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Conodont biostratigraphy of the Crawford Group, Southern Uplands

Evolution of the Southern Uplands Terrane
Research Report RR/01/05

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Conodont biostratigraphy of the Crawford Group, Southern Uplands

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Foreword

This report is the published product of Research Contract GA/98E/46 carried out by Dr H A Armstrong, Department of Geological Sciences, University of Durham, as part of BGS Project ESB7190002602, Evolution of the Southern Uplands Terrane. Dr J D Floyd and Mr H F Barron (BGS) provided biostratigraphical material and geological background information.

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Summary

This report describes the biostratigraphical conclusions resulting from a study of a large quantity of conodont material from the Crawford–Leadhills area of the south of Scotland. The fossils were collected in 1997–99 by Dr J D Floyd and Mr H F Barron during the resurvey of 1:50 000 Sheet 15E (Leadhills) as part of the Southern Uplands Regional Geological Survey.

The Crawford Group stratigraphically underlies the Moffat Shale Group of the Southern Uplands and consists mainly of a sequence of bedded chert, mudstones and volcanic rocks. It typically crops out along the southern margins of fault-bounded tracts in the terrane, particularly in the Northern Belt, and represents the oldest rocks in the Southern Uplands. The group includes the Kirkton and Raven Gill formations of *Pygodus anserinus* Biozone (late Llanvirn/early Caradoc) and *Oepikodus evae* Biozone (mid Arenig) age respectively. This stratigraphy was based on historical conodont collections from only a few localities, and no instances were known of strata within the Crawford Group containing faunas of intervening age.

Detailed examination of significant new conodont collections (reported herein) from many new localities confirms this age gap in the conodont biostratigraphy of the Crawford Group. This, together with the disrupted nature and restricted outcrop of the Raven Gill Formation, suggests that this unit may represent an older olistostrome or mélange unit incorporated within the Kirkton Formation, and that the Southern Uplands basin *sensu stricto* is therefore no older than latest Llanvirn in age.

1 Introduction

The Crawford Group, the oldest sedimentary/volcanic succession in the Southern Uplands, contains rocks previously dated as lower Whitlandian, Arenig age (*sensu* Fortey et al., 1995) and latest Llandeilian to Aurelucian, Llanvirn to Caradoc age (*sensu* Fortey et al., 1995). These dates are based on historic conodont collections. It is unclear from field relationships or from the historic collections whether a continuous Lower Ordovician succession is present in the Northern Belt or if there is a significant stratigraphical gap spanning the late Arenig and most of the Llanvirn.

New field collecting, during regional remapping, has provided significant additional material from previously known and new fossiliferous localities. The aim of this project was to close or confirm the postulated stratigraphical gap. This report lists the conodonts identified in the new collections.

All samples have been identified and age assignments made (see below). Representative photomicrographs have been produced and assembled into plates and a systematic description of the faunas has been completed.

2 Stratigraphical context

The Leadhills Imbricate Zone (LIZ) extends as a 1.8km wide zone to the immediate north of the Leadhills Fault (Figure 1) and is one of the most complex parts of the Northern Belt (Leggett et al., 1979; Armstrong et al., 1999). The zone is characterised by faulted repetitions of volcanic rocks, cherts, black shales and greywackes (Hepworth, 1981; Hepworth et al., 1982; Leggett, 1978; Leggett and Casey, 1982). At least some of the greywackes belong in the Kirkcolm Formation (= Abington Formation of Hepworth, 1981; Hepworth et al., 1982) and the black shales are assumed to represent parts of the Moffat Shale Group either below or interbedded within the basal part of the Kirkcolm Formation.

Floyd (1996) formalised the dominantly volcanic and chert units of the LIZ as the Raven Gill and Kirkton formations within what he termed the Crawford Group (Figure 2).

2.1 RAVEN GILL FORMATION

The Raven Gill Formation was defined, following Hepworth (1981) and Hepworth et al. (1982), to include the basaltic pillow lavas, basic sheets, brown mudstones and radiolarian cherts at the eponymous type locality. Floyd (1996, p.157) noted the Arenig age of the conodonts from the type section in Raven Gill (*Oepikodus evae* Biozone—see also Lamont and Lindström, 1957; Löfgren, 1978, p.38; Armstrong et al., 1990) but expressed uncertainty as to the unequivocal recognition of the Raven Gill Formation elsewhere along the LIZ. He suggested that the formation name should only be applied to rocks of proven Arenig age and followed Hepworth (1981) in assigning the extensive development of grey and red cherts, red and green siliceous mudstones and lavas in the LIZ to the Kirkton Formation. Floyd (1996) considered the red and green siliceous mudstones described by Hepworth (1981) in Glencaple Burn near the confluence of Raven Gill [NS 9252 1988] as a reference section in the type area. Other reference sections were designated further to the north-east.

The rocks of the Raven Gill Formation are also exposed on the hills to the north of Crawford (see Leggett and Casey, 1982, fig. 5) where faulted repetitions of grey radiolarian chert, greywacke and igneous rocks, brown shales and red cherty mudstones occur. The latter unit, now named the Castle Hill Member, has yielded conodonts of the *O. evae* Biozone (Armstrong and Dean, 1996).

2.2 KIRKTON FORMATION

Hepworth (1981) proposed the term 'Kirkton Beds' for the red, green and grey cherts and mudstones presumed to lie between the Raven Gill Formation and the Moffat Shale Group, along the Leadhills Line. Floyd (1996) formalised the unit as the Kirkton Formation and proposed the temporary exposure in the 1976 gas pipeline trench at Abington as the type section. In the type section approximately 70m of chert and siliceous mudstones overlie a lava succession up to 50m thick (Floyd, 1996, p.157). Further reference sections in Glencaple Burn [NS 9252 1988; Hepworth, 1991] within the type area, Norman Gill Burn [NS 971 241] and Hawkwood Burn [NS 976 254] were also defined. Lamont and Lindström (1957) described *Pygodus anserinus* from red chert sequences from Norman Gill, Fardingmullach [NS 819 042] and 11km north-west of Thornhill (see also Bergström and Orchard, 1985; Armstrong et al., 1990 and Armstrong et al., 1996 for more recent identifications).

Armstrong et al. (1990) described a conodont faunule from Hawkwood Burn, ascribing a Llanvirn age, though largely on negative evidence. Smith (1907) first reported conodonts from the red siliceous mudstones in Morroch Bay [NX 017 524]. Lamont and Lindström (1957) described what would now be called *Spinodus spinatus* and *Periodon aculeatus* from red shales at the base of the succession. Lindström (1957) described coniform conodonts and *Periodon* (probably *P. grandis*—see Löfgren, 1978, p.75) from black shales (Moffat Shale Group) with *Climacograptus wilsoni* Biozone graptolites (see also Bergström and Orchard, 1985).

Graptolites of the *gracilis* Biozone are commonly found in the Glenkiln Shale Formation overlying or tectonically interleaved with the Kirkton Formation (Finney and Bergström, 1976; Floyd, 1996). The close association of *anserinus* Biozone conodonts and *gracilis* Biozone graptolites indicates a Llandeilian – Aurelucian age for the Kirkton Formation in the type area. In the more southerly exposures in Morroch Bay, the red shales and mudstones could also be of this age.

The historic but limited biostratigraphical evidence thus suggests that there is a major stratigraphical gap between the mid-Arenig Raven Gill Formation and latest Llanvirn to early Caradoc Kirkton Formation. Remapping of Sheet 15E (Leadhills) over the last few years has brought to light a number of additional conodont-bearing chert localities that could potentially fill this stratigraphical gap. The aim of this study was to document the new collections and hence extend the limited historic dataset. The existence of a stratigraphical gap spanning much of the Lower Ordovician has significant implications for dating the onset of deposition in the Northern Belt basin and the accretionary prism model for the Southern Uplands. The latter was in part based upon the assumption of stratigraphical continuity from the Arenig to the Silurian (Leggett et al., 1979).

3 Conodonts

3.1 SPECIMENS AND CURATION

Specimens were collected in the field and are scattered on the bedding planes of siliceous mudstone, commonly as fragments and occasionally as demineralised moulds. Where original phosphate is preserved, conodonts are black (CAI 5) in colour, indicating heating to a temperature in excess of 300°C (Epstein et al., 1977). White specimens could have a CAI of 6 or higher or, more likely, have been altered to clay minerals. The nature of the preservation is such that it is difficult to give specific names to many of the specimens which commonly can only be compared to named species or tentatively identified. Comprehensive faunal lists are presented in Appendix 1 to this report and biostratigraphically useful taxa are illustrated on Plates 1 and 2. Sample numbers are for rock fragments bearing the conodont specimens, each locality thus has multiple sample numbers. Samples are housed in the collections of the British Geological Survey.

