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CHANGES IN OSTRACOD PROVINCIALISM DURING THE EARLY TOARCIAN IN THE EUROPEAN EPICONTINENTAL SEA-WESTERN TETHYS AREA

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Abstract

Spatial and temporal variations in ostracod biological diversity and composition are critical in understanding the role of paleoambiental on Pliensbachian-Toarcian mass extinction (Early Jurassic). An analysis based on a latest revision of the palaeobiogeographical distribution patterns of 274 Early Jurassic ostracods species within the Boreal and Tethyan provinces in the European-Western Tethys region suggests an important change in ostracod provincialism at the beginning of Toarcian. During the Early Jurassic, the ostracod faunas recovered from Western Europe show a change from a provincial to a cosmopolitan character. In the Late Pliensbachian, the ostracod assemblages from central and southern Europe changed from ostracod faunas characteristic of the Tethys Province to more cosmopolitan forms. This faunal change suggests that the temperatures of the water column changed from warm to temperate. From the late Pliensbachian and into the beginning of Toarcian new taxa, belonging to the Boreal Province (i.e. *Ektyphocythere* and *Kinkelinella*), appeared and established important evolutionary lineages on the South European platforms. The "cytheroid" spread matches to the extinction of the Superfamily Healdioidea in both provinces at the beginning of Toarcian. The change of fauna from provincial to cosmopolitan is connected with sea level variations, water temperature changes or ocean current patterns alterations.

Key words: Early Jurassic, European Epicontinental Sea, Ostracoda, Palaeobiogeography, Paleoenvironmental changes, Tethys Ocean.

Resumen

Las variaciones temporales y espaciales en la composición y diversidad de las asociaciones de ostrácodos son de gran importancia para conocer el papel del ambiente en el episodio de extinción masiva del Pliensbachiense-Toarciense (Jurásico inferior). El análisis revisado del patrón de distribución paleobiogeografica de 274 especies de ostrácodos del Jurásico inferior procedentes de las provincias Boreal y del Tethys en el área del mar epicontinental europeo y del Tethys occidental, sugiere un cambio importante en el provincialismo de los ostrácodos al inicio del Toarciense. Durante el Jurásico inferior, las faunas de ostrácodos descritas en Europa occidental muestran un cambio desde un carácter provincial a cosmopolita. En el Pliensbachiense superior, las asociaciones de ostrácodos de centro y sur de Europa cambian su composición, al pasar de tener características propias de la Provincia del Tethys a ser más cosmopolita. Este cambio faunístico sugiere que la temperatura del agua varió de cálida a templada. Desde el Pliensbachiense superior y en el Toarciense basal, aparece una nueva fauna con características boreales (representada por géneros como *Ektyphocythere* y *Kinkelinella)* y establecen unas nuevas líneas evolutivas en las plataformas del Sur de Europa. La expansión de los cytheroideos coincide con la extinción de la Superfamilia Healdioidea en ambas provincias al inicio del Toarciense. El cambio de una fauna con un marcado provincialismo a una cosmopolita debe estar vinculado a cambios eustáticos, cambios térmicos en las masas de agua o modificaciones en el patrón de corrientes oceánicas.

Palabras clave: Jurásico inferior, Mar Epicontinental Europeo, Ostrácodos, Paleobiogeografía, Cambios ambientales, Océano del Tethys.

INTRODUCTION

Palaeobiogeography transcends the classical subject of the study of the spatial distribution of organisms. The main causes behind palaeobiogeographical differentiation are frequently complex and many times, difficult to understand. They include both ecological and historical aspects as well as the phylogeny of each fossil group. A major problem with the Early Jurassic is that we have an incomplete knowledge about palaeogeographical and palaeoclimatological conditions of the marine environments. In an ecological context, zoogeographers have used geographical patterns of distribution to infer the ecological role of several factors such as, temperature, pH, light, etc. (Elofson, 1941; Hallam, 1969, 1978, 1983; Gordon, 1970, 1975; Hazel, 1970; Stevens, 1973; Wood and Whatley, 1994). Nevertheless, when we work on fossils, our considerations must incorporate new aspects, such as, palaeogeographical reconstructions, phylogenetic relationships and those taphonomic processes that could have affected palaeobiogeographical results.

Early Jurassic palaeobiogeographical studies usually have been concentrated on a few invertebrate groups, especially, ammonoids, brachiopods and bivalves (Donovan, 1967; Géczy, 1973, 1984, 1985; Enay, 1980; Dommergues, 1982; Enay and Mangold, 1982; Hallam, 1984a, Crame, 1986, 1991; Doyle, 1987; Ziegler, 1988, 1991, 1992; Riccardi, 1991; Damborenea, 1993). Among the fossil groups, microfossils have provided remarkable palaeoceanographic and palaeoclimatologic information about the Jurassic period (Gordon, 1970; Bate, 1977; Lord, 1982; 1988; Herrig, 1988; Whatley, 1988; Bucefalo-Palliani and Riding, 2003; Van de Schootbrugge *et al.*, 2005).

Before the distribution pattern of the ostracod taxa will be analysed, a very comprehensible knowledge of the palaeogeography would be required. By the mid-1970, several palinspastiques reconstructions of Pangea were proposed, reflecting uncertainties in the available geologic and paleomagnetic information (Dewey *et al.*, 1973; Biju-Duval., *et al.*, 1977; Owen, 1983; Dercourt *et al.*, 1985; Ziegler, 1988; Veevers, 2004). In the most generally accepted of these reconstructions, we could see a world dominated by the presence of a single clustered supercontinent, the Pangea, surrounded by a giant ocean, the Panthalassa Ocean. This supercontinent comprised two large landmasses: one southern continent known as Gondwana (which included South America, Africa, India and Antarctica) and another northern continent called Laurasia (which included Europe, North America and Southeast Asia).

During the Early Jurassic, in central Laurasia, the present European continent (Fig.1) was covered by an epicontinental sea with restricted basins among an archipelago of islands (Ziegler, 1988, 1991, 1992). This setting of European landmasses was a metastable sub-plate, limited to the northeast by the Fenno-Scandian-Russia Craton and the Polish-Danish Rift, to the northwest by the mega-rift system of the Arctic-North Atlantic oceans and to the south by the "V" shaped oceanic basin of the Tethys Ocean. The Tethys area shows different structural characteristics. The complex palaeogeography that characterized the Western Tethys (a complicated mosaic of structural heights and lows consequence of the evolution of the Early Jurassic rifting system), was covered for many small carbonate platforms. Theses platforms extended from the Iberian Massif to the Apulia Block (Hsü, 1971; Thierry, 1976; Biju-Duval *et al.*, 1977; Smith, 1983; Cariou *et al.*, 1985; Bassoullet *et al.*, 1991, 1992; Meister and Stampfly, 2000; Ziegler *et al.*, 2000).

The present study considers the spatial distribution of the European and Tethyan Ostracoda species during the Early Jurassic. It has been analyzed the palaeobiogeographical distribution of 274 ostracod species from 15 fossil ostracod localities: C: Grand Banks, Canada; CI: the Cordillera Iberica, Spain; DK: Danish Embayment, Denmark; FB: the Fasnet Basin, SW Ireland and North Celtic basins (Mochras borehole included); GB: British basins; It: Italy; NA: Morocco and Argelia; NEG: Northeast Germany; NWG: Northwest Germany; PB: the Paris Basin, France; Q: Quercy, France; P: the Lusitanian Basin, Portugal; SWG: Southwest Germany; Sz: Switzerland and S: Southern Sweden (Fig. 1).

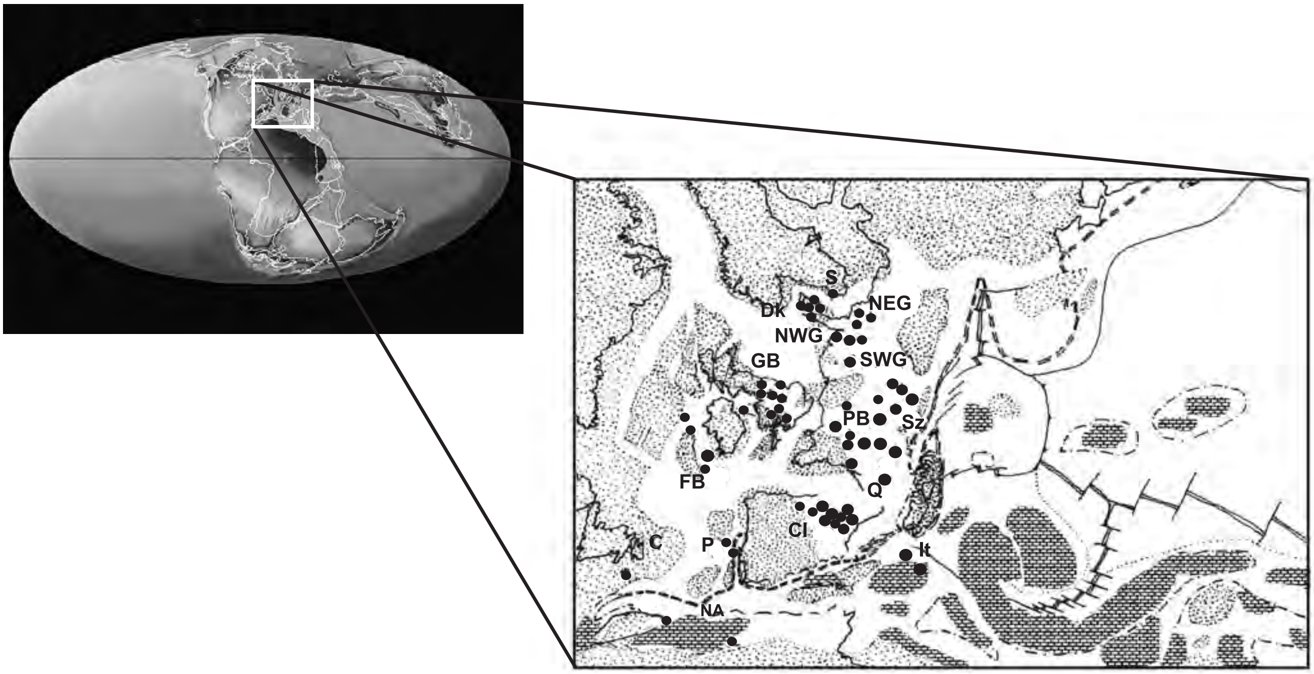

FIGURE 1–Location of the studied areas (palaeogeographical reconstruction after Ziegler, 1988 and Bassoullet *et al*., 1992). Abbreviations: C: Grand Banks, Canada; CI: the Cordillera Iberica, Spain; DK: Danish Embayment, Denmark; FB: the Fasnet Basin, SW Ireland and North Celtic basins (Mochras borehole included); GB: British basins; It: Umbrian and Sicily, Italy; NA: Morocco and Argelia; NEG: Northeast Germany; NWG: Northwest Germany; PB: the Paris Basin, France; Q: Quercy, France; P: the Lusitanian Basin, Portugal; SWG: Southwest Germany; Sz: Northeast Switzerland and S: Southern Sweden. Plate tectonic maps and Continental drift animations modified Scotese (2002)-PALEOMAP Project (www.scotese.com).

