundance of the belemnite *Actinocamax plenus* (Blainville) in Bed 4, and the presence of a $\delta^{13}C$ positive excursion in the Plenus Marls and the overlying white chalks (GALE *et al.*, 1993).

The summit of the Plenus Marls marks an important lithological boundary in the Anglo-Paris Basin; below this level, grey-hued marly chalks of the Lower Chalk Formation include up to 30% clay whereas the overlying chalks of the White Chalk Formation contain little clay (generally less than 5%). The basal **Ballard Cliff Member** comprises nodular calcisphere-rich chalks with thin flaser marls and numerous intraclasts. This unit includes rare ammonites of the *M. geslinianum* and *N. juddii* Zones, and the base of the Turonian, defined by the first appearance of rare *Watinoceras* spp. at Merstham, Kent, and Eastbourne, Sussex (WRIGHT & KENNEDY, 1981), falls close to the summit of the Ballard Cliff Member (GALE, 1996).

SEQUENCE STRATIGRAPHY

The criteria used to recognise sequences in the marly Cenomanian chalks of the Anglo-Paris Basin have been described by OWEN (1996) and ROBASZYNSKI *et al.* (1992, 1998). The basal **transgressive systems tract** of each sequence typically rests upon an erosional surface (**sequence boundary**) and includes a condensed lag, commonly containing glauconite, quartz sand and mineralised (phosphatised and glauconitised) intraclasts at the base; sand and glaucony decrease above in the higher part of the transgressive systems tract. **The maximum flooding surface** is marked by an increase in carbonate content/ decrease in clay, representing the maximum distancing of clastic source. **Highstand chalks** are relatively carbonate-rich and evenly rhythmic on a decimetre scale. At the top they are truncated by the succeeding sequence boundary, marked by an increase in clay content representing the **lowstand**. In more marginal condensed suc-


A
Turonian
Upper Cenomanian
Middle Cenomanian
Lower Cenomanian
Albian
Acanthoceras rhotomagense
Mantelliceras dixoni
S. dispar
Sequence 6
Sequence 5
Sequence 4
Sequence 3
VII
VI
V
IV
III
II
I
70
60
50
40
30
20
10
0
debris flows, chalk conglomerates
glauconitic marls erosion surface
white chalks containing thin flaser marls
Amphidonte
Amphidonte
massive chalk unit marls poorly developed
bentonite?
rhythmically bedded chalk-marl alternations; 20 and 100Kyr cyclicity visible
thin hard limestones; Sciponoceras in Bed 5
Orbirhynchia
hiatus: clasts and glauconite
irregularly bedded marly chalks; I. virgatus common
bentonite?
limestones containing I virgatus
thin conglomerate rests on erosional surface
glauconitic sandstones
0 1 2 3 4 5 6 7 8
TOC
disappearance of Rotalipora cushmani
chalk with debris flows
org-rich marls; fish scales
fine sandy glauconitic marls
erosion surface
hard white chalk
Aksudere
D
Sciponoceras baculoide
Orbirhynchia mantelliana
intraclasts, glauconite
entry of R. cushmani
erosion surface
I. virgatus common; rare Mantelliceras
Bed IV of Naidin & Alekseev 1980
Selbukhra (N)
C
common I. virgatus
abrupt increase in carbonate
I. virgatus common
Mantelliceras sp.
coarse glauconitic lag over erosion surface
glauconitic sandstones containing Stoliczkaia
B13
B12
B11
B8-10
?
?
?
possible correlation with B couplets of Gale 1995
Kacha River
B

cessions, as on the borders of the Anglo-Paris Basin, an erosional sequence boundary is commonly overlain directly by a condensed representative of the overlying transgressive systems tract. In more distal, basinal developments, there is little hiatus between successive sequences, and marly lowstand deposits are often present; neither glauconite nor intraclasts are present in the transgressive units. The 6 sequences described in outline below have been identified from the sedimentological criteria outlined above and correlated biostratigraphically between four separate regions of the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998). For a different sequence nomenclature, see HARDENBOL *et al.* (1998).

*Sequence 1*

At Folkestone, the Glauconitic Marl is a condensed transgressive systems tract at the base of the Cenomanian succession, resting upon a composite sequence boundary of Late Albian age (GALE *et al.*, 1996). The Glauconitic Marl at Folkestone rarely yields phosphatised ammonites of the *N. carcitanense* Subzone, but these are abundant in the southern Isle of Wight (KENNEDY, 1969, 1971). The lower part of the overlying Chalk Marl represents a maximum flooding surface which lies at the base of the *S. schlueteri* Subzone (GALE, 1995).

*Sequence 2*

The base of this sequence contains phosphatised intraclasts and glaucony grains representing a transgressive systems tract, and rests non-sequentially upon a hard limestone (M4 of GALE, 1989b) which is a sequence boundary. The upper part of 2 is developed as marly chalks at Folkestone. The entire sequence falls within the *M. saxbii* Subzone. Sequence 2 is not recognised widely elsewhere in northern Europe (OWEN, 1996).

*Sequence 3*

The marly chalks of 2 are widely surmounted by an erosional surface, which at Folkestone and elsewhere is overlain by a coarse glauconitic calcisiltite containing phosphatised intraclasts representing the basal transgressive part of 3 (Couplet B1 of GALE, 1995, fig. 4). At Southerham, this bed contains the lowest specimens of *M. dixoni*, and is taken as the base of the *M. dixoni* Zone. An increase in carbonate content several metres higher (B11/12 of GALE, 1995) represents the maximum flooding surface. The overlying marly chalks represent a highstand. An increase in clay content at the level of B34 marks the contact with the lowstand of overlying sequence 4. *C. inerme* appears a short distance above in B38. 3 therefore corresponds approximately with the *M. dixoni* Zone.

*Sequence 4*

The base of couplet C1 (''Cast Bed''; GALE, 1989) contains abundant calcitic fossil debris at Folkestone, and elsewhere in southern England phosphates and glauconite are present. It is the basal transgressive unit of 4. The conspicuous increase in carbonate at the base of the Grey Chalk is taken as the maximum flooding surface of this sequence and falls close to the boundary between *T. costatus* and *T. acutus* Subzones. The highstand comprises strikingly rhythmic chalks which show bundling that corresponds to the short eccentricity cycle. The base of the *A. jukesbrownei* Zone falls in the summit of the highstand.

*Sequence 5*

An erosional surface at the level of couplet B45 is identified as a sequence boundary. The overlying couplets B46-49 contain lenses of winnowed calcite bioclasts and constitute a lowstand deposit. The overlying massive, coarse bed (D1-8) containing laminated structures (''Jukes-Browne Bed VII''; JUKES-BROWNE & HILL, 1903) represents slight condensation and contains abundant calcispheres and locally phosphatised intraclasts (Eastbourne). It is identified as a transgressive systems tract. At the level of couplet D12 an increase in carbonate content and loss of conspicuous rhythmicity represents a maximum flooding surface. Sequence 5 falls in the upper part of the *A. jukesbrownei* Zone and includes the entire overlying *C. guerangeri* Zone.

*Sequence 6*

The base of the highest sequence in the Cenomanian is taken at the sub-plenus erosion surface which is ubiquitously developed in the northern Anglo-Paris Basin (sequence boundary at the limit of the *C. guerangeri* and *M. geslinianum* Zones). Beds 1-3 of the Plenus Marls comprise a lowstand, and the Bed 3-4 erosional contact represents a transgressive surface (mid - *M. geslinianum* Zone). The prominent increase in carbonate content at the top of the Ballard Cliff Member (*N. juddii* - *W. devonense* Zones) marks maximum flooding. For a slightly different interpretation of this sequence, see HANCOCK (1993).