3.2 CONODONT BIOSTRATIGRAPHY

In the Lower Ordovician, two conodont realms have traditionally been distinguished, the temperate to cool water North Atlantic Realm and the tropical, warm water Mid-continent Realm. The former has been reported from Balto-Scandinavia, the Appalachians, South China, South America, the Nevada–Utah region of North America, and north-western Australia (Bergström, 1990; Bagnoli and Stouge, 1991). The latter is reported from cratonic North America, north China, eastern Australia and the Siberian Platform (see Ji and Barnes, 1994 for a review). Provincial faunas can be delimited within the two major realms (Bergström and Sweet, 1966; Lindström, 1971; Bergström, 1971, 1973; Sweet and Bergström, 1972; Barnes and Poplawski, 1973). The Mid-continent Realm includes the Mid-continent and Chinese provinces while the North Atlantic Realm includes the Baltic and Precordillera provinces. Bagnoli and Stouge (1991) differentiated a 'Pandemic Group' of conodonts including *Oepikodus* and *Periodon* which preferred cool temperate oceanic water, representing a group of cosmopolitan species. The Pandemic Group appeared on the East European Platform during the *evae* transgression in the early Arenig (Stouge and Bagnoli, 1988; Nielsen, 1992). Raven Gill Formation conodonts are referred to the Pandemic Group of the Baltic Province, North Atlantic Realm and compared for biostratigraphical purposes with Lower Ordovician sections from Balto-Scandinavia. Interestingly however, the fauna also contains *Bergstroemognathus extensus* found in the Lower Ordovician of New York State but absent from Balto-Scandinavia (see below).

Rasmussen and Stouge (1995) recognised four conodont biofacies in the Arenig–Llanvirn Stein Formation of the Oslo region. The biofacies from shallow to deep water included the *Scalellodus-Microozarkodina* Biofacies, the *Baltoniodus* Biofacies, the *Drepanoistodus* Biofacies and the *Protopanderodus-Periodon* Biofacies. Bagnoli and Stouge (1996) proposed an additional *Oepikodus* Biofacies, defined by the dominance of *O. evae* and subordinate *Periodon*, *Drepanoistodus*, *Protopanderodus* and *Oistodus*. They considered this to be a deep-water assemblage typical of slope deposits of palaeocontinental margins (Stouge and Bagnoli, 1990). The fauna from the Raven Gill Formation is referred to the *Oepikodus* Biofacies.

3.2.1 *Oepikodus evae* Biozone fauna

The Raven Gill fauna is dominated by two species *Oepikodus evae* (eponymous zonal species) and *Periodon flabellum* (Lindström) with subsidiary numbers of *Drepanoistodus forceps* (Lindström), *Drepanodus arcuatus* Pander, *Oistodus lanceolatus* Pander, *Paroistodus originalis* (Sergeeva), *Paroistodus proteus* (Lindström), *Protopanderodus rectus* (Lindström) and *Paracordylodus gracilis* Lindström. All these species are typical of the *O. evae* Biozone in Balto-Scandinavia (Lindström, 1960, 1971; van Wamel, 1974; Stouge and Bagnoli, 1988; Bagnoli and Stouge, 1991, 1997; Löfgren, 1978, 1993, 1994). In addition, the fauna contains a single specimen tentatively assigned to *Bergstroemognathus extensus* Serpagli, a species absent from Balto-Scandinavia but found in coeval strata in New York State (Landing, 1976).

In Balto-Scandinavia, *O. evae* and *P. flabellum* first appear in the *evae* Biozone (Löfgren, 1978). Löfgren (1993, 1994) modified the original biozonation proposed by Lindström (1971) for the region, informally subdividing the *evae* Biozone into four sub-biozones. The lower *evae* Subbiozone contains *O. evae* and reworked and in situ *Prioniodus elegans* (Löfgren, 1978, 1993, 1994; Bergström, 1988; Bagnoli and Stouge, 1997). The lower–middle and middle–upper sub-biozones have the highest diversity of taxa including the zonal index species. In the upper *evae* Sub-biozone *O. evae* disappears, leaving an impoverished coniform fauna including species of *Protopanderodus*, *Drepanoistodus* and *Paroistodus* and lacking the zonal index species (Kohut, 1972; Löfgren, 1978, 1993, 1994; Bagnoli and Stouge, 1997). Samples from Glengonnar Water, Glencaple Burn 'A' and the cliff on the east bank of Glencaple Burn contain such a fauna and could conceivably be from the upper *evae* Biozone.

The *evae* Biozone has also been reported from cratonic margin sections in North America. Landing (1976) described a fauna from the Deep Kill Shale in New York State including the zonal index species, *P. flabellum*, *Scolopodus rex*, *Paroistodus* ? *gladiatus*, *Paracordylodus gracils* (absent from Jämtland but present in Öland, see van Wamel, 1974, and Scotland), *Paroistodus originalis* and questionably *P. parallelus*, *Protopanderodus gradatus* (which appears to replace *P. rectus* in the North American faunas) and *Bergstroemognathus extensus* (absent from Jämtland but present in Scotland). *Drepanoistodus forceps* and *Oistodus lanceolatus* are present in Balto-Scandinavia and Scotland but absent from the Deep Kill Shale. Bergström and Cooper (1973) described an *evae* Biozone fauna from the Upper Member of the Marathon Limestone, Texas which contained *O. evae*, *Paroistodus parallelus* and *Pro-*

topanderodus rectus. The *evae* Biozone in Argentina (Serpagli, 1974) appears similar to that from the Deep Kill Shale and Löfgren (1978) compared this directly to the *evae* Biozone in Balto-Scandinavia.

The conodont fauna from the Raven Gill Formation therefore contains taxa typical of the *O. evae* Biozone, possibly the lower–middle and middle–upper sub-biozones, indicative of a lower Whitlandian, Arenig age (*sensu* Fortey et al., 1995). Samples from Glengonnar Water, Glencaple Burn 'A' and the cliff on the east bank of Glencaple Burn contain an impoverished coniform fauna and lack the zonal index species. These samples could conceivably be from the upper part of the *evae* Biozone, but still within the lower Whitlandian.

In Britain, the *O.evae* Biozone is recorded only from the Northern Belt of the Southern Uplands. However, conodonts of an equivalent age were reported from the Dounans Limestone, Highland Border Complex (Ethington and Austin, 1991). This fauna includes representatives of both the North Atlantic Realm and the American Midcontinent Realm that may have occupied a shelf-margin setting. The presence of *Periodon flabellum* indicates that the Dounans Limestone can be correlated with the interval of the Ross/Hintze Zone J through lower Zone L. This interval is approximately equivalent to the *O. evae* and *B. triangularis* conodont biozones of the North Atlantic Realm (Ethington and Austin, 1991).

Palaeogeographical reconstructions (Torsvik et al., 1996) indicate that the Highland Border and terranes to the south lay adjacent to Laurentia within tropical latitudes. Though there has been significant tectonic reorganisation within the paratectonic Caledonides during the Grampian and subsequent later Caledonian deformation, it is reasonable to hypothesise that the conodont fauna of the Raven Gill Formation was a deep-water slope assemblage, in part equivalent to that of the Dounans Limestone.

3.2.2 *Pygodus anserinus* Biozone fauna

Samples of *P. anserinus* Biozone age contain taxa previously recorded from southern Scotland (Armstrong, 1997). We record *P. anserinus* in samples from Hunt Law Cleugh previously thought to be Arenig in age.

4 Implications

Conodont biostratigraphy of the newly collected cherts confirms the presence of a major stratigraphical gap within the Crawford Group, the oldest part of the Northern Belt succession. Cherts and volcanics occur at two distinct stratigraphical levels, in the Raven Gill Formation of Whitlandian, low to mid Arenig age, and the Llandeilian-Aurelucian, late Llanvirn to early Caradoc, Kirkton Formation. The stratigraphical gap is thus equivalent to the upper Arenig to upper Llanvirn (Llandeilian).

Armstrong et al. (1999) showed that early to mid Arenig cherts from the Raven Gill Formation have a continental margin rare earth element (REE) geochemistry and that they had not been overthrust by the Ballantrae Ophiolite Complex, which crops out to the immediate north of the Southern Upland Fault. The presence of an *O. evae* Biofacies conodont assemblage is consistent with the depositional setting predicted by the chert REE geochemistry. The new mapping indicates that the Raven Gill Formation is restricted to the type area around Crawford and that outcrops are largely fault controlled. These observations suggest the possibility that the Raven Gill Formation is a sedimentary mélange or breccia unit, containing large clasts of a mid Arenig continental margin basement, redeposited within the lower Crawford Group.