Much of the published footprint literature dates from the last 30 years, and contains considerable duplication (several different workers giving different names to the same ostracod species). As far as possible, we avoided this excess of species doing a new taxonomical revision. This revision from 230 published papers and private collections have allowed establishing a new database of 274 ostracod species (Table 1).

The aim of this research is to investigate if changes in the latitudinal gradient of taxonomic composition of ostracods in the late Pliensbachian to early Toarcian transition took place; to assess the correspondence of the palaeobiogeographical distribution with the general idea of a simple Boreal-Tethyan provincialism, and to offer tentative interpretations of these patterns with respect to palaeoclimatic and paleoenvironmental conditions.

PALEOENVIRONMENTAL DISTRIBUTION OF EARLY JURASSIC OSTRACODS

One of the most successful functional significance of Early Jurassic Ostracoda is their employ as paleoenvironmental indicators because of their limited ecological preferences. The majority of Early Jurassic ostracods were neritic and most of them specialized in shallow marine environments (Hallam, 1969; Fürsich, 1976).

In this next section, the distribution of Early Jurassic ostracods is assessed in terms of the availability of marine facies, and the influence of local paleoecological conditions. In general, Early Jurassic benthic ostracod faunas reached their highest diversity in mid-shelf, warm-water tropical and sub-tropical environments where shallow carbonates were deposited, meanwhile deep-water clastic sequences, deposited at higher latitudes in cooler water settings, had lower diversity.

According to Ziegler (1988) three major marine facies associations in the European area can be differentiated: (1) *the Baltic and Polish* (continental and estuarine clastic deposits located between the Fennoscandian High and the Bohemian Massif); (2) *the North sea-North Germany* (open marine colder water shale sediments which spread from the Norwegian-Greenland sea and Scottish Highlands into the Netherlands and northern Germany); and (3) *the*

Acrocythere gassumensis Michelsen, 1975
Acrocythere mimica Bate and Coleman, 1975
Acrocythere oeresundensis Michelsen, 1975
Acrocythere rectangula Michelsen, 1975
Acrocythere reticulata Knitter, 1983
Acrocythere troesteri Riegraf, 1984
Ambigocythere concentricostata Herrig, 1985
Aphelocythere kuhni Triebel and Klingler, 1959
Bairdia cariata Drexler, 1958
Bairdia clio Bizon, 1960
Bairdia crassa Drexler, 1958
Bairdia donzei Herrig, 1979
Bairdia fortis Drexler, 1958
Bairdia guttulae Herrig, 1979
Bairdia hahni Lord and Morley, 1974
Bairdia kempfi Ainsworth, 1989
Bairdia michelseni Herrig, 1979
Bairdia molesta Apostolescu, 1959
Bairdia ohmerti Knitter, 1983
Bairdia praehilda Herrig, 1979
Bairdia rostrata Issler, 1908
Bairdia thuringica Herrig, 1979
Bairdia undulata Herrig, 1979
Bairdia verrucosa Herrig, 1979
Bairdia? eirensis Ainsworth, 1986a
Bairdia sp. A Ainsworth, 1986b
Bairdia sp. A Ainsworth, 1990
Bairdia sp. A Ohm, 1986
Bairdiacypris dorisae (Knitter, 1984)
Bairdiacypris rectangularis Ainsworth, 1986b
Bairdiacypris sartriensis Donze, 1966
Bairdiacypris triangularis Ainsworth, 1986b
Bairdiacypris triasica postera Herrig, 1979
Bairdiacypris tumida Ainsworth, 1987
Bythocypris fabaeformis Drexler, 1958
Cardobairdia fastnetensis Ainsworth, 1987
Cardobairdia liassica (Drexler, 1958)
Cardobairdia Nr. 103 Klingler, 1962
Cardobairdia posteroprolata Ainsworth, 1987
Cardobairdia toarcensis Ainsworth, 1986b
Cardobairdia sp. A Ainsworth, 1987
Cardobairdia sp. K (Apostolescu, 1959)
Cristacythere betzi (Klingler and Neuweiler, 1959)
Cristacythere costata Michelsen, 1975
Cristacythere crassireticulata Michelsen, 1975
Cytherella demiexensis Ainsworth, 1989
Cytherella drexlerae Field, 1967
Cytherella lindseyensis Lord, 1974
Cytherella praecadomensis (Knitter and Riegraf, 1984)
Cytherella toarcensis Bizon, 1960
Cytherelloidea anningi Lord, 1974
Cytherelloidea cadomensis (Bizon, 1960)
Cytherelloidea circumscripta (Blake, 1876)
Cytherelloidea drexlerae (Field, 1976)
Cytherelloidea lacertosa Apostolescu, 1959
Cytherelloidea modesta Apostolescu, 1959
Cytheropteron alafastigatum Fischer, 1962
Cytheropteron byfieldensis Boomer and Bodergat, 1992
Cytheropteron cavatum Michelsen, 1975
Cytheropteron diversum Herrig, 1969b
Cytheropteron foveolatum Michelsen, 1975
Cytheropteron sp. B Riegraf, 1985
Cytheropteron? sp. A Riegraf, 1985
Cytheropteron? sp. Boomer, 1991
Ektyphocythere ambo Boomer, 1988
Ektyphocythere acuminata (Riegraf, 1984)
Ektyphocythere anterocosta Boomer, 1988
Ektyphocythere bucki (Bizon, 1960)
Ektyphocythere champeauae (Bizon, 1960)
Ektyphocythere debilis Bate and Coleman, 1975
Ektyphocythere dharennsourensis Boutakiout *et al.,* 1982
Ektyphocythere intrepida Bate and Coleman, 1975
Eocytheropterina jutlandica (Michelsen, 1975)
Eucytherura sp. Riegraf, 1985
Fabalicypris symmetrica Herrig, 1979
Gammacythere ubiquita Malz and Lord, 1976
Gen ind. sp. A Boutakiout *et al.,* 1982
Gramannella apostolescui (Gramann, 1962)
Gramannella laevigata Michelsen, 1975
Gramannella tatei (Gramann, 1962)
Gramannicythere aubachensis Riegraf, 1984
Gramannicythere bachi bachi Herrig, 1982a
Gramannicythere bachi ornata Herrig, 1982a
Gramannicythere coniuncta Herrig, 1982a
Gramannicythere sp. Malz and Nagy, 1989
Hemiparacytheridea (Tuberocytheridea) angulocostata Knitter, 1983
Infracytheropteron gwashense Bate and Coleman, 1975
Infracytheropteron pulchellum Bate and Coleman, 1975
Infracytheropteron rarum Knitter, 1983
Infracytheropteron supraliasicum (Herrig, 1981a)
Isobythocypis tatei (Coryell, 1963)
Isobythocypris? sp. Dreyer, 1967
Isobythocypris aff. *elongata* (Blake, 1876) Sivhed, 1980
Isobythocypris cf. *elongata* (Blake, 1876) Sivhed, 1980
Isobythocypris cf. *elongata* (Blake, 1876) Drexler, 1958
Isobythocypris cf. *elongata* (Blake, 1876) Michelsen, 1975
Isobythocypris cylindrica (Herrig, 1979)
Isobythocypris dorsoconversa Ainsworth, 1986b
Isobythocypris elongata (Blake, 1866)
Isobythocypris ovalis Bate and Coleman, 1975
Isobythocypris pliensbachiensis Ainsworth, 1986b
Isobythocypris unispinata Apostolescu, 1959
Kinkelinella kadeshensis Rosenfeld and Gerry, 1987
Kinkelinella costata Knitter, 1984
Kinkelinella persica Bate and Coleman, 1975
Kinkelinella procera Herrig, 1985
Kinkelinella sermoisensis (Apostolescu, 1959)
Kinkelinella tenuicostata Martin, 1960
Kinkelinella? idrissensis Boutakiout *et al.,* 1982
Klinglerella auleata (Klingler and Neuweiler, 1959)
Klinglerella bipartita (Klingler and Neuweiler, 1959)
Klinglerella elongata (Michelsen 1975)
Klinglerella foveolata Michelsen, 1975
Klinglerella glabellata (Klingler and Neuweiler, 1959)
Klinglerella herrigi Ainsworth, 1989
Klinglerella intermedia (Klingler and Neuweiler, 1959)
Klinglerella lacunosa Ainsworth, 1989
Klinglerella katsloesensis Sivhed 1980
Klinglerella medioreticulata (Michelsen, 1973)
Klinglerella moorei (Brady, 1872)
Klinglerella sinemuriana Ainsworth, 1989
Klinglerella sulcata (Klingler and Neuweiler, 1959)
Klinglerella translucens Ainsworth, 1989
Klinglerella variabilis (Klingler and Neuweiler, 1959)
Ledahia conviniens Herrig, 1980
Ledahia septenaria (Gründel, 1964)
Ledahia telata (Drexler, 1958)
Liasina cylindrica Ainsworth, 1986b

TABLE 1–List of Pliensbachian and Early Toarcian ostracod species.