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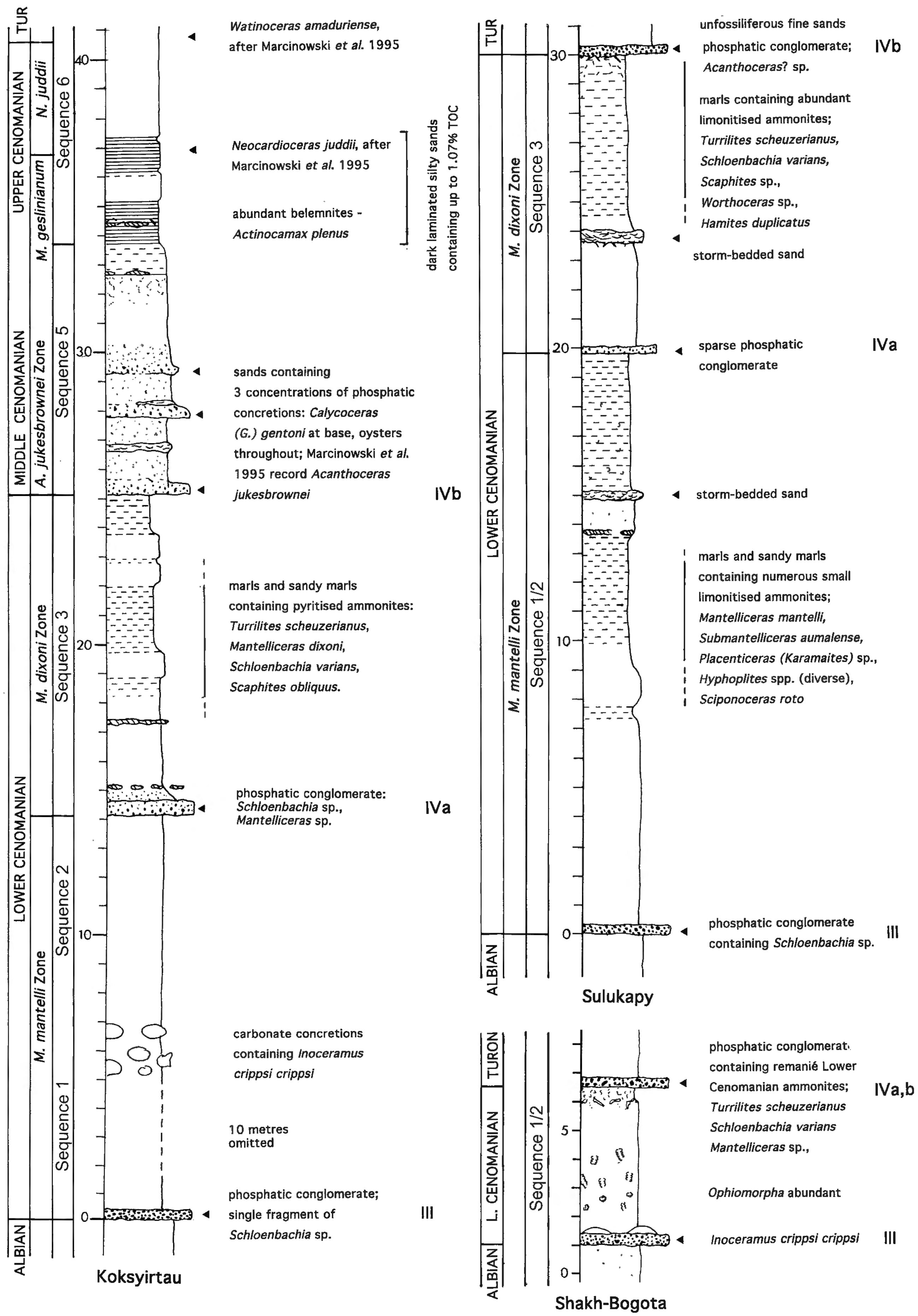
Text-figure 3 — Cenomanian of the Crimea. A, general succession after NAIDIN & ALEKSEEV (1980), with their Members I-VII indicated. B, details of basal Cenomanian in Kacha River; possible correlation with precession couplets (B1-13) in western Europe, numbered after GALE (1995). C, Lower-Middle Cenomanian contact, Selbukhra. D, Late Cenomanian succession at Aksudere. The total organic carbon (TOC) data is new.

## The Crimea, the Ukraine.

The Cenomanian succession in the Crimean Highland, 30 km south of Simferopol, was described by NAIDIN & ALEKSEEV (1981) and NAIDIN & KIYASHKO (1994a, b). MARCINOWSKI (1980) has described the Cenomanian ammonite faunas from the Crimea. Localities in the Crimea described by NAIDIN & ALEKSEEV (1981) were visited by ASG in the summers of 1996 and 1997 with the generous



TUR
UPPER CENOMANIAN
MIDDLE CENOMANIAN
LOWER CENOMANIAN
ALBIAN
N. juddii
M. geslinianum
A. jukesbrownei Zone
M. dixoni Zone
M. mantelli Zone
Sequence 6
Sequence 5
Sequence 3
Sequence 2
Sequence 1
Watinoceras amaduriense, after Marcinowski et al. 1995
Neocardioceras juddii, after Marcinowski et al. 1995
abundant belemnites - Actinocamax plenus
dark laminated silty sands containing up to 1.07% TOC
sands containing 3 concentrations of phosphatic concretions: Calycoceras (G.) gentoni at base, oysters throughout; Marcinowski et al. 1995 record Acanthoceras jukesbrownei
IVb
marls and sandy marls containing pyritised ammonites: Turrilites scheuzerianus, Mantelliceras dixoni, Schloenbachia varians, Scaphites obliquus.
phosphatic conglomerate: Schloenbachia sp., Mantelliceras sp.
IVa
carbonate concretions containing Inoceramus crippsi crippsi
10 metres omitted
phosphatic conglomerate; single fragment of Schloenbachia sp.
III
Koksyirtau
TUR
LOWER CENOMANIAN
ALBIAN
M. dixoni Zone
M. mantelli Zone
Sequence 3
Sequence 1/2
unfossiliferous fine sands
phosphatic conglomerate; Acanthoceras? sp.
IVb
marls containing abundant limonitised ammonites; Turrilites scheuzerianus, Schloenbachia varians, Scaphites sp., Worthoceras sp., Hamites duplicatus
storm-bedded sand
sparse phosphatic conglomerate
IVa
storm-bedded sand
marls and sandy marls containing numerous small limonitised ammonites; Mantelliceras mantelli, Submantelliceras aumalense, Placenticeras (Karamaites) sp., Hyphoplites spp. (diverse), Sciponoceras roto
phosphatic conglomerate containing Schloenbachia sp.
III
Sulukapy
TURON
L. CENOMANIAN
ALBIAN
Sequence 1/2
phosphatic conglomerate containing remanié Lower Cenomanian ammonites; Turrilites scheuzerianus Schloenbachia varians Mantelliceras sp.,
IVa,b
Ophiomorpha abundant
Inoceramus crippsi crippsi
III
Shakh-Bogota

help of A. S. Alekseev, R. R. Gabdullin, L. F. Kopaevich, T. A. Kuzmicheva and A. M. Nikishin from Moscow University. The succession is summarised in Fig. 3.

## LITHOLOGY AND GENERAL FEATURES

The Cenomanian of the Crimea comprises 50-60 metres of rhythmically bedded (decimetre-scale) marly chalks, which show an overall decrease in the clay component towards the top. The succession includes several region-wide erosional surfaces. Macrofossils are not abundant throughout, and diagnostic ammonites are restricted to a few levels (MARCINOWSKI, 1980). The Middle and Upper Cenomanian were deposited in deeper water than their equivalent strata in southern England. In terms of facies, rhythmicity and some of the faunas the succession is similar to that developed in the northern Anglo-Paris Basin (GALE, 1995).