The Kirkton Formation (and coeval Currarie Formation in the Ballantrae area) crops out in many tracts of the Northern Belt and clearly forms part of an extensive basal unit to the succeeding and prograding greywacke succession. Continental margin REE patterns for cherts within the Kirkton Formation (Owen et al., 1999) and the presence of conodonts of the *Protopanderodus-Periodon* Biofacies (Armstrong, 1990; this report), indicate that the Northern Belt basin succession was initiated in the latest Llanvirn It represents a deep-water continental margin setting (Owen et al., 1999) and lay adjacent to the Pomeroy area of Ireland (Scrutton et al., 1999).

The succeeding greywackes of the Kirkcolm, Portpatrick and Shinnel formations form a continuous southerly prograding succession extending into the Ashgill (Floyd 1996).

5 Conclusions

Samples from the Raven Gill Formation, within the Leadhills Imbricate Zone, contain conodonts of the *Oepikodus evae* Biozone and are of lower Whitlandian, Arenig age (*sensu* Fortey et al., 1995). The Raven Gill Formation is restricted to fault bounded exposures in the general vicinity of the type section and probably represents a mélange of late Llanvirn to early Caradoc age. The Kirkton Formation, though lithologically similar, can be distinguished on the presence of Llandeilian–Aurelucian, Caradoc, and *P. anserinus* Biozone conodonts and forms the basal unit of the Northern Belt succession.

Despite extensive recollecting, no conodonts from the intervening upper Arenig and Llanvirn have been found. It is therefore concluded that a significant stratigraphical gap exists within the Crawford Group. The chert-bearing succession of the Northern Belt of the Southern Uplands thus represents the juxtaposed sedimentary records of two entirely separate basins; the older apparently pre-dates the Grampian assembly of the Laurentian margin whereas the younger Northern Belt basin *sensu stricto* entirely post-dates this event.

Appendix 1 Conodonts from the Southern Uplands of Scotland

Specimen No: 16E6586–16E6590
Locality: (JF 165) West bank of burn, c. 180m N of Ruddenleys Farm [NT 2042 5122]
Lithology: Red mudstones
Unit: Marchburn Formation
Zone: *Pygodus anserinus* Biozone

16E6586: *Spinodus spinatus* S element
16E6587: *Periodon aculeatus* S element
16E6588: *Pygodus anserinus* Pa element
Genus et species indet. Ramiform
Genus et species indet. Coniform
15E6589: *Pygodus anserinus* Pa element
15E6590: *?Strachanognathus parvus*

Specimen No: 16E6591–16E6598
Locality: (JF 30) 'White Heather Burn', 400m SW of Ruddenleys Farm [NT 2025 5067]
Lithology: Red mudstones
Unit: Marchburn Formation
Zone: *Pygodus anserinus* Biozone

15E6591: *Pygodus anserinus* Pa element
Genus et species indet. Coniform
15E6592: *Pygodus anserinus* Pa element
15E6593: *Pygodus anserinus* Pa element
15E6594: *Pygodus anserinus* Pa element
Periodon aculeatus P element
15E6595: Genus et species indet. Ramiform
15E6596: *Pygodus anserinus* Pa element
Pygodus anserinus Pc element
Genus et species indet. Ramiform
15E6597: *Pygodus anserinus* Pa element
15E6598: Genus et species indet. Coniform

Specimen No: 16E6599–16E6602
Locality: (JF 166) Radio mast track, Castle Hill, Crawford [NS 9373 2175]
Lithology: Red mudstones
Unit: Castle Hill Member, Raven Gill Formation, Crawford Group
Zone: *Oepikodus evae* Biozone

15E6599: *Lingula* sp.
15E6600: *Oepikodus evae* S element
Oepikodus evae M element
?Periodon sp. P element
Genus et species indet. Ramiform
15E6601: *Oepikodus evae* S element
Genus et species indet. Conifom
16E6002: nothing

Specimen No: 16E758–16E788
Locality: (JF 176) North branch of Raven Gill, Glencaple Burn, Abington [NS 9204 1989]
Lithology: Brown cherty mudstone
Unit: Raven Gill Formation, Crawford Group
Zone: *Oepikodus evae* Biozone

16E758: *Oepikodus evae* P element
Oepikodus evae S element
Genus et species indet Coniform
Brachiopods
16E759: *Oepikodus evae* P element
Oepikodus evae M element
Oepikodus evae S element
Genus et species indet. Coniform
Lingula sp.
Paterula sp.
16E760: *Oepikodus evae* S element
Brachiopods
16E761: *Oepikodus evae* S element
Lingula sp.
16E762: *Oepikodus evae* S element
Brachiopods
16E763: *Oepikodus evae* S element
Brachiopods
16E764: *Oepikodus evae* S element
Genus et species indet. Coniform
Brachiopods

16E765: *Oepikodus evae* P element
Oepikodus evae M element
Oepikodus evea S element
16E766: *Oepikodus evae* S element
Periodon cf. *P. flabellum* P element
16E767: Brachiopods
16E768: Genus et species indet. Coniform
16E769: *Oepikodus evae* P element
Oepikodus evae S element
Brachiopods
16E770: Genus et species indet. ramiform
16E771: Genus et species indet. ?coniform
16E772: *Oepikodus evae* S element
Paterula sp.
16E773: *Drepanodus arcuatus*
Oepikodus evae P element
Oepikodus evae S element
Brachiopods
16E774: *Drepanodus arcuatus*
16E775: *Oepikodus evae* P element
Oepikodus evae M element
Oepikodus evae S element
Genus et species indet. Coniform
16E776: *Oepikodus evae* M element
Oepikodus evae S element
Drepanoistodus cf. *D. forceps*
16E777: *Oepikodus evae* S element
?*Bergstroemognathus extensus* M element
Genus et species indet. Ramiform
16E778: *Protopanderodus rectus*
16E779: *Protopanderodus rectus*
Oepikodus evae S element
Brachiopods
16E780: *Oepikodus evae* S element
16E781: *Oepikodus evae* S element
Protopanderodus rectus
Periodon sp. P S element
Brachiopods
16E782: *Oepikodus evae* S element
Brachiopds
16E783: *Oepikodus evae* S element
Brachiopods
16E784: *Oepikodus evae* S element
Paraoistodus parallelus
16E785: *Oepikodus evae* S element
Oepikodus evae P element
Brachiopods
16E786: *Protopanderodus* sp.
16E787: *Periodon* cf. *P. flabellum* S element
16E788: *Oepikodus evae* S element
Brachiopods

Specimen No: 16E789–16E808
Locality: (JF 166) Radio mast track, Castle Hill, Crawford [NS 9373 2175]
Lithology: Red cherty mudstones
Unit: Castle Hill Member, Raven Gill Formation, Crawford Group
Zone: *Oepikodus evae* Biozone

16E789: *Oepikodus evae* M element
16E790: Genus et species indet. Ramiform
16E791: Genus et species indet. Ramiform
16E792: *?Oepikodus evae* P element
16E793: *Oepikodus evae* S element
16E794: *Paracordylodus gracilis* S element
16E795: *Drepanoistodus* cf. *D. forceps*
16E796: *Periodon flabellum* S element
16E797: *Periodon flabellum* S element
16E798: *Paracordylodus gracilis* S element
16E799: *Periodon flabellum* M element
16E800: *Periodon flabellum* S element
16E801: Genus et species indet. Ramiform
16E802: *Oepikodus evae* S element
16E803: ? *Paracordylodus gracilis* S element
16E804: *Oepikodus evae* P element
16E805: *Paraoistodus* cf. *P. originalis*
16E806: Genus et species indet. Ramiform
16E807: *Periodon flabellum* M element
16E808: *Oepikodus evae* P element

Specimen:16E809–16E834
Locality: (JF 177) Hunt Law Cleugh, Snar Head, Leadhills [NS 8708 1568]
Lithology: Thin cream weathering shales between bedded chert bands
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

16E809: *Drepanodus* cf. *D. arcuatus*
16E810: *Periodon aculeatus* S element
16E811: *Periodon aculeatus* Pelement
Periodon aculeatus S element
16E812: *Protopanderodus varicostatus*
Pygodus anserinus Pa element
16E813: *Periodon aculeatus* Pb element
16E814: *Drepanoistodus* cf. *D. suberectus*
16E815: Genus et species indet. Ramiform
16E816: Genus et species indet. Coniform
16E817: ?*Periodon aculeatus* Pa element
16E818: *Protopanderodus* cf.*P. varicostatus*
Periodon aculeatus Pa element
Genus et species indet. Ramiform

