ORDOVICIAN TRILOBITE DISTRIBUTION AND GEOGRAPHY

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ABSTRACT. Dissimilarities between lists of trilobite families and genera from particular areas of the world have been assessed using Simpson's index. Analysis of these indices by a non-metric multidimensional scaling technique has revealed groupings which are interpreted as faunal provinces. Four such provinces are present in the Lower Ordovician; in the Caradoc certain of these provinces have merged, and in the Late Ordovician a single fauna appears to be world wide.

Assuming that a faunal province originally extended over parts of a single continental mass, an assemblage of parts of present continents is proposed to give a palaeogeographical map which differs in certain respects from that of Smith, Briden, and Drewry. Relative movements between these continental blocks is thought to have removed barriers to migration and resulted in the merging of faunal provinces.

THIS subject has been discussed by Whittington (1966, in Hallam 1972) and by Whittington and Hughes (1972). In this latter work we have assessed dissimilarities at the family and genus level between faunas from particular areas of the world, using Simpson's index. These indices were analysed by a non-metric multidimensional scaling technique, which revealed groupings that we interpreted as faunal provinces. Four such provinces were present in the Lower Ordovician (Arenig and Llanvirn series) and their distribution is shown on text-figs. 1 and 2. Three of these provinces, the Bathyurid, Asaphid, and Selenopeltis provinces, have à distribution like that shown by Whittington (1966, in Hallam 1972). The relations between faunas of South America, Australia, and south-east Asia are difficult to assess, because of the lack of recent descriptive work on Australian and Asian faunas. The opportunity to visit Australia and study collections enabled Whittington (in Hallam 1972) to re-examine the problem. Certain genera and families are common to all three regions, others are endemic to a particular area, and some in common with the Selenopeltis fauna of southern Europe and North Africa. The Asian–Australian–South American faunas were termed hungaiid–calymenid, and a particular symbol used on the map to plot the distribution of this fauna; this symbol was mixed with that for the Selenopeltis fauna to denote the presence of genera in common. Subsequently the method of analysis referred to above was utilized by Hughes, and at both family and generic level showed a relationship between South American and Australian faunas (Whittington and Hughes 1972, figs. 1, 2). Faunas from China, however, are related to Selenopeltis faunas only at the family level, and isolated at the generic level. We thus decided to use the term Asaphopsis fauna for those of South America and Australia, and to regard the faunas from China as of uncertain affinity. Neither of the treatments is to be regarded as satisfactory, they are different ways of showing uncertainty in assessing inadequate data.

Plotting early Palaeozoic faunal provinces on present-day geography is not enlightening, and a diagrammatic Ordovician palaeogeographical map was made by Whittington (in Hallam 1972, fig. 3). Subsequently we developed this approach to