## LOWER CENOMANIAN

The lowest one to several metres of the Cenomanian are sandy glauconitic marls, and a thin (<20cm) basal conglomerate includes glauconitised sandstone pebbles, gravel grade quartz and other clasts. This bed rests disconformably on glauconitic sandstones of Late Albian *S. dispar* Zone age (MARCINOWSKI & NAIDIN, 1976). The basal part of the Cenomanian succession is well exposed in the Kacha River section (Fig. 3), where a bed of silty glauconitic marl 2m above the basal erosion surface yields poorly preserved *Mantelliceras* sp. and common *Inoceramus virgatus* (Schlüter) which occurs frequently up to the highest levels accessible. *I. virgatus* first occurs in the *M. dixoni* Zone in the Anglo-Paris Basin (not in the *M. saxbii* Subzone, as recorded by TRÖGER, 1989) for the base of which it can be taken as a proxy marker (GALE, 1995). More expanded basal Cenomanian successions in the Crimea, like those in the Bodrak Valley (e.g. Kremennaya; NAIDIN & ALEKSEEV, 1981) also yield *I. virgatus* near the base of the Cenomanian. The ubiquitous presence of *I. virgatus* at or near the base of the Cenomanian successions in the Crimea is therefore taken as evidence that chalk sedimentation here commenced low in the *M. dixoni* Zone. The zonal ammonite species has however only been found near the top of the Lower Cenomanian in the Crimea (MARCINOWSKI, 1980).

The silty glauconitic beds of the basal Cenomanian pass upwards into alternating marls and marly limestones, which display a regular thickness for the lowest 5 or so metres, but above become of very variable thickness. There is a marked increase in carbonate content above 5m from the base of the Cenomanian in the Kacha River section. The entire Lower Cenomanian thickens northwards to Kremennaya Mountain (NAIDIN & ALEKSEEV, 1981). The highest few metres of the Lower Cenomanian again contains thin, evenly spaced limestones, and has yielded *Mantelliceras* cf. *dixoni* (MARCINOWSKI, 1980, pl. 2) and common *I. virgatus*; it thus falls within the *M. dixoni* Zone.

←

Text-figure 4 — Cenomanian of Mangyshlak, Kazakhstan. Sections at Sulukapy and Koksyirtau. The major nodule beds (III, IVa, IVb) of MARCINOWSKI *et al.* (1995) are marked. Stages, zones and sequences are marked.

## MIDDLE CENOMANIAN

The top of the Lower Cenomanian is truncated by a conspicuous erosion surface everywhere in the Crimea (NAIDIN & ALEKSEEV, 1981); the following description is based on the Selbukhra section (Fig. 3 herein; see map in MARCINOWSKI, 1980). The erosion surface is overlain by a coarse green-grey marl containing glauconitised intraclasts, inoceramid debris, and rare exotic clasts, including Triassic or Jurassic siltstones (A. S. Alekseev, personal communication). *Thalassinoides* pipe the marl down 20 cm from the erosion surface through the underlying limestone into the marl beneath. The beds above the erosion surface comprise an alternation of marls and well-lithified limestones which contain *Sciponoceras baculoides* (Mantell); rare *Acanthoceras* sp. confirm the Middle Cenomanian *A. rhotomagense* Zone age of these beds. The basal metre yields a rich and diverse fauna of calcitic fossils including echinoids, crinoids, brachiopods, serpulids and bivalves (NAIDIN & ALEKSEEV, 1981). The brachiopods include abundant *Orbirhynchia mantelliana* (d'Orbigny) which occurs in 2 intervals within the Middle Cenomanian of southern England (KENNEDY, 1969; GALE, 1995). The co-occurrence of abundant *O. mantelliana* and *S. baculoides*, coincident with the first occurrence of *Rotalipora cushmani* (40 cm above erosion surface; L. F. Kopaevich, personal communication) establishes a firm correlation with the band of *O. mantelliana* in the *Turrilites costatus* Subzone found in northern France (AMEDRO, 1993), southern England (KENNEDY, 1969) and northern Germany (MEYER, 1990). At this horizon, the faunas and facies are closely similar in the Crimea and the northern Anglo-Paris Basin, and individual limestone-marl couplets can be correlated precisely between the two, a confirmation of the accuracy of the Milankovitch timescale proposed by GALE (1989a, 1995).

The break between the Lower and Middle Cenomanian in the Crimea can thus be demonstrated to include an unknown part of the upper *M. dixoni* Zone, the entire *C. inerme* Zone (GALE, 1995; ROBASZYNSKI *et al.*, 1998), and the basal part of the *A. rhotomagense* Zone, and probably represents more than 0.5 m.y.

The higher part of the Middle Cenomanian is strikingly rhythmic in the Kacha and Selbukhra sections and time-series analysis has provided firm evidence of orbital frequencies representing the precession cycle (mode at 20 K.y.) and bundling by both long and short eccentricity cycles (100 and 400 K.y.; GALE *et al.*, in press). This part of the succession is poorly fossiliferous, and has not yielded age-diagnostic ammonites. However, the presence of *Inoceramus* cf *atlanticus* Heinz at 25m above the basal erosion surface at Selbukhra is indicative of a late *A. rhotomagense* or early *A. jukesbrownei* Zone level, indicative of the "I. atlanticus Event" in the Lower Saxony Basin (ERNST & REHFELD, 1997). Large, poorly preserved puzosiid ammonites between 25 and 30m at Selbukhra are associated with a diverse benthic fauna, not previously recorded, which includes serpulids, calcitic bivalves, echinoids (*Poriocidaris* sp. ), brachiopods, and abundant isocrinid columnals. The conspicuous thin marls at 28.5, 29.4 and 30.2m perhaps correlate with the "Pycnodonte Event" of northern Germany (ERNST, SCHMID & SEIBERTZ, 1983) and the D1-3 marls of GALE (1995). The condensed "Jukes-Browne Bed VII" of southern England (GALE, 1995) is represented in Selbukhra by seven coalesced couplets of calcisphere-rich chalk. A conspicuous 10 cm thick orange marl, possibly a weathered bentonite, is present at 32.5 m in Selbukhra (NAIDIN & ALEKSEEV, 1981). There is a sharp increase in the percentage of CaCO3 just beneath the bentonite, and the highest 25 m of Cenomanian chalks are very pure (85% carbonate) and white and contain thin flaser marls every 50-100 cm.

## UPPER CENOMANIAN

Ammonites are not recorded from the higher part of the Crimean Cenomanian succession, so the boundary of the Middle and Upper Cenomanian cannot be fixed precisely. However, the oyster *Amphidonte obliquatum* (Pulteney) is common at 2 levels in the succession at Selbukhra (40 m, 58 m), which correspond with abundances of the same species in the Münster and Lower Saxony Basins in northern Germany (ERNST & REHFELD, 1997; KAPLAN, *in press*) and in southern England (GALE, 1995).

White chalks containing marls at 0.5-1.0 m intervals (Member VI of NAIDIN & ALEKSEEV, 1981) are terminated by a planar, lithified, but unbored erosional surface cut in hard white chalk in all three sections examined (Selbukhra, Mender, Aksudere). This surface, sparsely burrowed by *Planolites*, is overlain by grey or brown sandy marls (ALEKSEEV *et al.*, 1997) and represents the "sub-plenus erosion surface" (JEFFERIES, 1962, 1963) in the Anglo-Paris Basin and the "*Fazieswechsel*" (MEYER, 1990) in northern Germany. This correlation is confirmed by the highest occurrence of *Rotalipora cushmani* 50 cm above the erosion surface at Selbukhra (ALEKSEEV *et al.*, 1997). This species is last found immediately beneath the Plenus Bank in northern Germany (SCHÖNFELD *et al.*, 1991) and at the top of Bed 3 of the Plenus Marls in southern England (JARVIS *et al.*, 1988).

There is considerable lateral variation in the succession immediately overlying the Late Cenomanian erosion surface in the Crimea. At Selbukhra 1 m of marly and sandy chalks are overlain by redeposited chalks containing debris flows (conglomerates, flow lamination) and microfaults. At Mender, a highly condensed glauconitic marl resting directly upon the basal erosion surface is overlain by flaggy chalks containing marl partings. Neither locality contains diagnostic macrofossils. At Aksudere (Fig. 3), a metre of organic-rich, variably laminated marls (Member VI3) containing fish-scales is present (NAIDIN, 1993; NAIDIN & KIYASHKO, 1994a, b), representing deposition within the oxygen minimum zone. This is a local representation of the Late Cenomanian "Oceanic Anoxic Event" (JENKYNS, 1980). The base of the Turonian *H. helvetica* planktic foraminiferan Zone boundary falls 2.7 m above the base of Member VI3, according to ALEKSEEV *et al.* (1997).