16E819: *Periodon aculeatus* Pa element
Periodon aculeatus S element
Genus et species indet. Ramiform
16E820: ? *Periodon aculeatus* Pb element
16E821: Genus et species indet. Coniform
Genus et species indet. Ramiform
16E822: Genus et species indet. Ramiform
16E823: *Pygodus anserinus* Pa element
Genus et species indet. Coniform
16E829: *Periodon aculeatus* Pa element
Periodon aculeatus S element
16E830: Genus et species indet. Ramiform
16E831: Genus et species indet. Ramiform
Genus et species indet. Ramiform
16E824: *Pygodus anserinus* Pa element
16E825: Genus et species indet. Coniform
16E826: *Periodon aculeatus* S element
Genus et species indet. Ramiform
16E827: *Periodon aculeatus* Pa element
Periodon aculeatus S element
16E828: ? *Periodon aculeatus* P element
16E832: Genus et species indet. Ramiform
16E833: *Periodon aculeatus* S element
Genus et species indet. Ramiform
16E834: *Periodon aculeatus* S element

Specimen: 16E835–16E875
Locality: (JF 175) Glencaple Burn, Glengonnar Water, Abington [NS 9255 1989]
Lithology: Red cherty mudstones, unbedded.
Unit: Castle Hill Member, Raven Gill Formation, Crawford Group
Zone: *Oepikodus evae* Biozone

16E835: Genus et species indet. Coniform
16E836: *Periodon flabellum* S element
16E837: *Periodon flabellum* S element
16E838: nothing
16E839: Genus et species indet. Ramiform
16E840: Genus et species indet. Ramiform
16E841: Genus et species indet. Ramiform
16E842: *Periodon* sp. S element
Genus et species indet. Ramiform
16E843: Brachiopods
16E844: Brachiopods
16E845: Genus et species indet. Ramiform
16E846: ? *Belodella* sp.
Genus et species indet. Ramiform
16E847: ? *Belodella* sp.
Genus et species indet. Ramiform
Genus et species indet. M element
16E848: *?Bergstroemognathus* extensus S element
Genus et species indet. Coniform
16E849: *Periodon flabellum* P element
Genus et species indet. Coniform
16E850: *Periodon flabellum* S element
Brachiopods
16E851: *Periodon flabellum* P element
Periodon flabellum S element
Periodon aculeatus Pb element
16E852: Genus et species indet.
16E853: Genus et species indet. Coniform
16E854: ? *Paracordylodus gracilis* S element
Periodon sp. S element
Brachiopods
16E855: Brachiopods
Genus et species indet. Coniform
Genus et species indet. Ramiform
16E856: Genus et species indet.
16E857: *Periodon flabellum* S element
16E858: *Periodon flabellum* P element
Genus et species indet. Ramiform
16E859: Genus et species indet. Coniform
Genus et species indet. Ramiform
16E860: *Periodon flabellum* P element
Periodon flabellum S element
16E861: Genus et species indet. Ramiform
16E862: *Bergstroemognathus extensus* S element
? *Periodon flabellum* P element
16E863: *Periodon aculeatus* S element
Genus et species indet. Coniform
Genus et species indet. Ramiform
16E864: *Periodon flabellum* S element
Genus et species indet. Coniform
Genus et species indet. Ramiform
16E865: Genus et species indet
16E866: *Periodon flabellum* S element
16E867: Genus et species indet. Ramiform
16E868: Genus et species indet. Ramiform
16E869: *Periodon aculeatus* ?Pa element
Genus et species indet. Ramiform
16E870: Genus et species indet.
16E871: Genus et species indet
16E872: *Periodon flabellum* P element
Brachiopods
16E873: Genus et species indet. Coniform
Genus et species indet. Ramiform
16E874: Brachiopods
16E875: nothing
16E951: *Periodon flabellum* P element
Periodon flabellum ?M element
Microzarkodina ?flabellum M element
Paroistodus sp.
16E952: *Oistodus lanceolatus*
Periodon sp.

Specimen No: 16E2863–16E2880
Locality: (JF 175B) Glencaple Burn 'B' [NS 9255 1989]
Lithology: Red-grey/buff transition at north end of red mudstones
Unit: Castle Hill Member (top?), Raven Gill Formation, Crawford Group
Zone: *Oepikodus evae* Biozone

16E2863: *Periodon flabellum* P element
Periodon flabellum S element
Genus et species indet. Ramiform
16E2864: *Periodon flabellum* P element
Periodon flabellum S element
Genus et species indet. Ramiform
16E2865: ? *Periodon flabellum* P element
Genus et species indet. Coniform
16E2866: Genus et species indet. Coniform
Genus et species indet. Ramiform
16E2867: Genus et species indet. Ramiform
16E2868: *Periodon flabellum* P element
Periodon flabellum S element
Genus et species indet. Coniform
16E2869: *Periodon flabellum* P element
Periodon flabellum S element
16E2870: *Periodon flabellum* P element
Periodon flabellum S element
16E2871: *Periodon flabellum* S element
Genus et species indet. Ramiform
16E2872: *Periodon flabellum* S element
Genus et species indet. Coniform
Genus et species indet. Ramiform
16E2873: *Periodon flabellum* S element
16E2874: *Periodon flabellum* P element
Periodon flabellum S element
Genus et species indet. Coniform
16E2875: *Periodon flabellum* P element
Periodon flabellum M element
Periodon flabellum S element
16E2876: *Periodon flabellum* M element
16E2877: *Periodon flabellum* P element
Periodon flabellum S element
Genus et species indet. Ramiform
16E2878: *Periodon flabellum* P element
Periodon flabellum S element
16E2879: *Periodon flabellum* S element
Genus et species indet. Ramiform
16E2880: *Periodon flabellum* P element
Periodon flabellum S element

Specimen No: 16E2881–16E2884
Locality: (JF 166) Radio mast track, Castle Hill, Crawford [NS 9373 2175]
Lithology: Buff mudstone (16E2881), Red mudstones(16E2882–4)
Unit:Castle Hill Member, Raven Gill Formation, Crawford Group
Zone: *Opikodus evae* Biozone?

16E2881: Brachiopods
16E2882: Brachiopods
Genus et species indet coniform
16E2883: ?*Oepikodus evae* P element
Genus et species indet. Ramiform
16E2884: ?*Oepikodus evae* P element
Genus et species indet. Coniforn

Specimen No: 16E2885–16E2888
Locality: (JF 175A) Glencaple Burn 'A' [NS 9255 1989]
Lithology: Red mudstones
Unit: Castle Hill Member, Raven Gill Formation, Crawford Group
Zone: *Oepikodus evae* Biozone

16E2885: *Periodon flabellum* S element
Periodon sp. P element
16E2886: *Periodon flabellum* P element
Periodon flabellum S element
Genus et species indet. Coniform
16E2887: *Parapanderodus* sp.
16E2888: *Periodon flabellum* P element
Genus et species indet.

Specimen No: 17E91–17E99
Locality: (JF 175B) Glencaple Burn, Abington. Cliff on E bank of stream [NS 9255 1989]
Lithology: Red mudstones
Unit: Castle Hill Member, Raven Gill Formation, Crawford Group
Zone: *Oepikodus evae* Biozone

17E91: *Paracordylodus gracilis* S element
Genus et species indet. Coniform
Genus et species indet. Ramiform
17E92: *Periodon flabellum* M element
Periodon flabellum S element
17E93: *Paroistodus originalis*
Paracordylodus gracilis M element
Genus et species indet. Coniform
Genus et species indet. Ramiform
Brachiopods
17E94: *Periodon flabellum* P element
Periodon flabellum S element
Protopanderodus ?varicostatus
Genus et species indet. S element
Genus et species indet. Coniform
17E95: *Periodon flabellum* P and S elements
17E96: *Periodon flabellum* M element
Periodon flabellum S element
Genus et species indet. Coniform
17E97: *Periodon flabellum* S element
Genus et species indet. S element
17E98: *Paracodylodus gracilis* S element
Periodon flabellum S element
17E99: *Periodon flabellum* P element

Specimen No: 17E100–17E110
Locality: (JF 176A) Raven Gill, Glencaple, Abington. NW side of gully [NS 9204 1989]
Lithology: Brown mudstones
Unit: Raven Gill Formation , Crawford Group
Zone: *Oepikodus evae* Biozone