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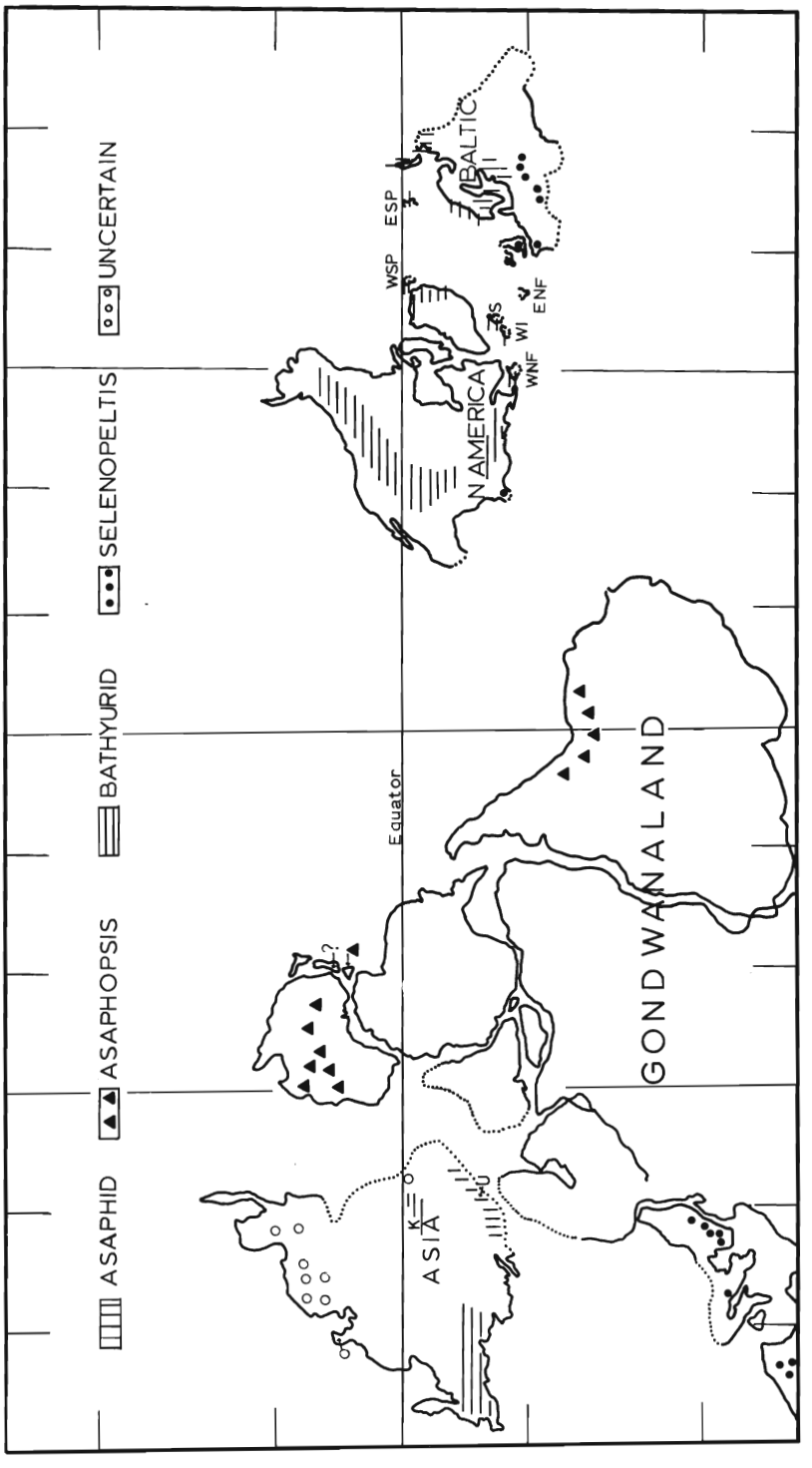
propose a series of four palaeogeographical maps for the Ordovician period (Whittington and Hughes 1972, figs. 3, 6, 9, 12). These maps used palaeomagnetic data, combined with the assumption that a faunal province originally extended over parts of a single continental mass. The corollary to this assumption is that physical characters of seas between the masses such as width, depth, pattern of circulation, and temperature differences, inhibited migrations of the dominantly benthonic trilobites between provinces. For example, this assumption enabled us to propose a subdivision of the present Eurasian continent, largely on grounds of faunal distributions, into five major blocks and several fragments, and to suggest how these may have been disposed. The map by Smith, Briden, and Drewry (text-fig. 1) is based on more recent palaeomagnetic data, including some from Cambrian as well as Ordovician rocks, and may be compared with ours for the Arenig–Llanvirn series (Whittington and Hughes 1972, fig. 3). The differences are chiefly in the subdivision and placement of parts of present Eurasia, large areas of which are shaded in Smith, Briden, and Drewry's map to denote uncertainty of geographical position. Text-fig. 2 gives our proposed modifications, the lines of subdivision of present continental masses shown dotted to indicate that their course is a gross approximation. The faunal provinces are plotted on both maps, and certain provinces are disjunct on text-fig. 1. Our modifications are suggested in such a way that each province is disposed over parts of a single continental mass, and separated from another either by a sea or a latitudinal distance suggesting possible temperature difference. The modifications may be discussed on a geographical basis as follows:

Europe. The Asaphid faunas are not known to extend south of the island of Bornholm and north-eastern Poland. In south-east Ireland, England and Wales, Brittany, Czechoslovakia, southern France, Spain, Portugal, and Turkey are the Selenopeltis faunas. We therefore suggest a division of Europe approximately along the southern margin of the East European platform (Størmer 1967). Since the faunas of Novaya Zemlya and the Urals are Asaphid in type, we extend this North European or Baltic block eastward to include part or all of the area that is now the Ural mountains. The southern European block is discussed below under Gondwanaland.

North America. Bathyurid faunas are widespread over this region, which includes western Newfoundland, north-western Ireland, Scotland, and Spitsbergen. We have no reasons from Ordovician faunas to suggest a division of Spitsbergen, but because of the occurrence of bathyurid faunas place it adjacent to northern Greenland. Bathyurid faunas are present in the Trondheim area, western Norway, so we also place a portion of this region (of unknown extent), adjacent to Greenland. Cambrian faunas of eastern Newfoundland, Nova Scotia, New Brunswick, and eastern Massachusetts are like those of Wales, so that these present portions of North America were placed by Wilson (1966) on the opposite side of his proto-Atlantic ocean. We accept this view, though there is no evidence from trilobites in Ordovician rocks to support it.