## SEQUENCE STRATIGRAPHY

The detailed similarity of facies between the Cenomanian of the Crimea and chalks in the northern Anglo-Paris Basin enables us to apply identical criteria for the recognition of sequences and systems tracts to those used by ROBASZYNSKI *et al.* (1998) in basinal marly chalks in southern England and northern France. In the following section, the correlation of Cenomanian sequences recognised in the Anglo-Paris Basin by ROBASZYNSKI *et al.* (1998) with those developed in the Crimea is discussed.

### *Sequence 3*

The lowest Cenomanian sequence present in the Crimea rests directly on Upper Albian sandstones; its base can be dated as *M. dixoni* Zone from the presence of *I. virgatus* low in the succession (see above). The pronounced increase in carbonate 5 m above the base of the Cenomanian in the Kacha River is taken as the maximum flooding surface of this lowest sequence, and can probably be correlated on a bed scale with the successions in the Anglo-Paris and Saxony Basins (see GALE, 1995, fig. 4). The overlying highstand chalks are entirely of *M. dixoni* Zone age and are truncated by the erosional surface at the Lower-Middle Cenomanian contact. This sequence therefore corresponds with 3 in the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998) which falls entirely within the *M. dixoni* Zone and provides evidence of late Cenomanian onlap in the Crimean region. This is similar to the progressive onlap of successive Cenomanian zones recorded by KENNEDY (1970) across Dorset and Devon in southern England.

### *Sequence 4*

The erosional surface at the Lower-Middle Cenomanian boundary in the Crimea is identified as a transgressive surface resting directly upon a sequence boundary. The transgressive systems tract is represented by the residual glauconitic lag at the base of the Middle Cenomanian succession and the overlying marly chalks and thin limestones mark the maximum flooding surface. An erosional break at the Lower-Middle Cenomanian boundary is widely developed in thinner successions across Europe (GALE, 1995; OWEN, 1996). The duration of the hiatus at this level in the Crimea is similar to that developed over the London Platform in eastern England, where highstand *M. dixoni* Zone Chalks are overlain with erosive contact by the condensed Totternhoe Stone (a calcarenite containing phosphatised and glauconitised intraclasts), the matrix of which contains abundant *Orbirhynchia mantelliana* from the *T. costatus* Subzone acme of the species.

*Sequence 5*
The highstand chalks of 4 display a very even rhythmicity, but at 30-33 m above the Lower-Middle Cenomanian erosion surface there is a slight but distinct condensation and the couplets thin and fuse as a result of the disappearance of the intervening marls. The sediment becomes coarser and contains more calcispheres. We interpret this a a weakly developed transgressive systems tract which correlates with the sequence which commences within the *A. jukesbrownei* Zone in the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998).

*Sequence 6*
The sharp, planar erosion surface which is found regionally at the summit of the white coccolith chalks of Upper Cenomanian age at Mender, Selbukhra and Aksudere is lithified but apparently not bored or encrusted, and represents a sequence boundary correlative with the sub-plenus erosion surface in the Anglo-Paris Basin (base of sequence 6). Overlying this surface at Aksudere and Selbukhra are about 1 m of sandy and silty marls which locally contain glauconite. *Rotalipora cushmani* disappears about 0.5 m above the basal erosion surface, in a marly bed probably equivalent to Bed 3 of the Plenus Marls. Immediately overlying this bed, laminated organic rich-marls at Aksudere represent the transgressive systems tract of sequence 6.

## Mangyshlak Hills, west Kazakhstan

Excellent exposures of Cretaceous rocks exist in the Mangyshlak Hills, and are present in the pericline 100 km northeast of Aktau (NAIDIN *et al.*, 1984). ASG and JMH visited three of these sections (Sulukapy, Shakh Bogota and Koksyirtau) in a party led by Professor D. P. Naidin and his colleagues in 1994. The lithological and faunal succession at Sulukapy has been briefly described by MARCINOWSKI (1980) and this and other localities described in detail by MARCINOWSKI *et al.* (1995). Our observations differ in some details from those of previous authors.

### LITHOLOGY AND GENERAL FEATURES

The Cenomanian in Mangyshlak comprises 5 to 50+ metres of sands, silts, marls and thin phosphatic conglomerates that were deposited in a shallow marine setting (MARCINOWSKI, 1980; MARCINOWSKI *et al.*, 1995). The conglomerates comprise variably sized (1 to 10 cm) often well rounded clasts which according to MARCINOWSKI (1980) have a complex mineralogy including silica and iron oxides as well as calcium phosphate. The conglomerates have a sandy matrix which is locally glauconitic. The sands fall into two categories; structureless, bioturbated sands which commonly contain silt and a little clay, and thin trough-cross laminated units which may represent storm events. The silty marls contain abundant limonite burrows which replace pyrite.

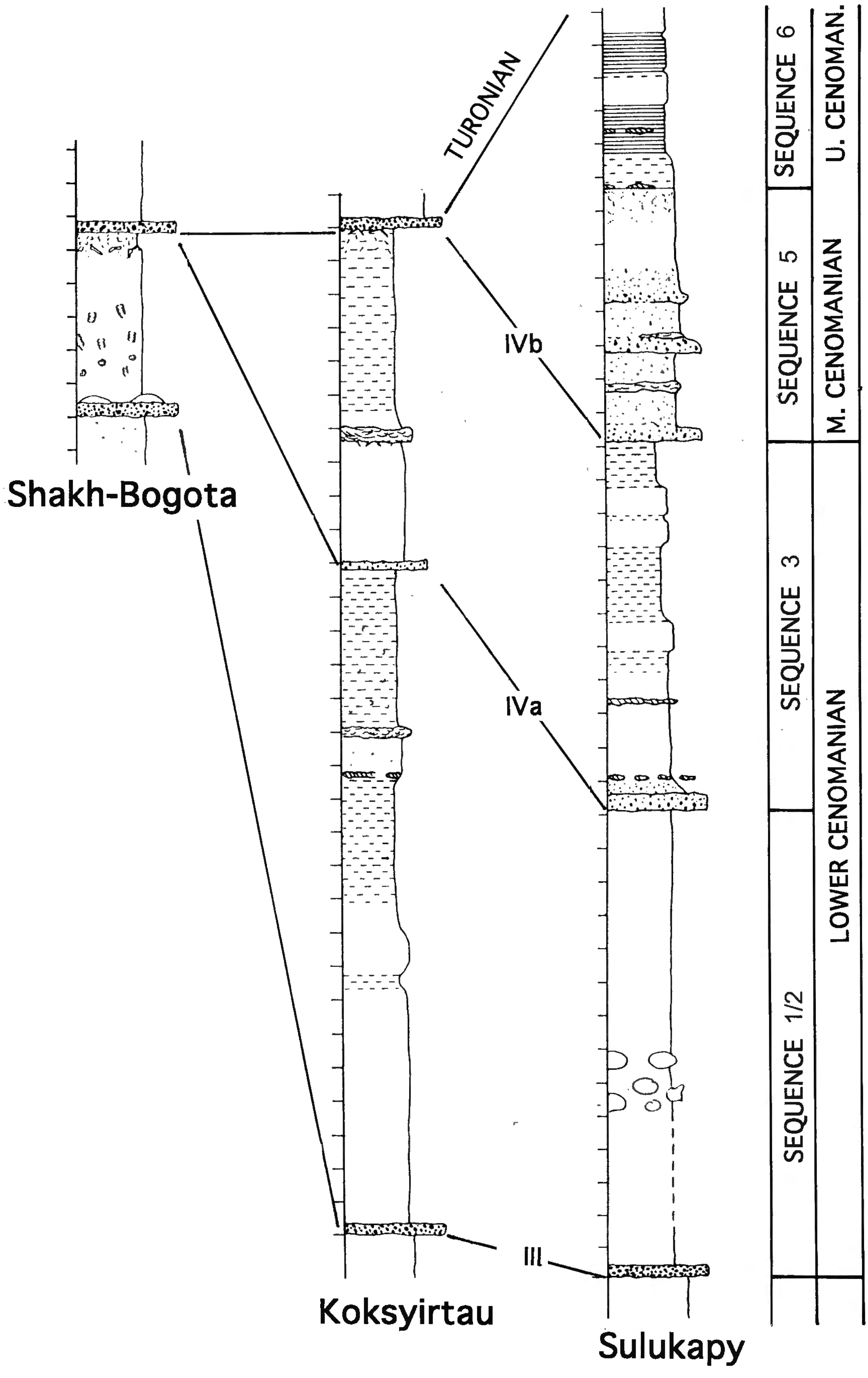
Ammonites are preserved as a) infrequent worn steinkerns among the phosphatic clasts, b) as internal moulds of limonite after pyrite which are locally very abundant in the marls, c) as calcite replacements of original shell filled with phosphate. It is quite difficult to collect material *in situ*, and many of the specimens were collected as float.