17E100: *Oepikodus evae* Pb element
Oepikodus evae M element
Oepikodus evae S element
Periodon flabellum S element
17E101: *Oepikodus evae* P element
Oepikodus evae S element
Paracordylodus gracilis S element
Paracordylodus gracilis M element
17E102: *Oepikodus evae* P element
Oepikodus evae S.element
Genus et species indet. Coniform
Genus et species indet. ramiform
17E103: *Oepikodus evae* P element
Oepikodus evae M element
Oepikodus evae S element
17E104: *Oepikodus evae* S.element
Genus et species indet. Coniform
17E105: *Oepikodus evae* Sd element
17E106: *Oepikodus evae* P element
Oepikodus evae S element
Brachiopods
17E107: *Oepikodus evae* P element
Oepikodus evae S element
Paracordylodus gracilis S element
Paroistodus originalis
Brachiopods
17E108: *Oepikodus evae* P element
Oepikodus evae S element
Periodon flabellum P element
Periodon flabellum S element
17E109: *Oepikodus evae* S element
Periodon flabellum S element
Paroistodus originalis
17E110: *Oepikodus evae* M element
Oepikodus evae S element
Protopanderodus gradatus

Specimen No: 17E111–17E122
Locality: (JF 176B) Raven Gill, Glencaple, Abington. NE side of gully [NS 9204 1989]
Lithology: Brown mudstones
Unit: Raven Gill Formation , Crawford Group
Zone: *Oepikodus evae* Biozone

17E111: *Oepikodus evae* P element
Oepikodus evae M element
Oepikodus evae S element
Drepanoistodus forceps
Brachiopods
17E112: *Oepikodus evae* P element
Oepikodus evae S element
Paracordylodus gracilis S lement
Genus et species indet. Coniform
17E113: *Oepikodus evae* S element
Drepanoistodus forceps
Brachiopods
17E114: *Oepikodus evae* P element
Oepikodus evae S element

Drepanoistodus forceps
Brachiopods
Genus et species indet. Coniform

17E115: *Oepikodus evae* P element
Oepikodus evae S element
Paroistodus proteus

17E116: *Oepikodus evae* P element
Oepikodus evae Sd element
Brachiopods

17E117: *Oepikodus evae* P element
Oepikodus evae S element
Periodon flabellum P element
Periodon flabellum S element
Genus et species indet. Coniform
Genus et species indet. Ramiform

17E118: *Oepikodus evae* P element
Oepikodus evae S element
Periodon flabellum P element
Brachiopods

17E119: Brachiopods

17E120: *Oepikodus evae* P element
Brachiopods

17E121: *Oepikodus evae* S element
Brachiopods

17E122: *Oepikodus evae* S element
Brachiopods

Specimen No: 17E123–17E126
Locality: (JF 176C) Raven Gill, Glencaple, Abington. SE side of gully [NS 9204 1989]
Lithology: Brown mudstones
Unit: Raven Gill Formation, Crawford Group.
Zone: *Oepikodus evae* Biozone

17E123: *Paracordylodus gracilis* S element
Genus et species indet. Coniform

17E124: *Paracordylodus gracilis* S element
Genus et species indet. Ramiform

17E125: *Paracordylodus gracilis* S element
Paroistodus proteus

17E126: *Paracordylodus gracilis* S element

Specimen No: 17E127–17E136
Locality: (JF 177) 'Hunt Law Cleuch', Snar Water , Leadhills [NS 8708 1568]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group.
Zone: *Pygodus anserinus* Biozone

17E127: *Periodon aculeatus* Pb element
Periodon aculeatus M element
Periodon aculeatus S element

17E128: *Periodon aculeatus* S element

17E129: *Periodon aculeatus* Pb element
Periodon aculeatus S element

17E130: *Periodon aculeatus* Pb element

17E131: *Periodon aculeatus* M element
Periodon aculeatus S element

17E132: *Periodon aculeatus* S element

17E133: ?*Spinodus* sp. S element

17E134: *Protopanderodus* sp.
Periodon aculeatus P and M element

17E135: *Periodon aculeatus* M element
Periodon aculeatus S element
?Microzarkodina sp. S element

17E136: *Protopanderodus* sp.
Periodon aculeatus P and S elements

Specimen No: 17E137–17E156
Locality: (JF 227A) Gripps Shaft, Leadhills [NS 8843 1652]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E137: *Pygodus anserinus* Pa element
Periodon aculeatus S element

17E138: *Pygodus anserinus* Pa element

17E139: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Pygodus anserinus Pc element
Periodon aculeatus S element

17E140: *Pygodus anserinus* Pb element
Pygodus anserinus Pc element
Genus et species indet. Ramiform

17E141: *Pygodus anserinus* Pb element
Pygodus anserinus Pc element
Periodon aculeatus S element
Genus et species indet. Coniform
Genus et species indet. Ramiform

17E142: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Periodon aculeatus S element

17E143: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Pygodus anserinus Pc element
Periodon aculeatus S element
Protopanderodus varicostatus
17E144: *Pygodus anserinus* Pa element
17E145: *Pygodus anserinus* Pa element
17E142: *Pygodus anserinus* Pb element
Periodon aculeatus P element
Periodon aculeatus S element
Genus et species indet. Ramiform
17E147: ?*Periodon aculeatus* M element
17E148: *Pygodus anserinus* Pa element
Spinodus spinatus M element
17E149: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Genus et species indet. Coniform
Genus et species indet. Ramiform
17E150: *Pygodus anserinus* Pb element
17E151: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Pygodus anserinus Pc element
Periodon aculeatus Pa element
Periodon aculeatus S element
17E152: *Pygodus anserinus* Pb element
Pygodus anserinus Pc element
17E153: *Pygodus anserinus* P element
Genus et species indet. Ramiform
17E154: *Pygodus anserinus* Pa element
Periodon aculeatus Pa element
Periodon aculeatus Pb element
Periodon aculeatus S element
Genus et species indet. Coniform
17E155: barren
17E156: *Pygodus anserinus* Pa element

Specimen No: 17E157–17E232
Locality: (JF 227B) Gripps Shaft, Leadhills [NS 8843 1652]
Lithology: Black indurated mudstones (c. 0.4m) interbedded with grey cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E157: *Periodon aculeatus* Pa element
Periodon aculeatus Pb element
Periodon aculeatus S element
Protopanderodus varicostatus
Drepanoistodus suberectus
17E158: *Periodon aculeatus* Pa element
Periodon aculeatus Pb element
?*Periodon aculeatus* M element
Periodon aculeatus S element
Protopanderodus varicostatus
17E159: Genus species indet. Coniform
Genus species indet. Ramiform
17E160: *Periodon aculeatus* Pb element
Periodon aculeatus S element
17E161: *Periodon aculeatus* S element
17E162: *Periodon aculeatus* S element
16E163: *Periodon aculeatus* Pa element
Periodon aculeatus Pb element
Periodon aculeatus S element
Paroistodus sp.
17E164: *Periodon aculeatus* S element
Genus et spcies indet. Coniform
17E165: *Periodon aculeatus* Pb element
Periodon aculeatus S element
17E166: *Periodon aculeatus* Pb element
Periodon aculeatus S element
17E167: *Periodon aculeatus* S element
Genus et spcies indet. Coniform
17E168: *Protopanderodus* sp.
17E169: *Periodon aculeatus* S element
Protopanderodus sp.
17E170: *Protopanderodus* sp.
Genus species indet. Ramiform
17E171: *Periodon aculeatus* S element
Protopanderodus varicostatus
17E172: *Periodon aculeatus* P element
Periodon aculeatus M element
Periodon aculeatus S element
Protopanderodus varicostatus
17E173: Genus et species indet. Coniform
17E174: *Periodon aculeatus* S element
Spinodus spinatus S element
Genus et species indet. Coniform
17E175: *Periodon aculeatus* S element
17E176: *Periodon aculeatus* S element
17E177: *Spinodus spinatus* S element
Genus et species indet. Coniform
17E178: *Periodon aculeatus* S element
17E179: *Periodon aculeatus* S element
Protopanderodus sp.
17E180: *Periodon aculeatus* S element
Protopanderodus sp.
17E181: *Periodon aculeatus* Pa element
Periodon aculeatus S element
Protopanderodus varicostatus
17E182: *Periodon aculeatus* Pa element
Periodon aculeatus Pb element
Periodon aculeatus S element
17E183: *Periodon aculeatus* S element
17E184: *Periodon aculeatus* S element
17E185: *Periodon aculeatus* Pb element
Periodon aculeatus S element
17E186: *Periodon aculeatus* Pa element
Periodon aculeatus M element
Periodon aculeatus S element
17E187: *Periodon aculeatus* S element
17E188: *Periodon aculeatus* S element
Genus et species indet. Ramiform