Liasina lanceolata (Apostolescu, 1959)
Liasina vestibulifera Gramann, 1963
Liasina cf. *vestibulifera* Sivhed, 1980
Monoceratina amlingstadtensis Triebel and Bartenstein, 1938
Monoceratina frentzeni Triebel and Bartenstein, 1938
Monoceratina mesoliassica Triebel and Bartenstein, 1938
Monoceratina michelseni Riegraf, 1984
Monoceratina seebergensis Triebel and Bartenstein, 1938
Monoceratina stimulea (Schwager, 1866)
Monoceratina striata Triebel and Bartenstein, 1938
Monoceratina ungulina Triebel and Bartenstein, 1938
Nanacythere (G.) circumcostata Michelsen, 1975
Nanacythere (G.) elegans (Drexler, 1958)
Nanacythere (G.) elongata Michelsen, 1975
Nanacythere (D.) firma Herrig, 1969b
Nanacythere (D.) fissicosta Herrig, 1969b
Nanacythere (G.) minor Michelsen, 1975
Nanacythere (G.) paracostata Michelsen, 1975
Nanacythere persicaeformis Riegraf, 1984
Nanacythere (N.) simplex Herrig, 1969b
Ogmoconcha (Hermiella) ambo Lord and Moorley, 1974
Ogmoconcha (Hermiella) cincta Malz, 1975
Ogmoconcha (Hermiella) circumvallata Dreyer, 1967
Ogmoconcha (Hermiella) cista Malz, 1975
Ogmoconcha (Hermiella) comes Malz, 1975
Ogmoconcha (Hermiella) hyblea (Barbieri, 1964)
Ogmoconcha (Hermiella) intercedens Dreyer, 1967
Ogmoconcha (Hermiella) klingleri Malz, 1975
Ogmoconcha amalthei amalthei (Quenstedt, 1967)
Ogmoconcha amalthei rotunda Dreyer, 1967
Ogmoconcha contractula Triebel, 1941
Ogmoconcha convexa Boomer, 1991
Ogmoconcha dentata (Issler, 1908)
Ogmoconcha eocontractula Park, 1984
Ogmoconcha hagenowi Drexler, 1958
Ogmoconchella adenticulata (Pietrzenuk, 1961)
Ogmoconchella aequalis (Herrig, 1969a)
Ogmoconchella aspinata (Drexler, 1958)
Ogmoconchella celticensis Ainsworth, 1989
Ogmoconchella danica Michelsen, 1975
Ogmoconchella gruendeli Malz, 1971
Ogmoconchella impressa Malz, 1971
Ogmoconchella michelseni Michelsen, 1975
Ogmoconchella mouhersensis (Apostolescu, 1959)
Ogmoconchella propinqua Malz, 1971
Ogmoconchella scanica Sivhed, 1977
Ogmoconchella serratostriata Ainsworth, 1989
Ogmoconchella sp. A Lord, 1974
Ogmoconchella sp. B (Apostolescu, 1959)
Ogmoconchella sp. B Cubaynes, 1986
Ogmoconchella transversa (Gründel, 1970)
Paracypris liassica (Bate and Coleman, 1975)
Paracypris redcarensis (Blake, 1876)
Paracypris sp. 1 Exton, 1979
Paracypris sp. 2 Exton, 1979
Paracypris sp. A Riegraf, 1985
Paracypris sp. C Ainsworth, 1986b
Paracypris sp. Cubaynes, 1986
Paracypris? longiformis Sivhed, 1980
Paradoxostoma? fusiforme (Drexler, 1958)
Paradoxostoma? pulchellum Michelsen, 1975
Paranotacythere (Unicosta) mochrarensis (Boomer, 1991)
Paranotacythere (Unicosta) terquemiana (Jones, 1872)
Paranotacythere (Unicosta) decorata (Apostolescu *et al.,* 1961)
Pleurifera harpa harpa (Klingler and Neuweiler, 1959)
Pleurifera harpa harpoidea (Gramann, 1962)
Pleurifera perplexa (Klingler and Neuweiler, 1959)
Pleurifera plicata (Apostolescu, 1959)
Pleurifera vermiculata (Apostolescu, 1959)
Polycope cerasia Blake, 1876
Polycope cincinnata Apostolescu, 1959
Polycope decorata Apostolescu, 1959
Polycope discus Fischer, 1961a
Polycope minor Michelsen, 1975
Polycope pelta Fischer, 1961a
Polycope plumhoffi Bate and Coleman, 1975
Polycope tenuireticulata (Herrig, 1981 c)
Pontocyprella fabaeformis (Drexler, 1958)
Praeschuleridea aspera Knitter, 1983
Praeschuleridea arguta Ainsworth, 1986a
Praeschuleridea bernierensis (Apostolescu, 1959)
Praeschuleridea costata Ainsworth, 1986a
Praeschuleridea ellipsoidea Ainsworth, 1986b
Praeschuleridea gallemannica Malz, 1966
Praeschuleridea levita Ainsworth, 1986b
Praescleridea magnycourtensis (Apostolescu, 1959)
Praeschuleridea punctulata Plumhoff, 1963
Praeschuleridea reticulata Ainsworth, 1986a
Praeschuleridea pseudokinkelinella Bate and Coleman, 1975
Praeschuleridea ventriosa Plumhoff, 1963
Praeschuleridea whatleyi Ainsworth, 1986b
Praeschuleridea sp. A Ainsworth, 1986b
Procytheridea multiforata (Klingler and Neuweiler, 1959)
Procytheridea spinaecostata (Klingler and Neuweiler, 1959)
Procytheridea laneuvevillae Donze, 1967
Procytheridea lotharingiae Apostolescu, 1959
Procytheridea perplexa (Klingler and Neuweiler, 1959)
Procytheridea undulata Apostolescu, 1959
Procytheridea? jardensis Maupin, 1978
Procytherura? exquisita Ainsworth, 1986b
Procytherura? liassica Ainsworth, 1986b
Procytherura celtica Ainsworth, 1986b
Procytherura euglyphea Ainsworth, 1986b
Procytherura hastata Bate and Coleman, 1975
Procytherura mediocostata Bate and Coleman, 1975
Procytherura multicostata Ainsworth, 1986b
Procytherura suebica (Herrig and Richter, 1990)
Procytherura werneri (Riegraf, 1984)
Procytherura? sp. Boomer, 1992
Progonoidea acuticostata (Klingler and Neuweiler, 1959)
Progonoidea auleata (Gramann, 1962)
Progonoidea polygonata Sivhed, 1980
Progonoidea reticulata (Klingler and Neuweiler, 1959)
Pseudohealdia etaulensis (Apostolescu, 1959)
Pseudohealdia nasuta (Drexler, 1958)
Pseudohealdia pseudospina (Herrig, 1969a)
Pseudohealdia pseudohealdiae (Gründel, 1964)
Pseudohealdia sp. A Ainsworth, 1987

TABLE 1 (continued)–List of Pliensbachian and Early Toarcian ostracod species.

Pseudohealdia transversa (Gründel, 1970)
Pseudohealdia truncata Malz, 1971
Pseudomacrocypris? sp. A Ainsworth, 1986 b
Pseudomacrocypris cf. *subtriangularis* Michelsen, 1975
Pseudomacrocypris subaequalis Michelsen, 1975
Renicytherura liassica (Bate and Coleman, 1975)
Renicytherura tricostata (Michelsen, 1975)
Rutlandella tatei Ainsworth, 1986b
Trachycythere tubulosa seratina Triebel and Klingler, 1959
Trachycythere tubulosa tubulosa Triebel and Klingler, 1959
Trachycythere verrucosa Triebel and Klingler, 1959
Triassocythere multiestriata Michelsen, 1975
Triassocythere? sp. 4135 (Michelsen, 1975)
Triceratina sp. Boomer, 1992
Wicherella semiora kirtonensis Lord, 1972
Wicherella semiora semiora Lord, 1972

TABLE 1 (continued)–List of Pliensbachian and Early Toarcian ostracod species.

South-western Europe (warmer water carbonate-shale facies described from the Bohemian-Rhenish-London-Brabant massifs area to the Irish Massif). In the Tethys area, Bassoullet *et al.* (1992) distinguished three environments: (1) warm carbonate platforms along the northwestern African coast (Moroccan High Atlas, Algerian), (2) argillaceous and arenaceous deposits accumulated on basinal environments (Subbetic and Tellian basins) and in a large extension, (3) pelagic or hemipelagic deposits *(Ammonitico Rosso limestone* facies) deposited in the northwestern Tethys areas. In this paper it has been followed this broad scheme as initial approach.

The preliminary idea of this paper is to analyze if there is a good correlation, both in space in time between the ostracod fauna and sedimentary facies. This correlation could document (1) ecological parameters that controlled the development and distribution of ostracod fauna, and (2) the taphonomic path that led to the preservation of ostracod shells. Together, these ecological and taphonomic windows are hypothesized to control the distribution of ostracod shells in different environments. Gaps in the fossil record of Pliensbachian-Toarcian boundary ostracods could result in erroneous interpretations of possible provincialism patterns. Because of this, the completeness of the Early Jurassic ostracod fossil record for each facies provinces in this section is assessed.

Shallow marine shale and/or clastic sediments

The Early Jurassic deposits in the North sea and surrounding areas are predominantly shallow marine argillaceous sediments. In northwestern European marginal areas bordering the Fennoscanian Shield, ostracod assemblages from Danish Embayment and southern Sweden basins, are sparse and poorly preserved. Smooth healdioids, bairdioids and a few groups of large cytheroids *(Klinglerella*, *Nanacythere)* dominate Ostracoda assemblages.

Pliensbachian marine claystone- shale, with a varying silt content, sandstone intercalations and calcareous beds deposits of the Fjerritslev Formation (members F-II and F-III) in the Norwegian-Danish Basin (Michelsen, 1975, 1978) shows very diverse ostracod assemblages, mainly consist of healdioids *(Ogmoconcha*, *Ogmoconchella* and *Hermiella)* and cytheraceans *(Gramannella*, *Klinglerella* and *Cristacythere)*, small cytherurids *(Nanacythere, Cytheropteron*, *Procytherura)* and bythocytherids. Other important components of the ostracod assemblages are several species of *Bairdia, Isobythocypris* and *Polycope* (Michelsen, 1975).

Only a few small and juvenile specimens have been described from the Early Pliensbachian claystones and mudstones of the Katslšsa Member, Rya Formation in western Skøne, southern Sweden (Sivhed, 1980). These sediments yielded moderately rich ostracod assemblages, which show close similarity to that of the Danish Embayment (e.g. *Ogmoconchella danica*, *Nanacythere minor, Gramannella apostolescui*, *Pleurifera harpa*). Late Pliensbachian and Toarcian siltstones of the Rydehsck Member (Sivhed, 1980) have yielded fragmentary specimens of *Ogmoconcha* and *Gramannella laevigata* (Figs. 2, 3).