### LOWER CENOMANIAN

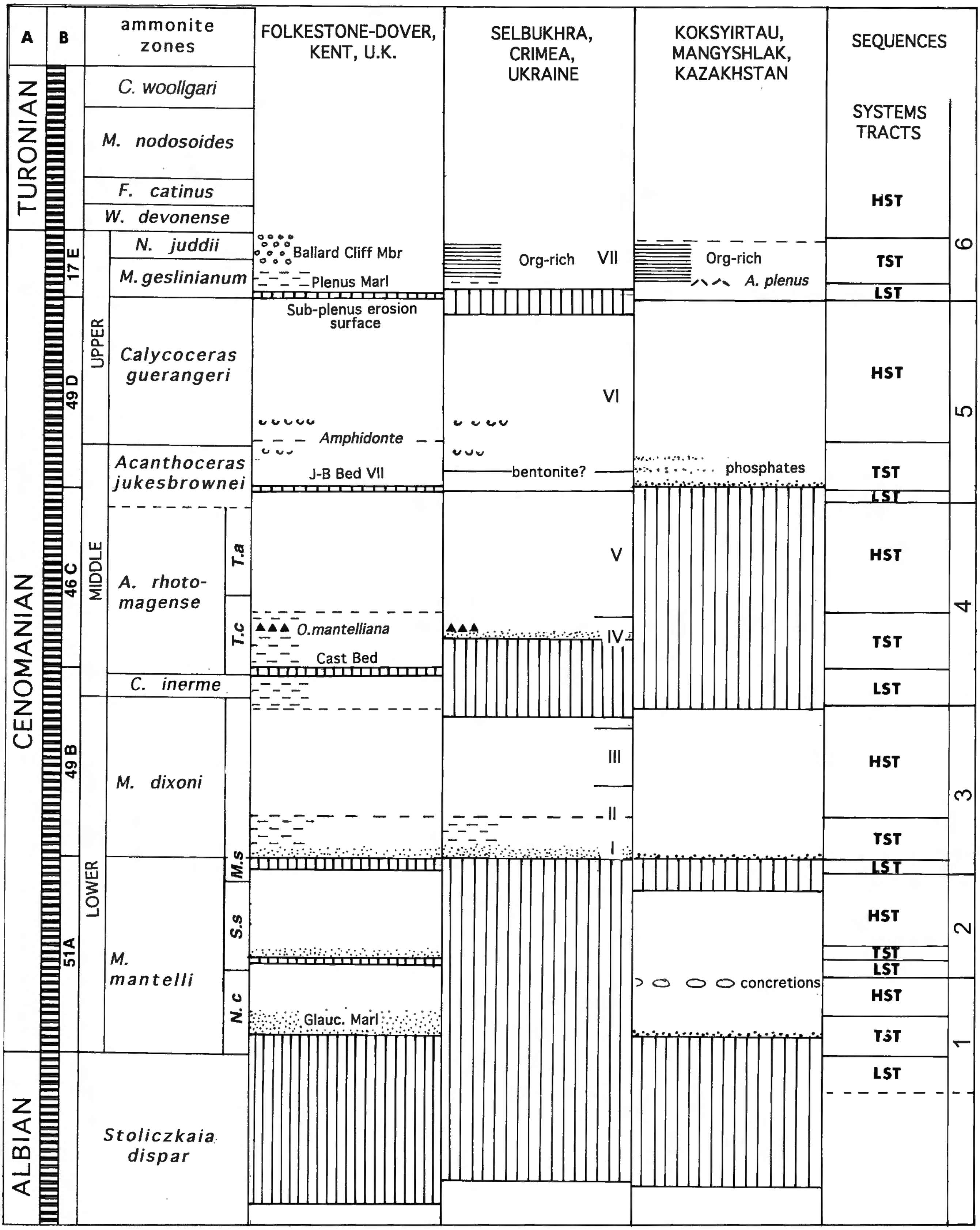
The base of the Lower Cenomanian in Mangyshlak is marked by a 0.2 m thick phosphatic conglomerate (Fig. 4) which rests upon Upper Albian sands containing *Callihoplites* spp. (MARCINOWSKI *et al.*, 1995). The conglomerate is poorly fossiliferous, but has yielded *Schloenbachia* sp. which indicate a Cenomanian age at Sulukapy (MARCINOWSKI *et al.*, 1995) and at Koksyirtau (personal observation). This latter record indicates that the base of the Cenomanian is 17.4 m lower than shown by MARCINOWSKI *et al.* (1995, fig. 9). At 9-13 m above the basal conglomerate at Sulukapy, small limonitised ammonites are common, and include abundant and diverse *Hyphoplites* spp., including *H. costosus* Wright & Wright (Pl. 2, Figs. 1, 2, 18-20), *H. curvatus curvatus* (Mantell) (Pl. 2, Figs. 23, 24), *H. curvatus* (Mantell) *arausionensis* (Hébert & Munier-Chalmas) (Pl. 2, Figs. 21, 22), *H. curvatus* (Mantell) *pseudofalcatus* (Semenov) (Pl. 2, Figs. 3, 4, 16, 17), and *H. falcatus falcatus* (Mantell) (Pl. 2, Figs. 7, 8). Other taxa we have collected from this level include *Schloenbachia varians* (J. Sowerby) (Pl. 2, Figs. 5, 6, 11, 12), *Sciponoceras roto* Cieślinśki (Pl. 2, Fig. 15), *Submantelliceras aumalense* (Coquand) (Pl. 2, Figs. 13, 14), and *Placenticeras (Karamaites)* sp. (Pl. 2, Figs. 9, 10). MARCINOWSKI *et al.* (1995) record other ammonites including *Neostlingoceras morrisiformis* (Collignon), *Mantelliceras mantelli* (J. Sowerby), *Anisoceras* spp. and *Hamites* spp. from their Bed 8 at Sulukapy (8.2-10.7 m above the base of the Cenomanian). Altogether, this assemblage is indicative of a Lower Cenomanian, *Neostlingoceras carcitanense* Subzone age.

The Lower Cenomanian is well represented at Besakty, about 150 km ESE of Koksyirtau (MARCINOWSKI *et al.*, 1995, fig. 12) where it yields diagnostic taxa of the two lower subzones of the *mantelli* Zone, the *N. carcitanense* and *S. schlueteri* assemblages (GALE, 1995). We have not seen this section, but the fauna collected and figured from Bed 25 by MARCINOWSKI *et al.* (1995) includes *N. carcitanense* (Matheron) and *Idiohamites* spp. which are diagnostic of the *carcitanense* Subzone. From Bed 30, MARCINOWSKI *et al.* record *Sharpeiceras schlueteri* and common *Inoceramus crippsi crippsi* Mantell, which characterise the *schlueteri* Subzone (GALE, 1995).