Gondwanaland. We used the same reconstruction, but Briden, Smith, and Drewry place the pole closer to the present west African coast than we did (Whittington and Hughes 1972, fig. 3b, following McElhinny and Luck 1970), so that Australia lies



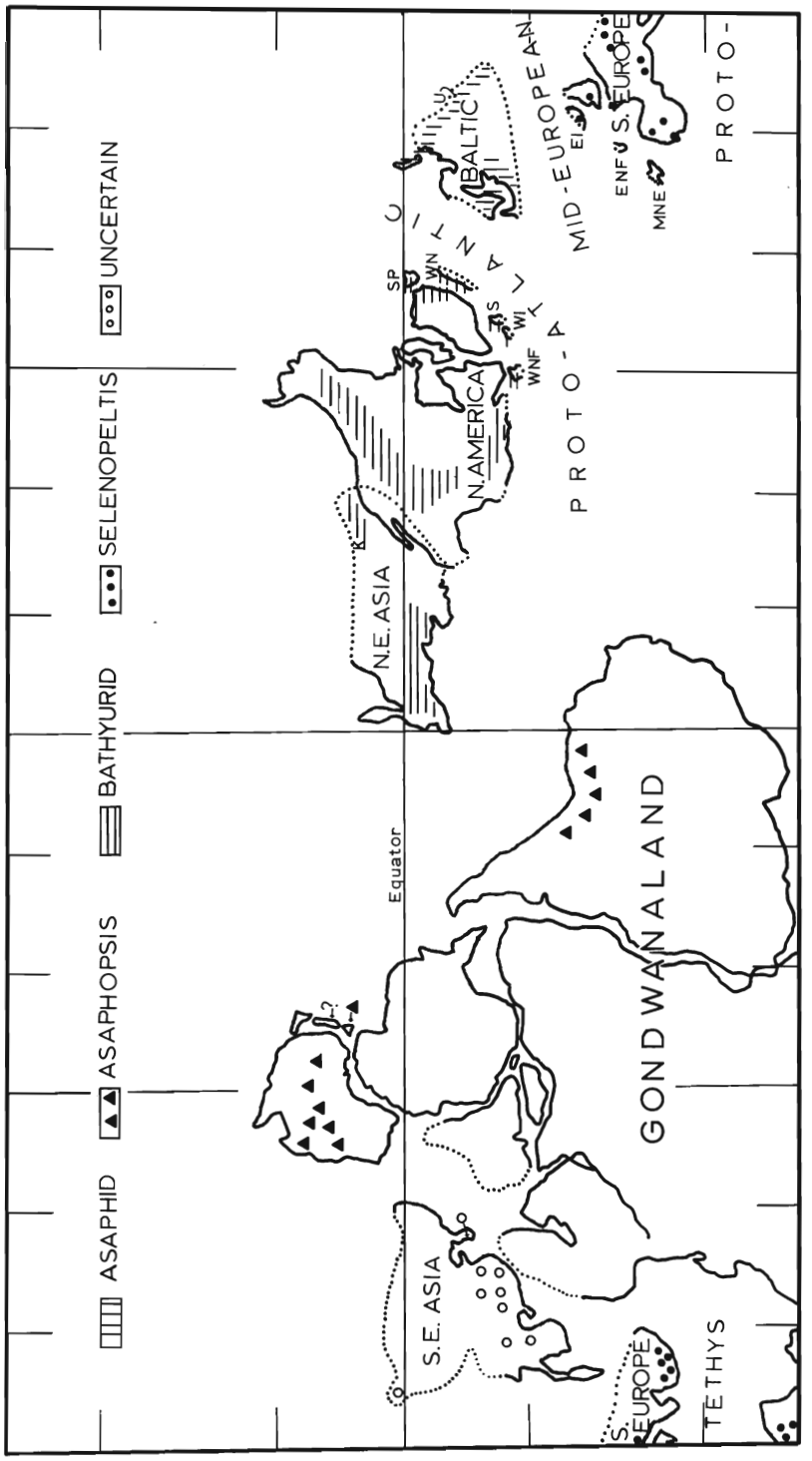
TEXT-FIG. 1. Trilobite faunal provinces in Arenig and Llanvirn series plotted on palaeogeographical map for Cambrian and Lower Ordovician of Smith, Briden, and Drewry. Selenopeltis fauna shown in area of what is now Tunisia, to draw attention to presence of this fauna in North Africa, where it is known only in Morocco. Abbreviations for geographical areas: ENF = eastern Newfoundland; ESP = eastern Spitsbergen; K = Kazakhstan; S = Scotland; WI = western Ireland; WNF = western Newfoundland; WSP = western Spitsbergen; U = Ural mountains. Lines of subdivision of present continental masses shown dotted to indicate that their course is a gross approximation.