Malz and Nagy (1989) described Pliensbachian and Toarcian ostracod assemblages from core samples of the North sea area (East Shetland Basin). The Lower Jurassic mudstone and siltstone of the Admundsen, Cook, and Drake formations deposited under offshore marine to prodelta in shelf embayment conditions, yielded a very poorly preserved ostracod assemblages dominated by healdioids and a few cytheraceans (mainly *Gramannella apostolescui*).

To the south, offshore Southwest Ireland (the Fastnet Basin, Celtic sea and the Cardigan Bay) the facies change and are dominated by argillaceous sediments. The mudrocks sequences assigned to the *Croyde* and

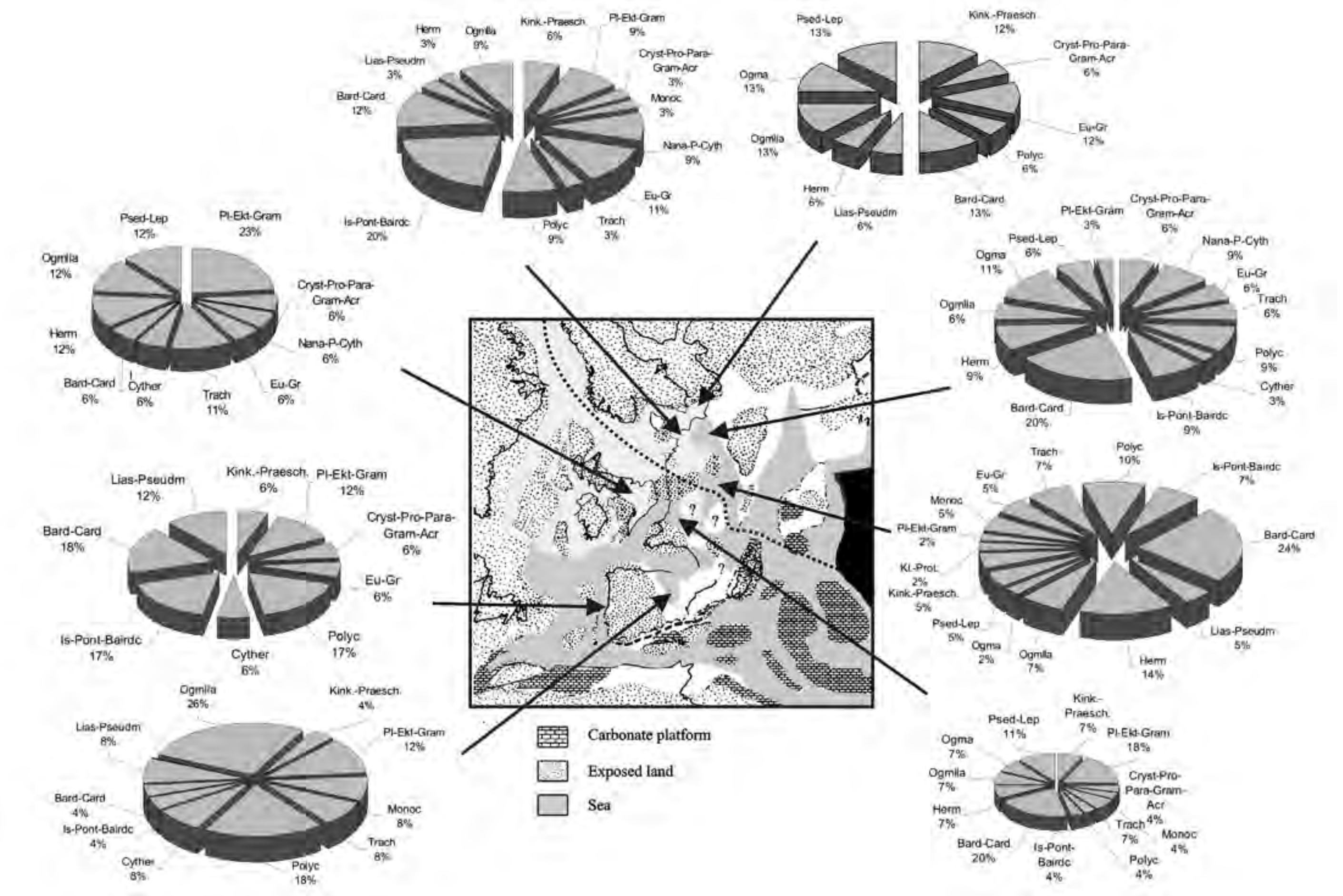

FIGURE 2–Percentage of Late Pliensbachian ostracod genera recorded in each studied areas. Abbreviations of ostracod genera: Kink.-Praesch: *Kinkelinella* and *Praeschuleridea*; Kl.-Prot. *Kliglerella* and *Procytheridea*; Pl-Ekt-Gram: *Pleurifera*, *Ektyphocythere* and *Gramannella*; Cryst-Pro-Para-Gram-Acr: *Crystacythere*, *Paracytheridea*, *Acrocythere*; Monoc. *Monoceratina*; Nana-P-Cyth: *Nanacythere*, *Paranocythere* and *Cythere*; Eu-Gr: *Eucytherura*, *Gramannicythere*; Trach: *Trachycythere*; Polyc: *Polycope*; Cyther: *Cytherella*, *Cytherelloidea*; Is-Pont-Bairdc: *Isobythocypris*, *Pontocypris* and *Bairdiacypris*; Bard-Card: *Bairdia* and *Cardobairdia*; Lias-Pseudm: *Liasina* and *Pseudomacrocypris*; Herm: *Hermiella*; Ogmlla: *Ogmoconchella*; Ogma: *Ogmoconcha* and Psed-Lep: *Pseudohealdia* and *Ledahia.*

Kikhampton formations (Sinemurian-Pliensbachian) and the *Stratton Formation* (Toarcian) were probably deposited in nearshore marine. Pliensbachian hard grey claystone-shale sequence contains very rich and diverse assemblages, with bairdioids and healdioids as dominant components *(Bairdia, Cardobairdia, Isobythocypris, Bairdiacypris, Hermiella, Ogmoconcha, Pseudohealdia),* together with several species, many news, of *Liasina*, *Polycope* and *Procytherura* (Ainsworth 1986a, b, 1987, 1989; Ainsworth and Horton, 1986 and Ainsworth *et al.*, 1987). Toarcian dark calcareous bituminous shales probably in shelf environment yielded less abundant ostracod assemblages (Ainsworth, 1989), where healdiids are absent and large cytheroids *(Kinkelinella*, *Ektyphocythere* and *Praeschuleridea)* dominate (Figs. 2, 3).

Deeper marine shales and /or clastic sediments

Lower Jurassic Scalpa Sandstone Formation from Western Irish basins (Porcupine, Slyne, Erris and Donegal basins comprises shales and silstones deposited in deeper marine conditions with restricted water circulation (Ainsworth *et al.*, 1987). These assemblages are moderately diverse and are dominated by smooth bairdioids and healdioids *(Bairdia kempfi*, *Ledahia septenaria*, *Ogmoconcha* aff. *Ogmoconcha*

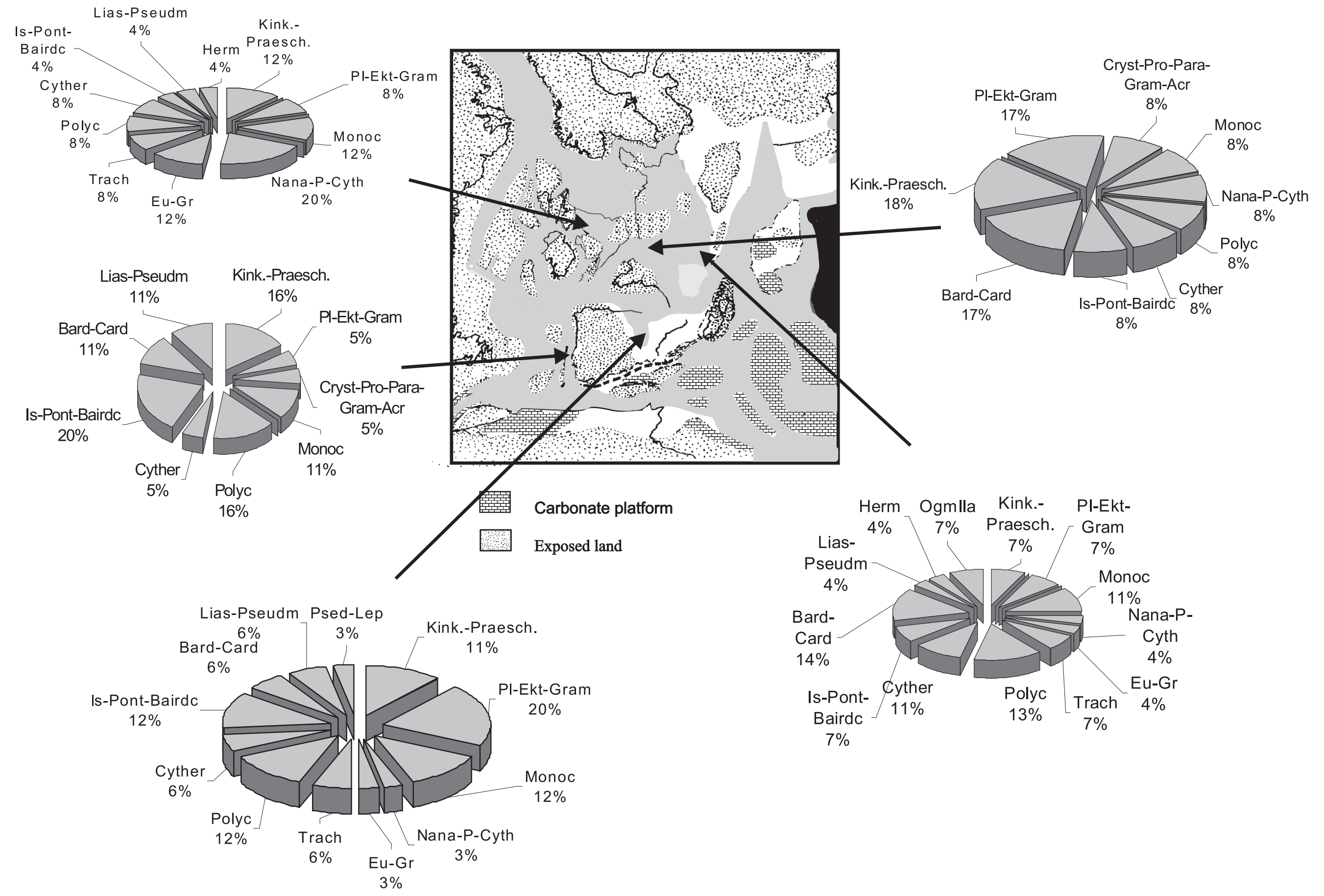

FIGURE 3–Percentage of Early Toarcian ostracod genera recorded for each studied areas. For abbreviations of ostracod genera (see legend to Fig. 2).

rotunda, *Ogmoconchella aequalis*, *Ogmoconchella adenticulata* and *Pseudohealdia etaulensis)*.