A conspicuous 0.2 m thick phosphatic conglomerate is present 14 m above the base of the Cenomanian succession at Koksyirtau (MARCINOWSKI *et al.*,1995, Bed 11; herein Text-fig. 4, 14 m) and an equivalent bed is found at




Text-figure 5 — Correlation of Cenomanian sections in Mangyshlak, showing condensation of the Middle and Upper Cenomanian westwards to Shakh Bogota.




Text-figure 6 — Correlation of Cenomanian sequences and system tracts between southern England, Crimea and Mangyshlak. Column A shows Stages, B the precession timescale of GALE (1995).

Sulukapy (Fig. 4, 20 m) not marked on the MARCINOWSKI log). It does not yield zonally diagnostic ammonites. Overlying this conglomerate, the highest 10 m of the Lower Cenomanian comprises marls containing thin units of fine sand, either bioturbated or with small-scale trough cross-sets. When freshly exposed, the marls yield bivalve taxa very similar to those common in Cenomanian marly chalks of the Anglo-Paris Basin including the bivalves *Euthymipecten beaveri* (J. Sowerby) and *Plicatula inflata* (J. Sowerby). The marls at both localities contain numerous limonitised ammonites which are particularly abundant at Sulukapy (Text-fig. 4, 25-29.5 m), from which MARCINOWSKI (1980) and MARCINOWSKI *et al.* (1995, Bed 14) recorded abundant *Turrilites costatus* Lamarck (figured by MARCINOWSKI, 1980, pl. 4, figs. 1-10). These authors used this identification to assign a Middle Cenomanian age to Bed 14 at Sulukapy, but curiously, placed equivalent strata at Koksyirtau, from which they also record *T. costatus* (Beds 19-22), in the Lower Cenomanian. Because they possess interrupted ribs, but entirely lack tubercles, these ammonites are correctly identified as immature *T. scheuchzerianus* BOSC (Pl. 1, Figs. 23-25; see also WRIGHT & KENNEDY, 1996). At Koksyirtau (Text-fig. 4, 18-23 m), *T. scheuchzerianus* is associated with a single specimen of *Mantelliceras dixoni* (Pl. 1, Figs. 9-11) which confirms the Lower Cenomanian, *M. dixoni* Zone age of this assemblage. At Southerham, Sussex, UK, *T. scheuchzerianus* first appears as a rarity in the middle part of the *M. dixoni* Zone, but becomes abundant in the upper part of the zone, and persists as a rarity into the Middle Cenomanian. The *T. scheuchzerianus* at Sulukapy are associated with *Schloenbachia varians* (Pl. 1, Figs. 14, 15, 17, 18), *Hyphoplites falcatus* (Mantell), *Scaphites (Scaphites)* sp.juv. (Pl. 1, Figs. 21, 22, 28-31), *Hamites duplicatus* Pictet & Campiche (Pl. 1, Figs. 26, 27) and *Worthoceras* sp. (Pl. 1, Fig. 16). The specimens of *Schloenbachia varians* are of Lower Cenomanian rather than Middle Cenomanian aspect. At Koksyirtau, levels 18-23 m above the base of the Cenomanian yield *T. scheuzerianus, M. dixoni* and *S. varians* (Pl. 1, Figs. 1, 2, 12, 13).

## MIDDLE CENOMANIAN

The marls of *M. dixoni* Zone age are disconformably overlain by a 5 m succession of sands with 3 levels of phosphatic intraclasts at Koksyirtau, the lowest of which (Text-fig. 4, 25.2 m) has yielded 3 phosphatised steinkerns of *Calycoceras (Gentoniceras) gentoni* (Brongniart) (Pl. 1, Figs. 3-8). MARCINOWSKI *et al.* (1995) record *Acanthoceras* cf. *jukesbrownei* (Spath) from their Bed 23, which is probably equivalent to the 25.2 m level on our Text-fig. 4. The beds containing numerous phosphates alternate with sandstones containing sparser gravel-grade chips of phosphate and oysters. At Sulukapy, the phosphatic conglomerate which rests disconformably upon Lower Cenomanian marls (see above) and underlies Turonian sands has yielded a single remanié *A. jukesbrownei* (MARCINOWSKI *et al.*, 1995). Thus, the Middle Cenomanian in Mangyshlak is represented only by remanié, phosphatised ammonites of *A. jukesbrownei* Zone age, which at Koksyirtau are set in a sandy matrix of which the precise age is unknown.

## UPPER CENOMANIAN

The Upper Cenomanian is only identified in the succession at Koksyirtau; in the western part of the Mangyshlak inlier (Sulukapy and Shakh Bogota) it is presumably incorporated (together with the Middle Cenomanian) within the phosphatic conglomerate at the base of Turonian sands which rests upon Lower Cenomanian marls (Text-fig. 5).

The Upper Cenomanian at Koksyirtau is represented by about 8 m of fine sands, silts and clays, of which the lowest 4 m is weakly to strongly laminated and coloured dark grey by up to 5% organic matter. An abundance level of the belemnite *Actinocamax plenus* (Blainville) probably correlates with the acme occurrence of the species in the Anglo-Paris Basin in Bed 4 of the Plenus Marls (JEFFERIES, 1963) within the *Metoicoceras geslinianum* Zone (WRIGHT & KENNEDY, 1981). At a level 2.7 m above the *A. plenus* horizon at Koksyirtau, MARCINOWSKI *et al.* (1995; their Bed 26) record *Neocardioceras juddii* (Barrois & Guerne), index of the *N. juddii* Zone. 4 m higher, they record *Watinoceras amaduriense* (Arkhangelsky) indicating the Lower Turonian zone of *W. devonense*.

## SEQUENCE STRATIGRAPHY

Sequences in the Cenomanian of Mangyshlak are clearly defined by sedimentological criteria. The base of each sequence comprises a thin (20-30 cm) lag of worn phosphatic concretions which rest on an erosion surface which is sometimes strongly burrowed and represents an abrupt lithological break. We interpret these surfaces as sequence boundaries which are directly overlain by transgressive surfaces. The phosphatic conglomerates are thus residual lags formed during the early stages of transgression and are very similar to other transgressive accumulations of phosphatic pebbles such as the Cambridge Greensand in the UK and the "Tourtias" of Belgium. The basal conglomerates are overlain by silty sands which formed during the latter part of transgressive systems tracts. They are overlain by silty marls representing the deepest water (most distal) facies in the succession and are interpreted as highstand deposits.

### *Sequence 1-2*

The lowest part of the Cenomanian of Mangyshlak includes the basal phosphatic conglomerate (Shakh Bogota, Sulukapy, Koksyirtau) which is interpreted as a transgressive lag, and the overlying sands and marls which are possibly highstand deposits (Text-fig. 4). This part of the succession is dated as *M. mantelli* Zone from the ammonite faunas (MARCINOWSKI, 1980; MARCINOWSKI *et al.*, 1995). The presence of large carbonate concretions at 15-18 m above the base of the Cenomanian at Koksyirtau, and in Bed 30 at Besakty (MARCINOWSKI *et al.*, 1995), both in the middle part of the *M. mantelli*

Zone, is taken as tentative evidence of the 1-2 sequence boundary, because widespread concretion development often occurs beneath significant hiatuses (e.g. HUGGETT, 1995). However, there is no conclusive sedimentological evidence to separate the two sequences. The concretions at Besakty contain a *S. schlueteri* Subzone assemblage similar to that occurring at the summit of sequence 1 at Folkestone (GALE, 1989b). In Mangyshlak there is thus limited evidence of two separate sequences (1 and 2) within the *mantelli* Zone, as found in the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998), but these are not ubiquitously separable even within the Anglo-Paris Basin (GALE, 1995; OWEN, 1996).

*Sequence 3*

The summit of the *M. mantelli* Zone sequence 1-2 in Mangyshlak (Sulukapy, Koksyirtau) is truncated by an erosional surface overlain directly by a phosphatic conglomerate, interpreted as a transgressive surface overlying a sequence boundary. The marl succession above the conglomerate contains limonitic ammonites of the *M. dixoni* Zone, and represents the highstand of the same sequence. We correlate this sequence with 3 in the Anglo-Paris Basin, which is there co-eval with the *M. dixoni* Zone.