17E189: Genus et species indet. Ramiform
17E190: *Protopanderodus* sp.
17E191: *Periodon aculeatus* S element
Protopanderodus sp
17E192: *Periodon aculeatus* S element
Protopanderodus varicostatus
17E193: *Periodon aculeatus* P element
Periodon aculeatus S element
Protopanderodus varicostatus
Strachanognathus parvus
17E194: *Periodon aculeatus* S element
Protopanderodus varicostatus
17E195: *Spinodus spinatus* S element
Genus et species indet. Coniform
17E196: *Periodon aculeatus* S element
Periodon aculeatus P element
17E197: *Periodon aculeatus* S element
17E198: *Periodon aculeatus* Pb element
Protopanderodus sp.
17E199: *Periodon aculeatus* S element
Genus et species indet. Coniform
17E200: *Periodon flabellum* S element
Genus et species indet. Ramiform
17E201: *Periodon aculeatus* S element
Perodon aculeatus Melement
17E202: *Spinodu spinatus* S element
17E203: *Periodon aculeatus* S element
Protopanderodus varicostatus
17E204: *Periodon aculeatus* P element
Periodon aculeatus S element
Protopanderodus sp.
17E205: *Periodon aculeatus* S element
17E206: *Periodon aculeatus* S element
17E207: *Periodon aculeatus* S element
17E208: *Periodon aculeatus* P element
Genus et species indet. Coniform
17E209: *Protopanderodus* sp.
Genus et species indet. Coniform
17E210: *Periodon aculeatus* S element
Genus et species indet. Coniform
17E211: *Periodon aculeatus* M element
Periodon aculeatus S element
17E212: *Periodon aculeatus* S element
17E213: *Periodon aculeatus* S element
17E214: *Periodon aculeatus* S element
Protopanderodus sp.
17E215: *Periodon aculeatus* P element
Periodon aculeatus M element
Periodon aculeatus S element
Protopanderodus sp.
Genus et species indet. Coniform
17E216: Genus et species indet. Coniform
17E217: *Periodon aculeatus* S element
Genus et species indet. Coniform
17E218: *Periodon aculeatus* M element
Periodon aculeatus S element
17E219: *Periodon aculeatus* P element
?Periodon aculeatus M element
Periodon flabellum S element
Protopanderodus varicostatus
17E220: *Periodon aculeatus* Pb element
17E221: *Periodon aculeatus* P element
Periodon aculeatus M element
Periodon aculeatus S element
Protopanderodus sp.
17E222: *Periodon aculeatus* S element
Protopanderodus varicostatus
17E223: *Periodon aculeatus* S element
Spinodus spinatus S element
17E224: *Periodon aculeatus* Pb element
Periodon aculeatus S element
Periodon aculeatus S element
17E225: *Periodon aculeatus* S element
Genus et species indet. Coniform
17E226: *Protopanderodus varicostatus*
Drepanodus arcuatus
17E227: *Periodon aculeatus* Pb element
Periodon aculeatus S element
Genus et species indet. Coniform
17E228: *Periodon aculeatus* S element
17E229: *Periodon aculeatus* Pb element
Periodon aculeatus M element
Periodon aculeatus S element
Protopanderodus sp.
17E230: *Periodon aculeatus* P element
Genus et species indet. Coniform
17E231: *Periodon aculeatus* P element
17E232: Genus et species indet. Coniform

Specimen No: 17E233–17E238
Locality: (JF 227C) Gripps Shaft, Leadhills [NS 8843 1652]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E233: *Pygodus anserinus* Pb element
17E234: *Periodon aculeatus* S elment
17E235: *Pygodus anserinus* Pb element
17E236: *Pygodus anserinus* Pb element
17E237: Genus et species indet. Ramiform
17E238: Genus et species indet. Ramiform

Specimen No: 17E239–17E244
Locality: (JF 227D) Gripps Shaft, Leadhills [NS 8843 1652]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E239: *Drepanoistodus suberectus*
17E240: *Drepanoistodus suberectus*
17E241: *Perodon aculeatus* S element
17E242: *Periodon aculeatus* S element
17E243: *Protopanderodus varicostatus*
17E244: *Protopanderodus varicostatus*

Specimen No: 17E245–17E252
Locality: (JF 227E) Gripps Shaft, Leadhills [NS 8843 1652]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E245: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Pygodus anserinus Pc element
17E246: Genus et species indet. Coniform
17E247: *Pygodus anserinus* Pa element
17E248: *Pygodus anserinus* P element
Genus et species indet. Coniform
17E249: *Pygodus anserinus* Pb element
Periodon aculeatus P element
Periodon aculeatus M element
17E250: *Periodon aculeatus* M element
17E251: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Pygodus anserinus Pc element
17E252: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element

Specimen No: 17E253–17E321
Locality: (JF 233) Glenkip Head, Leadhills [NS 8752 1606]
Lithology: Pink-buff mudstones between grey bedded cherts
Unit: Crawford Group
Zone: *Pygodus anserinus* Biozone

17E253: *Periodon aculeatus* Pb element
Periodon aculeatus M element
Periodon aculeatus S element
*?Drepanodus ar*cuatus
17E254: *Periodon aculeatus* S element
17E255: *Periodon aculeatus* S element
17E256: *Periodon aculeatus* S element
17E257: *Periodon aculeatus* Pb element
Periodon aculeatus M element
Periodon aculeatus S element
17E258: *Periodon aculeatus* S element
17E259: *Periodon aculeatus* Pa element
Periodon aculeatus S element
17E260: *Periodon aculeatus* S element
17E261: *Periodon aculeatus* Pa element
Periodon aculeatus S element
17E262: *Spinodus spinatus* S element
Periodon aculeatus S element
Periodon cf. *aculeatus* S element
17E263: *Periodon aculeatus* S element
17E264: *Periodon aculeatus* Pb element
17E265: *Periodon aculeatus* M element
Periodon aculeatus S element
17E266: *Spinodus spinatus* S element
Periodon aculeatus S element
17E267: *Periodon aculeatus* Pa element
Periodon aculeatus Pb element
Periodon aculeatus M element
Periodon aculeatus S element
17E268: *Periodon aculeatus* S element
17E269: *Periodon aculeatus* Pb element
Periodon aculeatus S element
Periodon cf.*aculeatus* S element
17E270: *Periodon aculeatus* M element
Periodon aculeatus S element
Periodon aculeatus S element
17E271: *Periodon aculeatus* S element
17E272: *Periodon aculeatus* Pb element
Periodon aculeatus S element
Periodon cf. *P. aculeatus* S element
17E273: *Periodon aculeatus* Pa element
Periodon aculeatus P element
17E274: *Periodon aculeatus* Pb element
17E275: *Periodon aculeatus* S element
17E276: Genus et species indet. Ramiform
17E277: *Periodon aculeatus* P element
17E278: *Periodon aculeatus* Pa element
Periodon aculeatus Pb element
Periodon aculeatus S element
17E279: *Periodon aculeatus* Pb element
Periodon aculeatus M element
Periodon aculeatus S element