Similar composition show ostracod assemblages described by Boomer (1991) from an Early Jurassic sequence of grey mudstones, siltstones and limestones of a borehole drilled at Mochras, on the coast of Cardigan Bay (Wales). These assemblages show a high similitude with southwestern European assemblages, but differ from the rest of the British assemblages by the large number of cytheroids, such as *Eucytherura*, *Cytheropteron*, *Gammacythere* and *Lophodentina* (Boomer, 1991; Boomer and Ballent, 1996) (Figs. 2, 3).

Shallow carbonate platform sediments

By contrast, carbonate marine environments yield profile high diversity ostracod faunas. They include most of documented Early Jurassic ostracod assemblages from the Cordillera Iberica, eastern Spain. In southern Europe, it has been described marine ostracod assemblages from Pliensbachian- Early Toarcian carbonate platform sediments of the Cordillera Iberica and Cordillera Vasco-Cantábrica, Spain (Arias, 1989, 1991, 1995, 1997; Arias and Comas Rengifo, 1992; Arias *et al.*, 1992 and Arias and Lord, 1999a, b). The Pliensbachian sequence comprises two litostratigraphic units, a mostly marly unit with limestones, marly limestones interbedding named the Margas Grises del Cerro del Pez Formation, and a bioclastic limestone unit, the Calizas Bioclásticas de Barahona Formation deposited under strong wave influence (Goy, 1974; Goy *et al.*, 1976; Arche *et al.* 1977; Comas-Rengifo, 1985). Ostracod assemblages from the Late Pliensbachian are dominated by healdioids (*Ogmoconchella aspinata*, large cytheroids (*Ektyphocythere* aff. *Ektyphocythere vitiosa*, *Gramannella apostolescui* and *Pleurifera harpa), Liasina lanceolata* and *Cytherella toarcensis.* So far, the genus *Hermiella* has not been recorded. Toarcian sediments are developed as alternating series of marly limestones and marls, formally named the Alternancia de Margas y Calizas de Turmiel (Goy, 1974; Goy *et al.*, 1976). One of the most significant differences in relation to previous areas is the absence of black shale facies. Cytheroids dominates all assemblages and most of the recorded taxa have been previously recorded from other parts of northwestern Europe. At the Pliensbachian-Toarcian boundary, cytherellids and cypridoids are very well represented, declining in importance upward. During the earliest Toarcian, ostracod assemblages (Figs. 2, 3) are dominated by large and ornamented cytheroids *(Ektyphocythere* aff. *Ektyphocythere vitiosa*, *Ektyphocythere anterocosta*, *Ektyphocythere bucki*, *Gramannella apostolescui*, *Kinkelinella tenuicostata*, *Kinkelinella sermoisensis* and *Praeschuleridea pseudokinkelinella)*, and in less proportion, by *Bairdiacypris dorisae*, *Cytherella toarcensis*, *Liasina lanceolata* and many species of the *Polycope* (Arias and Lord, 1999a, b).

The ostracod assemblages within the shallow carbonate platforms of North Africa (Morocco and Algeria) show close affinities with those of southern Europe (Maupin, 1977; Baloge, 1981; Boutakiout *et al.*, 1982; Lord, 1982; Bassoullet *et al.*, 1991). Boutakiout *et al.* (1982) and Bassoullet *et al.* (1991) described assemblages from three sections situated at *rides sud-rifaines*, close to the middle Atlas Meseta and eastern Moroccan Meseta. Overlying the Upper Pliensbachian bioclastic limestones there is a sequence of grey marls interbedded with marly limestones deposited during the Toarcian. Late Pliensbachian assemblages are dominated by healdiids *(Ogmoconchella*, *Pseudohealdia*, and *Hermiella)*, large cytheroids *(Gramannella*, *Kinkelinella)* and some species of *Liasina* and *Bairdia*. Toarcian assemblages are characterised by the absence of healdioids and by dominance of large cytheroids *(Ektyphocythere*, *Kinkelinella*, and *Praeschuleridea)* and several species of *Monoceratina* (Boutakiout *et al.*, 1982; Bassoullet *et al.*, 1991). Maupin (1977) described the ostracod fauna of three outcrops in western Oman plateau (Chain Calcaire Kabyle, Northern Constantinois) which are dominated by healdiids during the Early Pliensbachian *(Hermiella ambo*, *Ogmoconcha amalthei)* and by species of *Bairdia*, *Cytherella*, *Isobythocypris*, *Paracypris*, *Liasina* and large cytheroids *(Kinkelinella*, *Ektyphocythere)* in the Toarcian (Figs. 2, 3).

Shallow marine carbonates and shales sediments

The composition of the ostracod assemblages described in those basins located on the southern margin of the London-Brabant Massif is clearly conditioned by the deposition of black shale facies (Röhl *et al.*, 2001 Schmid-Röhl *et al.*, 2002).

Lower Jurassic deposits of the Quercy area, Basin of the Aquitaine (Cubaynes and Faure, 1981; Cubaynes, 1986) comprise marly and marly-calcareous sediments of the three members of the Penne and Lexos formations. At the base, green marls and bioclastic limestones of the Barrê Pecten (Late Pliensbachian) and the black shales facies of Schistes cartons (*Tenuicostum* Zone) contain only a few recognised species, such as *Ogmoconcha hagenowi*, *Cytherella praecadomensis* and *Kinkelinella sermoisensis*. The middle member, Marnes et calcaires Hildoceras of the Early Toarcian age yielded an ostracod fauna certainly richer, more diverse of large cytheroids *(Ektyphocythere*, *Kinkelinella*, *Praeschuleridea*, *Trachycythere*, *Monoceratina)* and in minor proportion, of *Cytherella toarcensis*, *Cytherella praecadomensis*, *Bairdiacypris dorisae* and *Cytheropteron byfieldensis* (Cubaynes and Ruget, 1985; Cubaynes, 1986, Bodergat *et al.*, 1991; Andreu *et al.*, 1988, 1995) (Figs. 2, 3).

In northern and southwestern Germany and Switzerland, black shales facies are called Posidonschiefer and occur in the middle of a marine cyclotherm, deposited during the Sinemurian-Middle Aalenian interval (Fischer, 1961 a,b; Riegraf *et al.*, 1984; Fischer *et al.*, 1986; Röhl *et al.*, 2001; Schmid-Röhl *et al.*, 2002). Upper Pliensbachian Schwarzjuratone Upper Delta Formation comprises mainly marls with intercalated micritic or mairly limestones, overlaying by marls and limestones in southwestern Germany and sandstones in eastern Germany (Fischer, 1961a; Riegraf *et al.*, 1984; Fischer *et al.*, 1986; Harloff, 1993; Röhl *et al.*, 2001; Schmid-Röhl *et al.*, 2002). Toarcian highly bioturbated light grey marls are substituted by the deposition of the black shale (Unterer, Mittlerer, Oberer and Wilderer Schiefer layers) during the *Tenuicostatum* Zone (Röhl *et al.*, 2001; Schmid-Röhl *et al.*, 2002). Late Pliensbachian and the Toarcian ostracod assemblages (Triebel and Bartenstein, 1938; Fischer, 1961b, Gramann, 1962, 1963; Herrig, 1969a, b, 1979, 1980, 1981a, b, c, 1982a, b, 1985; Malz, 1971, 1975; Knitter, 1983, 1984; Knitter and Ohmert, 1983, 1986; Riegraf, 1984, 1985; Richter, 1987; Tröster, 1987 and Harloff, 1993) are diverse and abundant. Bairdioids remained as one of the main components together with healdiids and small cytheroids *(Monoceratina, Eucytherura* and *Nanacythere)*. During the Early Toarcian, healdioids disappear and are replaced by larger cytheroids *(Kinkelinella sermoisensis, Ektyphocythere bucki and Pleurifera harpa)* (Figs. 2, 3).

The spread of the Toarcian black shale facies is easy to see when analysing the evolution of the ostracod faunas described from the Paris Basin (Viaud, 1963; Bodergat, *et al*., 1985; Depeche, 1985; Donze, 1985; Cubaynes, 1986; Bodergat and Donze, 1988). Pliensbachian deposition is very varied and generally consist of limestones, except in the central and southern parts of the Paris Basin, where continues the argillaceous sediments (Enay, 1980). The ostracod assemblages are characterized by a very important representation of cytherellids, metacopids *(Ogmoconcha, Ogmoconchella, Hermiella* and *Pseudohealdia*), cytheroids *(Ektyphocythere, Kinkelinella* and *Gramannella)* and bairdioids (Apostolescu, 1959, 1961; Bizon, 1960, 1961; Apostolescu, Magne and Malmoustier, 1961; Bizon and Oertli, 1961; Champeau, 1961; Cousin and Apostolescu, 1961; Magne *et al.*, 1961; Oertli, 1961, 1963, 1971, 1985; Oertli and Grosdidier, 1961; Donze, 1967; Magne, Malmoustier, 1967; Magne and Obert, 1967; Riegraf, 1984; Bodergat *et al.*, 1985; Depêche, 1985 and Bodergat and Donze, 1988). At the beginning of the Toarcian, the regressive phase is reflected in the occurrence of events of non-deposition and erosion in the Paris Basin. The Toarcian sedimentation is characterized by the initial deposition of argillaceous sediments that is overtaken by the lower Toarcian black shales facies ("Schistes carton"). Toarcian ostracod assemblages show this irruption with the presence of less diverse assemblages dominated by cytheroids, after the disappearance of the healdiids (Figs. 2, 3). Only in the Vendeé area (Maupin, 1978), ostracod, assemblages have been recorded throughout the Pliensbachian-Toarcian boundary, with cytheroids as the most important component and with many new species such as *Ektyphocythere neumannae, Ektyphocythere quadrata* and *Pleurifera harpa*. At the rest of the early Toarcian, ostracod assemblages are dominated by cytheroids *(Ektyphocythere, Kinkelinella, Pleurifera* and *Praeschuleridea)*, small cytherurids (*Cytheropteron, Infracytheropteron, Rutlandella and Eucytherura*) and in minor proportion, cytherellids (*Cytherella toarcensis, Cytherella praecadomensis*) and bythoceratids (Bodergat *et al.*, 1985 and Cubaynes and Ruget, 1985; Bodergat and Donze, 1988) (Figs. 2, 3).