*Sequences 4-5*

The succession of 3 phosphatic conglomerates which rest non-sequentially upon marls of *M. dixoni* Zone age at Koksyirtau are tentatively interpreted as lag deposits formed during a transgression. The lowest conglomerate contains poorly preserved steinkerns of Middle Cenomanian ammonites indicative of the *A. jukesbrownei* Zone (MARCINOWSKI *et al.*, 1995), and the sequence is tentatively identified as the transgressive systems tract of 5 in the Anglo-Paris Basin, the lower part of which falls within the *A. jukesbrownei* Zone (ROBASZYNSKI *et al.*, 1998). Sequence 4, which includes the *C. inerme* and *A. rhotomagense* Zones, is therefore missing in Mangyshlak, within the erosional surface underlying the lowest of the Middle Cenomanian phosphatic conglomerates at Koksyirtau.

*Sequence 6*

At Koksyirtau, the organic-rich silts and laminated fine sands of Late Cenomanian age (*M. geslinianum* and *N. juddii* Zones, *A. plenus* near the base) are interpreted as an overall transgressive event, a local representative of the Oceanic Anoxic Event which is developed globally at this horizon (JENKYNS, 1980). This corresponds with the lower part of sequence 6 in the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998).

## Conclusions

— Facies, faunas and detailed lithological successions are remarkably similar in the Crimea, the northern Anglo-Paris Basin (southern England and northern France) and the Lower Saxony and Münster Basins, north-west Germany.

a) Beds at the base of the *M. dixoni* Zone in the Crimea show very similar development in terms of carbonate content and thickness to those in southern England. In the Crimea, we are able to tentatively identify couplet B11 (GALE, 1995 - thin prominent limestone; see Text-fig. 3 herein) and an overlying group of carbonate rich beds (B12-13).

b) The major hiatus between the Lower Cenomanian *M. dixoni* Zone and the overlying Middle Cenomanian is of very similar extent in the Crimea, over the London Platform, and in the Lower Saxony Basin, involving the uppermost *M. dixoni* Zone, the *C. inerme* Zone and the lower part of the *T. costatus* Subzone of the *A. rhotomagense* Zone.

c) The faunas of the lowest part of the Middle Cenomanian in the Crimea are closely comparable to those of the upper *T. costatus* Subzone in the Anglo-Paris Basin (KENNEDY, 1969; AMEDRO, 1993) and Lower Saxony Basins (MEYER, 1990), including abundances of the brachiopod *Orbirhynchia mantelliana* and the ammonite *Sciponoceras baculoides*.

d) Chalk-marl couplets and bundles, representing Milankovitch cycles, of Middle Cenomanian age, can be individually correlated between the Crimea, southern England and northern Germany (cf. GALE, 1995; GALE *et al.*, in press), a total distance of 3,900 km.

e) In the Middle-Upper Cenomanian of the Crimea, three thin marls (''*Pycnodonte*-Event'' in Germany, couplets D1-3 in southern England), the overlying amalgamated couplets (''Jukes-Browne Bed VII'' of GALE, 1995; ''*Pycnodonte* Limestone'' of ERNST & REHFELD, 1997) and two acme abundances of *Amphidonte* (recognised in northern Germany and southern England) can be correlated.

f) The sub-plenus erosion surface of JEFFERIES (1963) and an unfossiliferous equivalent of the Plenus Marls of the Anglo-Paris Basin are present in the Crimea.

— The ammonite biostratigraphy described in the Cenomanian of southern England by KENNEDY (1969, 1970, 1971) can be recognised in outline in the Crimea and western Kazakhstan (Mangyshlak). We modify previous work by identifying the *M. dixoni* Zone in these regions from both ammonite evidence and associated inoceramid taxa. The lower part of the ''Middle Cenomanian'' of MARCINOWSKI (1980) and MARCINOWSKI *et al.* (1995) in Mangyshlak is shown to belong to the *M. dixoni* Zone.

— The 3rd/4th order sedimentary sequences described in the Anglo-Paris Basin by ROBASZYNSKI *et al.* (1992, 1998) and OWEN (1996) can be identified in the Crimea and Mangyshlak (Text-fig. 5). In the Crimea, late onlap resulted in sequence 3 (*M. dixoni* Zone) resting directly upon Upper Albian sandstones. Sequences 4, 5, and 6 display a very similar development to that seen in the marly chalk facies of the northern Anglo-Paris Basin, and individual system tracts can be identified and correlated. In Mangyshlak, three sequences are tentatively identified in the Lower Cenomanian (1, 2, 3), but 4 is missing on an erosional surface, as in Devon, SW England, UK (RO-

BASZYNSKI *et al.*, 1998). Sequences 5 is thin but identifiable, and 6 is present in one locality in Mangyshlak, where progressively increased condensation towards the top of the Cenomanian results in amalgamation of sequences within a phosphatic conglomerate underlying Turonian sands (Text-fig. 4).

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PLATE 1

| | |
|---|---|
| Figs. 1-2, 12-15, 17-20 | — *Schloenbachia varians* (J. Sowerby). 1,2, OUM KY2080; 12,13 OUM 2081; *Mantelliceras dixoni* Zone, Lower Cenomanian, 18-23m above base of measured section (Fig. 4), Koksyirtau. 14, 15, OUM KY2082; 17, 18 OUM KY2083; 19, 20, OUM KY2084, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measured section on Text-fig. 4, Sulukapy. |
| Figs. 3-8 | — *Calycoceras (Gentoniceras) gentoni* (Brongniart). 3,4, OUM KY2094; 5,6, OUM KY2095; 7,8, OUM KY2096, Middle Cenomanian, lowest phosphate bed, 25.3m above base of measured section in Text-fig. 4, Koksyirtau. |
| Figs. 9-11 | — *Mantelliceras dixoni* Spath. OUM KY2085, *Mantelliceras dixoni* Zone, Lower Cenomanian, 18-23m above base of measured section on Text-fig. 4, Koksyirtau. |
| Fig. 16 | — *Worthoceras* sp. OUM KY2086, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measured section on Text-fig. 4, Sulukapy. |
| Figs. 21-22, 28-29, 30-31 | — *Scaphites (Scaphites)* sp. juv. 21, 22, OUM KY2091; 28, 29, KY2092; 30, 31, OUM KY2093, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measure section on Text-fig. 4, Sulukapy. |
| Figs. 23-25 | — *Turrilites scheuchzerianus* Bosc. 23, OUM KY2087; 24, OUM KY2088; 25, OUM KY2089, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measured section on Text-fig. 4, Sulukapy. |
| Figs. 26-27 | — *Hamites duplicatus* Pictet & Campiche. OUM KY2090, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measured section in Text-fig. 4, Sulukapy. |

Figures 1-8 are X1; Figures 9-13 are X2.

PLATE 2

| | |
|---|---|
| Figs. 1-2, 18-20 | — *Hyphoplites costosus* Wright & Wright. 1,2, OUM KY2097; 18,19, OUM KY2098; 20, OUM KY2099. |
| Figs. 3-4, 16-17 | — *Hyphoplites curvatus* (Mantell) *pseudofalcatus* (Semenov). 3,4, OUM KY 2100; 16,17, OUM KY 2101. |
| Figs. 5-6, 11-12 | — *Schloenbachia varians* (J. Sowerby). 5,6, OUM KY 2102; 11,12, OUM KY 2103. |
| Figs. 7-8 | — *Hyphoplites falcatus falcatus* (Mantell). OUM KY2104. |
| Figs. 9-10 | — *Placenticeras (Karamaites)* sp. OUM KY2105. |
| Figs. 13-14 | — *Submantelliceras aumalense* (Coquand). OUM KY2106. |
| Fig. 15 | — *Sciponoceras roto* Cieśliński. OUM KY2107. |
| Figs. 21-22 | — *Hyphoplites curvatus* (Mantell) *arausoniensis* (Hébert & Munier-Chalmas). OUM KY2108. |
| Figs. 23-24 | — *Hyphoplites curvatus curvatus* (Mantell). OUM KY2109. |

All specimens from *Mantelliceras mantelli* Zone, *Neostlingoceras carcitanense* Subzone, Lower Cenomanian, 9-13 m above base of section in Text-fig. 4, Sulukapy. All figures X2.