17E280: *Periodon aculeatus* M element
17E281: *Periodon aculeatus* Pb element
Periodon aculeatus M element
Periodon aculeatus S element
17E282: *Periodon aculeatus* S element
17E283: *Periodon aculeatus* S element
Genus et species indet. Coniform
17E284: *Periodon aculeatus* M element
17E285: *?Drepanodus arcuatus*
17E286: *Periodon aculeatus* M element
Periodon aculeatus S element
17E287: *Periodon aculeatus* M element
17E288: *Periodon aculeatus* Pb element
17E289: *Periodon aculeatus* Pb element
Periodon aculeatus S element
17E290: *Periodon aculeatus* Pb element
Drepanodus planus
17E291: *Periodon aculeatus* Pb element
Periodon aculeatus S element
17E292: *Periodon aculeatus* Pb element
Drepanoistodus basiovalis
17E293: *Periodon aculeatus* S element
17E294: *Periodon aculeatus* S element
17E295: *Periodon aculeatus* Pb element
17E296: *Periodon aculeatus* S element
17E297: *Periodon aculeatus* S element
17E298: *Periodon aculeatus* Pa element
Periodon aculeatus Pb element
Periodon aculeatus S element
17E299: *Periodon aculeatus* S element
Genus et species indet. Ramiform
17E300: *Periodon aculeatus* S element
Protopanderodus sp.
17E301: *Periodon aculeatus* S element
Periodon aculeatus Pb element
Periodon aculeatus M element
Periodon aculeatus S element
17E302: *Periodon aculeatus* Pa element
Periodon aculeatus S element
17E303: *Periodon aculeatus* S element
17E304: *Periodon aculeatus* M element
Periodon aculeatus S element
17E305: *Periodon aculeatus* S element
17E306: *Periodon aculeatus* M element
17E307: *Periodon aculeatus* S element
17E308: *Periodon aculeatus* M element
Periodon aculeatus S element
Periodon aculeatus S element
Periodon aculeatus S element
17E309: *Periodon aculeatus* Pb element
Periodon aculeatus S element
Periodon cf. *P. aculeatus* S element
17E310: *Periodon aculeatus* Pb element
Periodon aculeatus S element
Periodon cf. *P. aculeatus* S element
17E311: *Periodon aculeatus* S element
17E312: Genus et species indet. Ramiform
17E313: *Periodon aculeatus* S element
17E314: Genus et species indet. Ramiform
17E315: *Periodon aculeatus* S element
Genus et species indet. Ramiform
17E316: *Periodon aculeatus* S element
17E317: *Periodon aculeatus* M element
Periodon aculeatus S element
17E318: *Periodon aculeatus* Pb element
17E319: *Periodon aculeatus* Pb element
17E320: Brachiopods
Genus et species indet. Ramiform
17E321: Brachiopods

Specimen No: 17E322–17E348
Locality: (JF 246B) 'Gripps Cleuch', Glengonnar, Leadhills. [NS 8829 1713]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E322: Genus et species indet. M element
17E323: *Periodon aculeatus* Pb element
Periodon aculeatus S element
17E324: *Periodon aculeatus* S element
17E325: *Pygodus anserinus* Pa element
Genus et species indet. Ramiform
17E326: Genus et species indet. Coniform
17E328: *Periodon aculeatus* Pb element
Periodon aculeatus M element
17E329: *Periodon aculeatus* Pb element
17E330: *Periodon aculeatus* Pb element
17E331: *Periodon aculeatus* Pb element
17E332: *Periodon aculeatus* S element
17E333: *Periodon aculeatus* S element
17E334: *Periodon aculeatus* Pa element
Periodon aculeatus S element
17E335: *Protopanderodus varicostatus*
17E336: *Periodon aculeatus* S element
17E337: *Periodon aculeatus* S element
Protopanderodus sp.
17E338: Genus et species indet. ?coniform
17E339: *Periodon aculeatus* M element
Periodon aculeatus S element
17E340: *Periodon aculeatus* M element
17E341: Genus et species indet. Ramiform
17E342: *Periodon acule*atus M element
17E343: *Periodon aculeatus* Pb element
17E344: *Periodon aculeatus* S element
17E345: *Periodon aculeatus* S element
17E346: *Periodon aculeatus* Pb element
17E347: *Periodon aculeatus* S element
17E348: *Periodon aculeatus* Pa element

Specimen No: 17E349–17E365
Locality: (JF 257) 'Kirk Gill Cleuch', Kirk Gill, Abington. Head of cleuch [NS 9151 1961]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E349: *Periodon aculeatus* S element
17E350: *Periodon aculeatus* M element
17E351: Genus et species indet. Ramiform
17E352: *Periodon aculeatus* M element
Periodon aculeatus S element
17E353: *Periodon aculeatus* S element
17E354: *Periodon aculeatus* M element
17E355: *Periodon aculeatus* Pb element
Periodon aculeatus S element
17E356: Genus et species indet. Ramiform
17E357: Genus et species indet. Ramiform
17E358: *Pygodus anserinus* Pb element
17E359: *Pygodus anserinus* Pb element
17E360: *Periodon aculeatus* M element
17E361: Genus et species indet. Ramiform
17E362: *Periodon aculeatus* M element
Periodon aculeatus S element
17E363: *Periodon aculeatus* M element
17E364: *Periodon aculeatus* M element
17E365: *Periodon aculeatus* Pa element
Periodon aculeatus M element
Pygodus anserinus ?Pa element

Specimen No: 17E366–17E368
Locality: (JF 258) Kirk Gill, Abington. Cliff on W bank of burn [NS 9150 2070]
Lithology: Dark grey mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E366: *Pygodus anserinus* Pa element
17E367: *Pygodus anserinus* Pa element
Pygodus anserinus Pc element
17E368: *Pygodus anserinus* Pc element
Periodon aculeatus M element

Specimen No: 17E36917E389
Locality: (JF 260) Clow Gill. Cliff on E bank, near head of burn [NS 8991 1815]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E369: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Protopanderodus varicostatus
Protopanderodus sp.
17E370: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Pygodus anserinus Pc element
Protopanderodus sp.
17E371: *Pygodus anserinus* Pa element
Protopanderodus sp.
17E372: *Periodon aculeatus* S element
Pygodus anserinus Pc element
17E373: *Periodon aculeatus* S element
Pygodus anserinus Pc element
17E374: *Pygodus anserinus* Pc element
17E375: *Pygodus anserinus* Pa element
17E376: *Pygodus anserinus* Pb element
Pygodus anserinus Pc element
17E378: *Pygodus anserinus* Pa element
Periodon aculeatus S element
17E379: *Pygodus anserinus* Pb element
17E380: *Pygodus anserinus* Pa element
Pygodus anserinus Pc element
17E381: *Pygodus anserinus* Pa element
17E382: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
17E383: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Pygodus anserinus Pc element
17E384: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Pygodus anserinus Pc element
17E385: *Pygodus anserinus* Pa element
Pygodus anserinus Pc element
17E386: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
17E387: *Pygodus anserinus* Pa element
Protopanderodus sp.
17E388: *Pygodus anserinus* Pa element
Pygodus anserinus Pc element
Periodon aculeatus M element
Periodon aculeatus S element
17E389: *Drepanoistodus* sp.

Specimen No: 17E390–17E391
Locality: (JF 262) Clow Gill, wood between Glengonnar Water and moor [NS 8914 1845]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E390: *Pygodus anserinus* Pa element
Periodon aculeatus S element
Genus et species indet. Coniform
17E391: *Pygodus anserinus* Pa element

Specimen No: 17E392–17E398
Locality: (HB 339) Black Grain, Abington. Top of gully on northernmost tributary [NS 9779 2460]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E392: *Protopanderodus cf. liripipus*
17E393: *Pygodus anserinus* Pa element
Periodon aculeatus M element
Periodon aculeatus S element
17E394: *Protopanderodus varicostatus*
17E395: *Pygodus anserinus* Pa element
Periodon aculeatus S element
Genus et species coniform
17E396: *Pygodus anserinus* Pa element
Periodon aculeatus S element
Genus et species coniform
17E397: *Pygodus anserinus* Pa element
17E398: *Pygodus anserinus* Pa element

Specimen No: 17E399–17E412
Locality: (HB 383) Lead Burn, Abington. Small quarry on NE side of forestry track to NE of Burn [NS 9850 2533]
Lithology: Red mudsts, grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E399: *Periodon aculeatus* M element
Periodon aculeatus S element
17E400: Genus et species indet. Coniform
17E401: *Periodon aculeatus* M element
17E402: *Periodon aculeatus* M element
Periodon aculeatus S element
17E403: *Periodon aculeatus* M element
Periodon aculeatus S element
17E404: *Periodon aculeatus* Pb element
Periodon aculeatus M element
17E405: *Periodon aculeatus* M element
Periodon aculeatus S element
17E406: *Periodon aculeatus* M element
17E407: *Periodon aculeatus* Pb element
17E408: *Periodon aculeatus* S element
17E409: *Pygodus anserinus* Pa element
Periodon aculeatus Pa element
Periodon aculeatus S element
Genus et species indet. Ramiform
17E410: *Periodon aculeatus* M element
17E411: *Periodon aculeatus* S element
17E412: *Periodon aculeatus* S element
Lingula sp.