There are relatively few publications dealing with the Early Jurassic ostracod from the British Isles. In many cases, that feature has been a consequence of the occurrence of facies generally unsuitable for microfossils preservation (such as ironstones, bioclastic and oolitic limestones) or hiatus in the stratigraphical record (Lord, 1971, 1972, 1974, 1978). A broad belt of Upper Pliensbachian mudstones, shales and silty shales (Belemnite Marls, Green and Ammonite Beds formations) extends from northeastern England to the Bristol Channel and Dorset. This clay-shale deposition was followed by increasing arenaceous sedimentation of the sandstones, silty mudstones and shales of the Upper Pliensbachian Three Tiers, Eype Clay and Down Cliff Sands formations (Lord, 1974 and Lord and Brown, 1987). The ostracod assemblages are dominated by healdioids and a few species of cytheroids *(Gramannella apostolescui* and *Wicherella semiora)* and *Liasina lanceolata*. Similar composition show the assemblages described from the yellow weathering sands of the Thorncombe Sands formation (*Margaritatus* Zone) and the oolitic limestones of the Marlstone Rock Bed *(Spinatum* Zone) of the Costwolds and Ilminster areas (Lord, 1974; Howarth, 1978; Lord and Brown, 1987; Boomer, 1992). These assemblages were dominated by healdiids *(Ogmoconcha, Ogmoconchella* and *Hermiella*). Upper Pliensbachian and the Lower Toarcian ostracod assemblages of the Midlands area (Lord, 1974 and the ostracod assemblages are dominated) by metacopids *(Ogmoconcha, Pseudohealdia*) and by some large cytheroids *(Kinkelinella, Ektyphocythere)*. Early Toarcian ostracod assemblages have been only recorded in the basal Junction Bed, a sequence of silty mudstones and argillaceous siltstones comprises a few species of metacopids *(Ogmoconcha, Ogmoconchella* and *Hermiella)* and a larger number of large cytheroids *(Ektyphocythere, Kinkelinella, Gramannella* and *Trachycythere)*. Lower Toarcian sediments from seven boreholes at Empingham and Upwood have yielded a rich and diverse ostracod fauna (Lord, 1974; Bate and Coleman, 1975 and Boomer, 1992) characterised by large cytheroids (*Kinkelinella sermoisensis, Ektyphocythere bucki* and *Praeschuleridea pseudokinkelinella*) (Figs. 2, 3).

Deeper carbonate platform sediments

Hemipelagic deposits, represented by alternations of marlstones and limestones alternations of Vale des Fontes, Lemede and S. Giao formations (Duarte and Soares, 2002) dominate the Pliensbachian and the Toarcian series in the Lusitanian basin. Pliensbachian ostracod assemblages from the Zambujal and Peniche sections (Exton, 1979; Boomer *et al.*, 1998; Pinto *et al.*, 2005) are characterized by healdioids *(Ogmoconchella gruendeli*, *Ogmoconchella adenticulata*, *Ogmoconchella aequalis* and *Ogmoconchella bispinosa)*, cladocopids *(Polycope cerasia, Polycope cincinnata)* and small cytheroids *(Gammacythere ubiquita)*. At the lowermost of the Toarcian, there is a change in the ostracod assemblages composition and only *Polycope* and some metacopids *(Ogmoconcha convexa, Ogmoconcha inflata, Hermiella intercedens)* remains well represented. The rest of the Early Toarcian assemblages begin to be dominated by *Bairdiacypris rectangularis*, few large cytheroids *(Kinkelinella tenuicostata)* and many species of *Paracypris*. *Cytherella toarcensis* and some species of *Bairdiacypris* and *Kinkelinella* dominate the remaining of the Toarcian ostracod assemblages (Exton, 1979; Lord, 1982; Exton and Gradstein, 1984; Boomer *et al.*, 1998 and Duarte and Soares, 2002) (Figs. 2, 3).

Pelagic sediments

Although our knowledge of Southern Europe ostracod assemblages has been improved during the last twenty years (Barbieri, 1964; Maupin, 1977; Baloge, 1981; Boutakiout *et al.*, 1982; Lord, 1982, 1988; Arias, 1993), they are less well known because of the isolated nature of many studies and the occurrence of unfavourable lithologies for preservation and extraction of microfossils. Southern Europe assemblages are characterised by the occurrence of ornamented and smooth bairdioids, ornamented healdioids and a few cytheroids (Bate, 1977; Lord, 1988). Few studies have been carried out in this region (Barbieri, 1964 and Arias 1993). Barbieri (1964) described thirty-four species from the Villagonia and Giardini formations of the Ragusa-1 borehole, Sicily. Limestones, marly limestones and green-grey marls of these formations yielded poor assemblages dominated by bairdiaceans *(Bairdia, Bairdiacypris, Cardobairdia* and *Isobythocypris)* and some species of *Ogmoconcha* and *Hermiella*. Early Toarcian ostracod assemblages comprise mainly species of *Polycope*, *Cytherella*, *Macrocypris, Paracypris, Liasina* and some small cytheroids (Figs. 2, 3).

Arias (1993) studied ostracod assemblages from the Umbria-Marche area, Northern Apennines. Early Pliensbachian carbonate platform sedimentation was replaced by an open marine sedimentation after the break up of the platform after extension and subsequent drowning (Colacicchi *et al.*, 1970, 1988). Calcareous sediments (micritic limestones with chert nodules) of the Pliensbachian Corniola Formation yielded ostracod assemblages dominated by healdioids *(Ogmoconcha*, *Ogmoconchella* and *Hermiella)*, bairdiaceans *(Bairdia* and *Bairdiacypris)* and some species of *Polycope*, *Cytherella* and *Paracypris* (Lord, 1978; Arias, 1993). Clayey and marly sediments with some interbedded calcarenites and black shales discontinuously represented belonging to the pelagic Toarcian Marne del Monte Serrone Formation (Cresta *et al.*, 1989). Their ostracod assemblages are dominated by bairdioids *(Bairdia, Cardobairdia, Pontocyprella, Isobythocypris,* and *Bairdiacypris)*, ornamented healdiids and cytheroids (Lord 1978, Arias, 1993). Baloge (1981) described the ostracod faunas from the Rosso-Ammonitico facies of Western Algeria. Late Pliensbachian assemblages comprise several species of *Ogmoconcha (Ogmoconcha* aff. *O contractula*, *O.* aff *O. amalthei), Hermiella (Hermiella vallata), Bairdia* and *Bairdiacypris* and low diversity Toarcian assemblages which are dominated by *Bairdiacypris*, *Cytherella*, *Polycope* and *Kinkelinella*. Metacopids are not present (Figs. 2, 3).

OSTRACOD PROVINCIALISM IN THE EARLY JURASSIC

When an attempt is made to plot, in a generalized way, the correlation of the main facies associations and ostracod faunas, for particular stages, it become apparent that there is a general passage from a time of local differentiation of ostracod assemblages (during the Late Pliensbachian) to a time of the great boreal “cytheroid” spread (from the Early Toarcian).

During Pliensbachian, European ostracod assemblages reached their highest diversity in tropical and subtropical warm water platform (shale and carbonates) and their lowest in shallow marine clastics and in deep-sea basins (hemipelagic carbonates). During the Late Pliensbachian, it can be observed a clear facies control on ostracod assemblages. Early Jurassic ostracod assemblages from deep shelf settings are characterized by having a very low diversity, comprising mainly smooth and above all, ornamented healdiids, and in minor proportion, small cytherurids, smooth bairdioids and a few species of large ornamented cytheraceans (Fig. 4). Toarcian ostracod assemblages from shallow carbonate platform sediment are dominated by smooth healdiids and in minor proportion, cypridoids and cytheroids during the Pliensbachian and by large and ornamented cytheroids (Fig. 5).