entirely on the opposite side of the equator. Gondwanaland incorporates one portion of present Eurasia, peninsular India south of the Himalayas. Because one distinctive trilobite, known only from the Selenopeltis fauna, occurs in a boring in north-western Florida, we detach the area of this state from North America (along a slightly different line from Smith, Briden, and Drewry) and place it in Gondwanaland in the position suggested by Bullard *et al.* (1965, fig. 8). This is not shown on the present map, since it lies between present west Africa and northern South America in high latitudes off the southern margin of the map. The amended southern European mass has faunas in common with those of Morocco, and we suggest a slightly different longitudinal position with proto-Tethys between the north African coast and southern Europe. The mid-European sea separated the southern European mass from the Baltic mass.

Asia. The greatest differences between our maps is in treatment of this area. We have already indicated that we consider the Ural mountain region is best regarded as part of a Baltic mass. On the remainder of Asia are distributed Bathyurid faunas in Siberia, north-eastern U.S.S.R., and Kazakhstan. In central and south-west China, Burma, and Vietnam are faunas of a quite different type, so that we suggested a division of this block along a tentative line south of Kazakhstan, extending along the Tien Shan–Mongolia–Okhotsh mountain belts. Because of the Bathyurid faunas we placed the north-eastern Asia block adjacent to North America, a large longitudinal shift but little change in latitude. The position of the south-east Asia block is problematical, but, relative to Smith, Briden, and Drewry, we suggest a 180° rotation and a position adjacent to Gondwanaland. As we have indicated, Ordovician faunas from China appear to have little affinity with those of Australia, but there were relationships in the Late Cambrian (Jones *et al.* 1971, p. 17). In the Early Ordovician some genera are in common between southern Asia and southern Europe. Our tentative solution is thus not at variance with available information on faunas, but the situation may have been more complicated; for example, the south-east Asian area may not have been a single mass during the Early Ordovician.

The modified map (text-fig. 2) is like our previous map (Whittington and Hughes 1972, figs. 3a, b), but, for example, southern Europe is placed at a slightly higher latitude, and the western part of South America at a lower latitude (because of a different pole position in Gondwanaland). These changes are favourable toward our earlier suggestion that the Selenopeltis fauna inhabited cooler waters on the margins of Gondwanaland, the Asaphopsis fauna the warmer waters.

The post-Llanvirn history of distribution appears to be one of decreasing provinciality in trilobites. By the Caradoc only the Selenopeltis province is distinct from a Remopleuridid province covering all other areas; the English, Irish, Australian, and Baltic faunas are all within this latter province. By Ashgill time the Selenopeltis fauna is difficult to recognize as a separate entity, and Late Ashgill faunas are world wide. It is considered (Whittington and Hughes 1972) that relative movements between continental blocks removed barriers to migration and led to progressive merging of provinces. The movements suggested include a partial closure of the proto-Atlantic, bringing both the Baltic and southern European masses closer to the North America–north-east Asia block. It was also suggested that Gondwanaland



TEXT-FIG. 2. Trilobite faunal provinces in Arenig and Llanvirn series plotted on amended palaeogeographic map (cf. Whittington and Hughes 1972, fig. 3). Selenopeltis fauna shown in area of what is now Tunisia, to draw attention to presence of this fauna in North Africa, where it is known only from Morocco. Florida State, U.S.A., not shown since it is fitted in between west Africa and northern South America in high latitudes off the southern margin of the map. Abbreviations for geographical areas as text-fig. 1, with the addition of EI = eastern Ireland; MNE = parts of the Maritime provinces of Canada and New England states of U.S.A.; SP = Spitsbergen. Lines of subdivision of present continental masses shown dotted to indicate that their course is a gross approximation.

moved relative to the pole, so that the pole may have been situated just inland of the coast at the present Bight of Biafra. McElhinny and Luck (1970) place the pole in South Africa in the Lower Devonian, and this suggested Ordovician drift is part of this change. Such drift of Gondwanaland, combined with some rotation of the North America–north-east Asia mass may have combined to narrow the gap between these masses, so facilitating migration of the Remopleuridid and younger faunas.

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