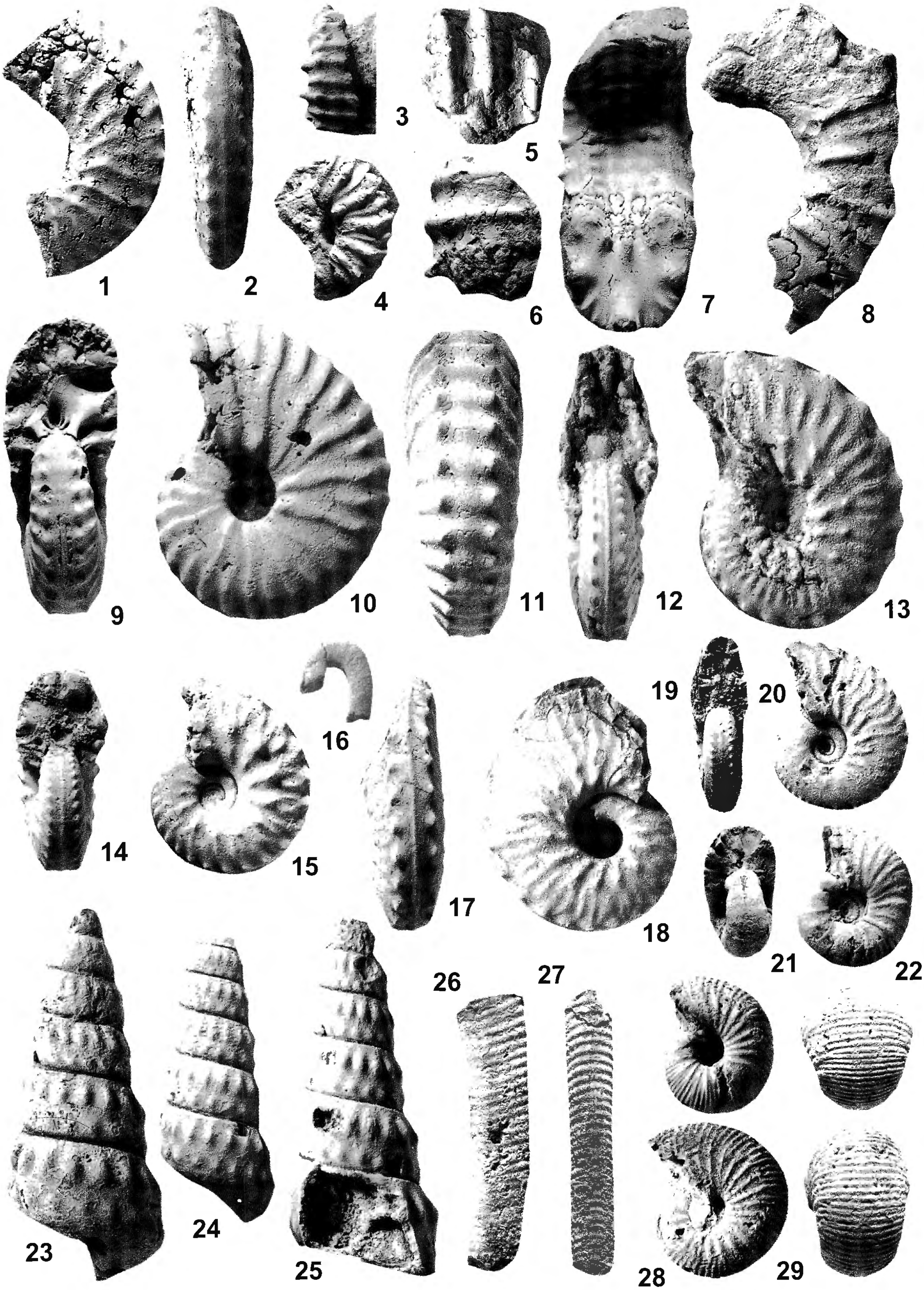


PLATE 1

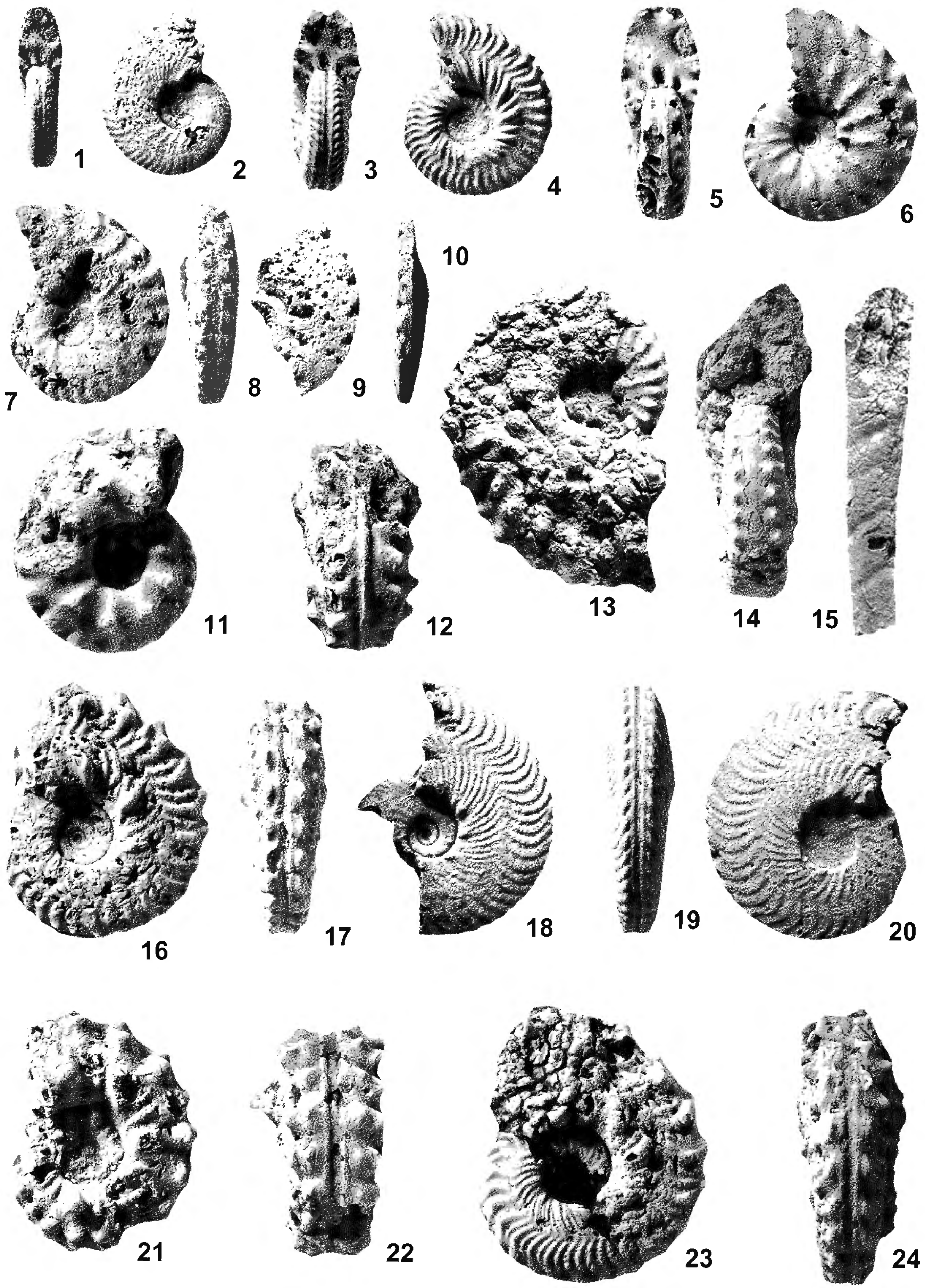


PLATE 2