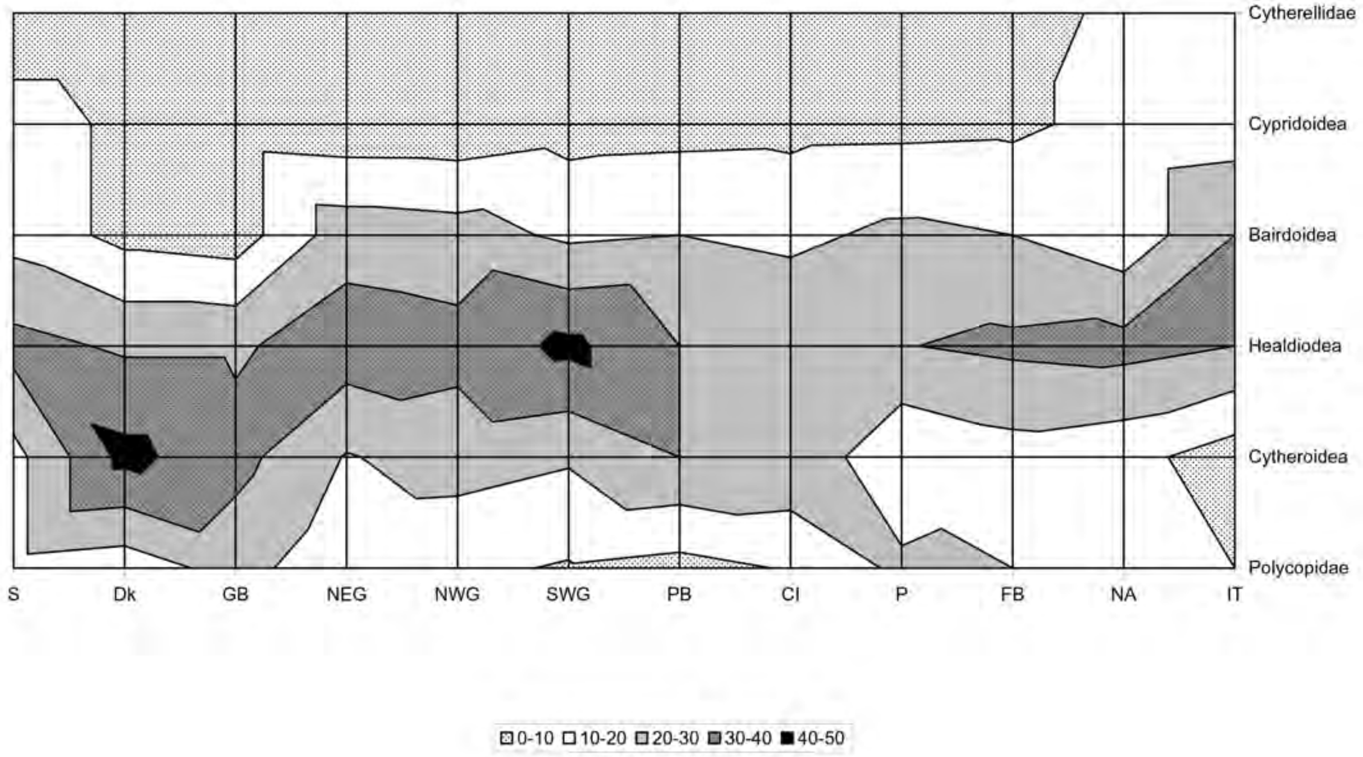

FIGURE 4–Distribution of major Late Pliensbachian ostracod faunal groups at all studied location areas. The percentage of most abundant families and superfamilies shows a latitudinal gradient.

Shallow marine carbonates and shales sediments yielded a very rich ostracod fauna dominated by smooth and ornamented bairdioids, smooth, and ornamented healdioids, with a minor representation of cytherellids and cytheroids.. In the Toarcian, smooth healdioids are replaced by larger cytheroids. Pliensbachian deeper carbonate platform ostracod assemblages are characterized by the occurrence of cladocopids, bairdioids, healdioids and small cytheroids. Pliensbachian ostracod faunas from pelagic sediments settings are very low diversity assemblages, which are composed of bairdioids, some ornamented healdioids and small cytherurids. Both Toarcian faunas show a dominance of large cytheroids and bairdioids.

It is clear therefore that there is a good general correlation between the Pliensbachian ostracod fauna and facies, where the Boreal and Tethys provinces can be distinguished by ostracod assemblages (Fig. 4). The Boreal Province would occupy the northern and central parts of the European area, its southern boundary is gradational and oscillated somewhat but generally corresponds closely with the line between the Alpine belts to the southwestern European basins. The rest belongs to the Tethyan Province. Tethyan ostracod fauna would be limited within the 35º latitude lines (normal salinity and warm temperature conditions) and would be characterized by the presence of smooth-shelled forms of bairdioids *(Bairdia, Cardobairdia, Pontocyprella, Isobythocypris*, and *Bairdiacypris)*, ornamented healdioids, and some small cytheroids (minor proportion), dominated the assemblages. An intermediate ostracod fauna (mainly located between 40º N and 40º S with high salinities and warm temperature conditions) characterized by the presence of few metacopids *(Ogmoconcha*, *Ogmoconchella)*, many large and thicker cytheroids *(Ektyphocythere, Kinkelinella, Gramannella, Praeschuleridea* and *Trachycythere)* and small cytherurids *(Cytheropteron, Infracytheropteron, Rutlandella* and *Eucytherura);* and cytherelloids *(Cytherella, Cytherelloidea)*, as a minor component. Boreal ostracod forms, which dominate the northern part of the European epicontinental sea were characterised by having a low diversity, and by comprising mainly smooth healdiids *(Ogmoconcha, Ogmoconchella* and *Pseudohealdia)*, small cytherurids *(Eucytherura, Cytheropteron, Gammacythere and*

Lophodentina) and bairdioids *(Bairdia, Bairdiacypris* and *Cardobairdia).*

In opposition, during the Early Toarcian, the faunal composition remains rather homogenous (Fig. 5). The Early Toarcian marked the time of the end of the notable Pliensbachian northward migration of tethyan faunas (ornamented and smooth healdiids and bairdioids) into the European epicontinental area, the disappearance of healdioids and the spread of large cytheroids, boreal elements that extended to all European basins (Arias and Whatley, 2004).

Provinciality in the Early Jurassic invertebrate faunas is well known since the pioneer study of Neumayr (1883). Many groups of fossil invertebrates, principally ammonites, brachiopods and bivalves have showed the existence of two major provinces during the Early Jurassic: the cold-water *Boreal* and the warm-water *Tethyan* provinces (Neumayr, 1882, 1883; Uhlig, 1911; Arkell, 1956; Hallam, 1975, 1983; Enay, 1980; Westermann, 1981; Taylor *et al.*, 1984; Cariou *et al.*, 1985; Damborenea, 1993; Liu *et al*. 1998). Nevertheless, palaeobiogeographical studies based on microfossils did not reflect Boreal/Tethyan provincialism. Foraminifera analysis distinguishes between platform (composed mainly of *Nodosaridae*) and tethyan assemblages (which included planktonic and arenaceous foraminifera). However, the two analysed assemblages seem to share the same spatial location (Gordon, 1970; Copestake and Johnson, 1984).

Before the present paper, Bate (1977) recognized five Early Jurassic Ostracoda provinces: the *European*, the *Tethyan*, the *North African*, the *American* and the *East African* provinces. Only, the two first ostracod provinces would be clearly recognisable during the Early Jurassic. The European Province extended from Newfoundland to the Ukraine; and from Greenland to the northern margin of the Tethys area. Although its total inclusion is open to doubt, the Iberian Peninsula usually has been included in European province. The Tethyan Province would extend from the eastern coast of Canada to North-West Africa. This latter province nevertheless has a less complete record during the Early Jurassic and its existence is more difficult to establish.

The results discussed in the present paper imply the impossibility to distinguish between Boreal and

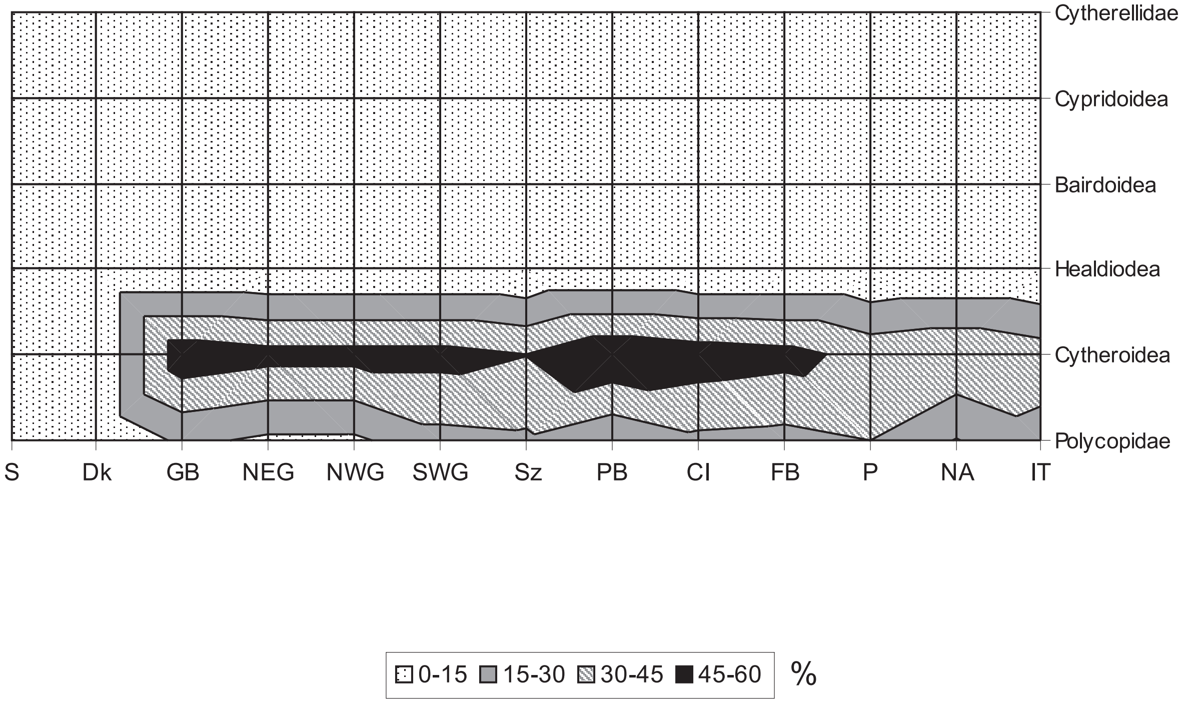

FIGURE 5–Distribution of major Early Toarcian ostracod faunal groups at all studied location areas. The percentage of most abundant families and superfamilies illustrates a clear faunal homogeneity across the European epicontinental sea and West Tethys Ocean.

Tethyan provinces (because no ostracod taxa are only restricted to Boreal or Tethyan provinces) from the Early Toarcian.

THE INFLUENCE OF WATER TEMPERATURES, SEA LEVEL CHANGES, PALAEOGEOGRAPHY AND OCEAN CURRENTS IN THE OSTRACOD DISTRIBUTION

For many authors, the hypothesis of temperature control remains as the major controlling factor on local distribution of invertebrate faunas (Donovan, 1967; Gordon, 1970, 1975; Howarth, 1978; Riccardi, 1991). Jurassic climate has been characterized by being warmer and more equable than the present climate (Frakes, 1979, Parrish, 1982; Parrish and Curtis, 1982; Hallam, 1984b, 1994; Frakes *et al.*, 1992; Scotese, 2001, 2002). The distribution of evaporite, bauxite, coal and peat deposits over the European epicontinental sea shows a clear increase of temperate and humid conditions northward, subtropical conditions in the middle, and arid conditions along the North Africa coast and the Iberian Peninsula area (Frakes, 1979; Barron and Washington, 1982; Parrish, 1982; Parrish and Curtis, 1982; Fleming, 1983; Crowley *et al.*, 1989, Kutzbach and Gallimore, 1989; Chandler *et al.*, 1992; Frakes *et al.*, 1992; Chandler, 1994 and Barron *et al.*, 1994). The distribution of several paleontological proxies seems to confirm the existence of a north-south temperature gradient, with cool temperatures in the northern part of the European epicontinental sea and warm (subtropical and tropical) temperatures in the Tethys area (Vakhrameev, 1964; Hallam, 1972, 1975; Frakes, 1979; Ziegler *et al.*, 2000; Arias and Whatley, 2004).

In relation to the ostracods fauna, it is possible to observe that large and thick-shelled ostracod, such as *Kinkelinella*, *Ektyphocythere*, *Cytheropteron are* initially dominant in high latitudes, meanwhile, smooth, and thinner shelled forms, such as *Ogmoconcha*, *Ledahia*, *Bairdia* or *Isobythocypris* are dominant in low latitudes. This sharing out would correspond to temperate and warm water ostracod faunas respective. The spatial distribution of the sedimentary and fossil records seems to suggest that the temperature of the water and water masses might have been the primary factor in controlling the initial distribution pattern of the ostracod fauna.

Another factor with a profound role in the development of a temperature gradient is the action of ocean currents. Several authors have attempted to reconstruct the paleocurrent patterns of the Jurassic oceans (Ager, 1975; Frakes, 1979, Enay, 1980; Frakes *et al.*, 1992; Arias and Whatley, 2004). Most of them have postulated the existence of Arctic/Boreal and Tethyan currents flowing in opposite directions. Both currents could meet in the northern part of the epicontinental sea contributing to the Boreal / Tethys provincialism (Ager, 1975; Fürsich and Sykes, 1977). Atmospheric General Circulation Models (Parrish, 1982; Parrish and Curtis, 1982; Crowley *et al.*, 1989, Kutzbach and Gallimore, 1989; Kutzbach *et al.*, 1990 and Chandler *et al.*, 1992) show easterlies winds crossing the European epicontinental sea. Easterlies would set in motion the water masses along the Western Tethys Ocean in a westerly direction (Fig. 6). When these westward currents reach the western portion of the European epicontinental sea they would turn and by the Coriolis Effect deflect as a western boundary current to higher latitudes (pre-Gulf stream). This current would carry warm waters towards the northeastern parts of the European epicontinental sea. The spread of warm waters eastward, by the Coriolis Effect and the continental landmasses configuration would turn toward the Equator, creating an eastern boundary current. Western and eastern boundary currents would combine to create a subtropical clockwise gyre. Distribution pattern of the Early Jurassic ostracod fauna indicate that the south-westward had priority over the north-eastward direction (Arias and Whatley, 2004). The repeated inflow of Tethyan warm

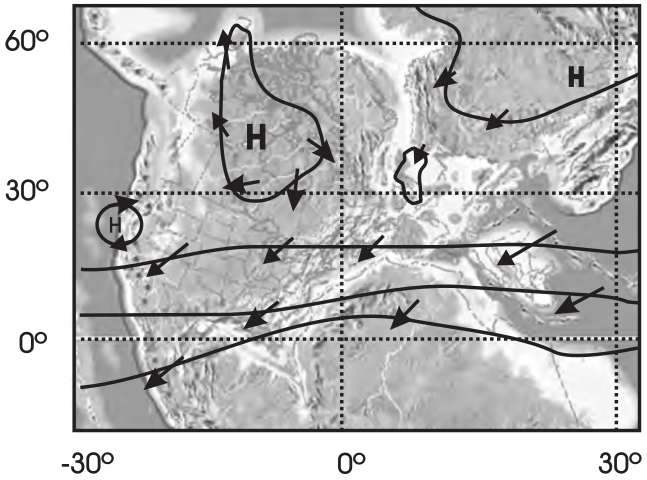

FIGURE 6–Early Jurassic Atmospheric circulation, Northern Winter Hemisphere (modified from Parrish and Curtis, 1982; Scotese and Summerhayes, 1996). Palaeogeographic map modified from Scotese (2002, http://www.scotese.com).

water into the European epicontinental sea would have configured a warm-temperate epicontinental sea. By the earliest Toarcian, the entrance of Tethyan fauna and thus, the communication between central and southwestern European and Tethyan basin ended. The ending of the warm water inflow would be consistent with the opening of the Hispanic Corridor by the latest Pliensbachian and would be responsible for the disappearance of this "pre Gulf-stream" current (and therefore, of the northward transport of warm water) and for the beginning of a temperate episode in the European epicontinental sea during the Early Toarcian (Fig. 7).

Another important environmental factor to explain ostracod fauna movements are the sea-level changes. Low stands reduce open seaways and the spread of the ostracod faunas; meanwhile high sea levels facilitate faunal exchange, what lead to an increase in overall diversity and extensive distribution of the ostracod assemblages (Jablonski, 1980; Meister and Stampfly, 2000). The Early Jurassic was a time of major sea-level transgressions and regressions in both regional and global scales. During the Late Pliensbachian, there was a general transgressive trend, only interrupted by a couple of regressive episodes during the latest Pliensbachian and mid Toarcian, respectively (Vail *et al.*, 1977; Hallam, 1978, 1984a, 1988; Haq *et al.*, 1987, 1988; Hardendol *et al.*, 1998; Meister and Stampfli, 2000 and Gómez and Goy, 2002). Early Jurassic transgressions would be linked to northward movements of the Tethyan faunas and regressive episodes to southward progresses and he spread of Central European faunas. Consequently, sea level changes would be another dominant control on faunal diversity, extinction, endemism and faunal migration.

Explanations for the distribution pattern of marine ostracod include, in addition to changes in temperature and eustatic sea level, the presence or absence of physical barriers (such as, landmasses or deep-water masses). The presence of seaways can determinate local changes in the movement pattern of the ostracod faunas, i.e. the opening of the Poitou Strait during the Pliensbachian facilitated a new route of communication between the Paris Basin and the rest of Central European basins. Most remarkable would be the case of the Hispanic Corridor (Smith, 1983) which could have allowed, probably since the Pliensbachian (Damborenea, 2000), the movement of European and Tethyan forms to the Panthalassa ocean. Another consequence related to the opening of these seaways would be the alteration of the ocean circulation pattern.

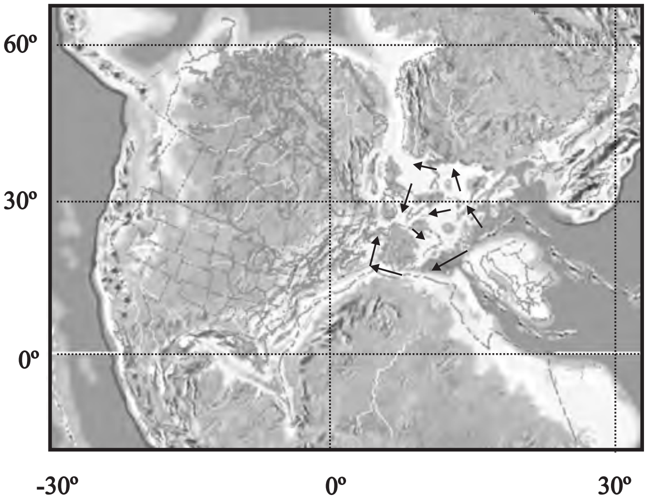

FIGURE 7–Early Jurassic Ocean circulation, Northern Winter Hemisphere (modified from Arias sand Whatley, 2004). Palaeogeographic map modified from Scotese (2002, http://www.scotese.com).

Barriers, i.e. shallow carbonate platforms or emerged land belts along the southern part of the European epicontinental sea (Briaconnais and Corso-Sardinia blocks or the Balears and Pre-Betic platforms) might have acted as a barrier insulating the European epicontinental sea from the Tethys Ocean (Almeras and Elmi, 1987). Only a few areas may have temporally worked as entry passages, i.e. the Lower Austroalpine, South Calcareous Alps, the Balcony Mounts, the Burgundy area or the Sub-Briaconnais area (Dommergues and Meister, 1991; Meister and Stampfly, 2000). This opening would be responsible for the north-south direction of the boundary during Pliensbachian. Another via of communication could be the Iberian-Moorish Strait. This route would favour the connection between North African and British basins (Dommergues and Mouterde, 1980; Dommergues, 1982; Enay and Mangold, 1982; Cariou *et al.*, 1985) and could explain the northward movement of Tethyan ostracod fauna in the Late Pliensbachian. The close of these seaways at the beginning of Toarcian because of a regressive episode could be the initial responsible of the end of the northward tethyan influx into the European epicontinental sea.

CONCLUSIONS

The Early Jurassic was a time of an important marine faunal innovation that gave rise to taxonomic prominence of several groups of microfossils that played a major role in the Early Jurassic oceans. Ostracoda, regarded as one the most important fossil group for the palaeoceanography of the Early Jurassic, is characterised by being more cosmopolitan in distribution than other important fossil groups, such as ammonoids or bivalves that show a clear Early Jurassic provincialism.

The distribution of Pliensbachian ostracods shows latitudinal, probably climatically controlled, compositional changes in both European epicontinental sea and Tethyan regions. In the European epicontinental sea, the north-south faunal differentiation is based on the northward expansion of ornamented healdioids and bairdioids. Therefore, two provinces can be recognized from the Late Pliensbachian: Boreal and Tethys. This ostracod provincialism was probably consequence of a latitudinal temperature gradient between the European epicontinental sea and the Western Tethys.

Based on the results discussed in the present paper, it is not possible to distinguish between the Boreal and the Tethyan provinces during the Early Toarcian, when the majority ostracod taxa show a cosmopolitan distribution. No single explanation can account for this lack of provincialism. A certain water temperature control, sea-level changes, adjustment in physical barriers and changes in the ocean currents pattern have been considered in this paper.

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