Specimen No: 17E413–17E418
Locality: (HB 384) Lead Burn, Abington.
Trackside outcrop on NE side of forestry track to NE of Burn [NS 9870 2516]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Fornmation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E413: *Spinodus spinatus* S element
Periodon aculeatus S element
17E414: *Spinodus spinatus* S element
Periodon aculeatus S element
Pygodus anserinus Pc element
Protopanderodus sp.
17E415: Genus et species indet. Ramiform
17E416: *Pygodus anserinus* Pc element

17E417: Genus et species indet. Coniform

17E418: *Pygodus anserinus* Pb element

Specimen No: 17E419–17E426
Locality: (HB 385) Lead Burn. Trackside outcrop on NE side of forestry track to NE of Burn [NS 9858 2528]
Lithology: Grey-buff mudstones between grey bedded cherts
Unit: Kirkton Formation, Crawford Group
Zone: *Pygodus anserinus* Biozone

17E419: *Pygodus anserinus* Pa element
Pygodus anserinus Pb element
Lingula sp.
17E420: *Pygodus anserinus* Pa element
17E421: *Pygodus anserinus* Pa element
17E422: *Pygodus anserinus* Pa element
17E423: *Climacograptus* sp.
17E424: *Climacograptus* sp.
17E425: *Climacograptus* sp.
17E426: *Climacograptus* sp

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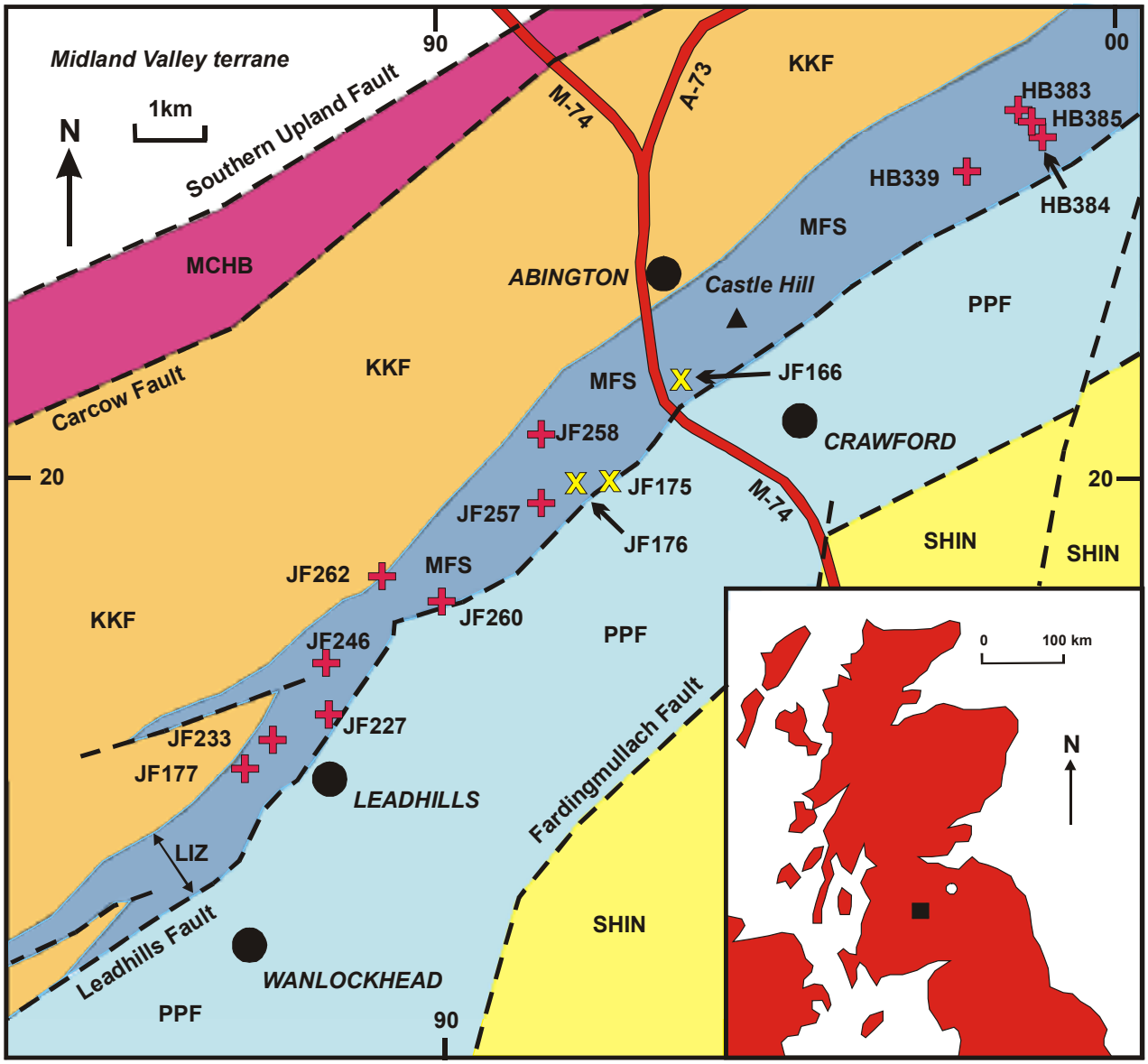

Figure 1 Outline geology of the Leadhills–Crawford area in the Southern Uplands.

Shows localities with *P. anserinus* Biozone faunas (red +) and those with *O. evae* Biozone faunas (yellow x). Inset shows area of main map and approximate location of the two localities at Lamancha (white circle).
Geological units: KKF, Kirkcolm Formation; MCHB, Marchburn Formation; MFS, Moffat Shale Group and Crawford Group (undivided); PPF, Portpatrick Formation; SHIN, Shinnel Formation; LIZ, Leadhills Imbricate Zone.

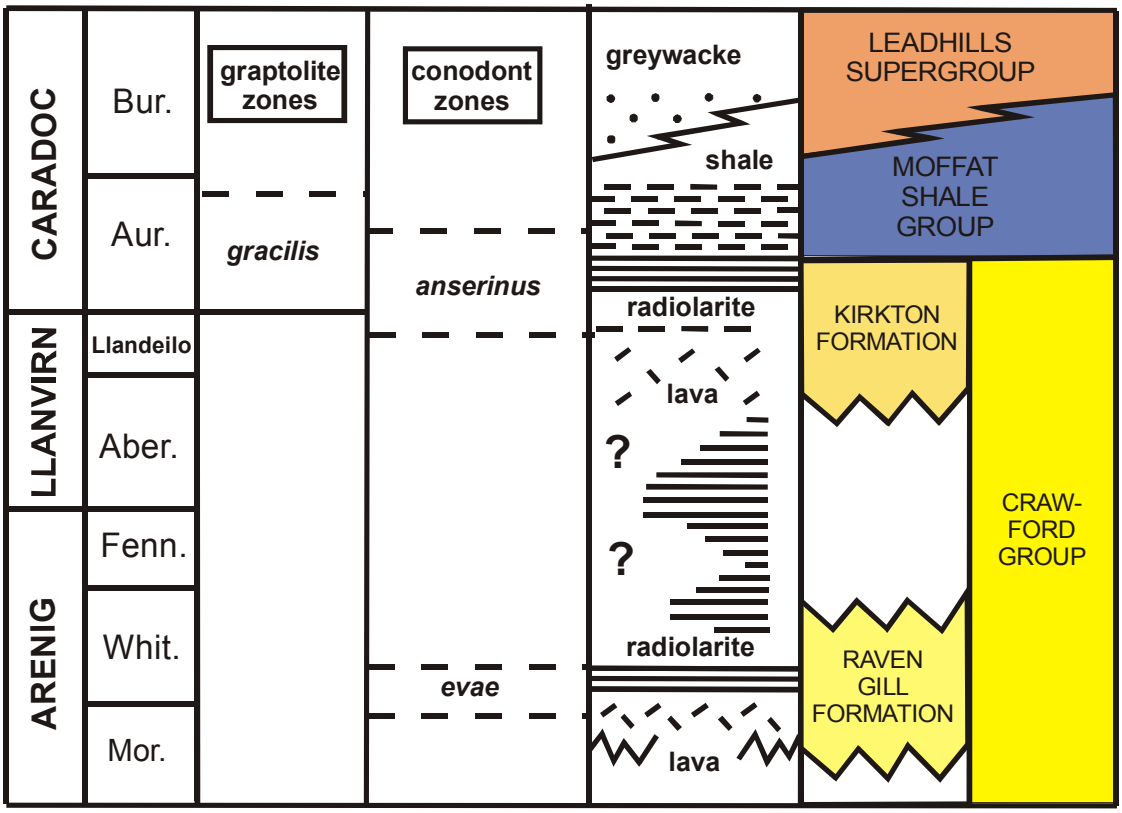

Figure 2 Simplified stratigraphical diagram of early–mid Ordovician successions in the Southern Uplands.

Highlighted are the established biozones recognised so far in the radiolarian cherts of the Crawford Group (after Danelian, 1999). Lithostratigraphical terminology according to Floyd (1996). Chronostratigraphy and biostratigraphy from Fortey et al. (1995).

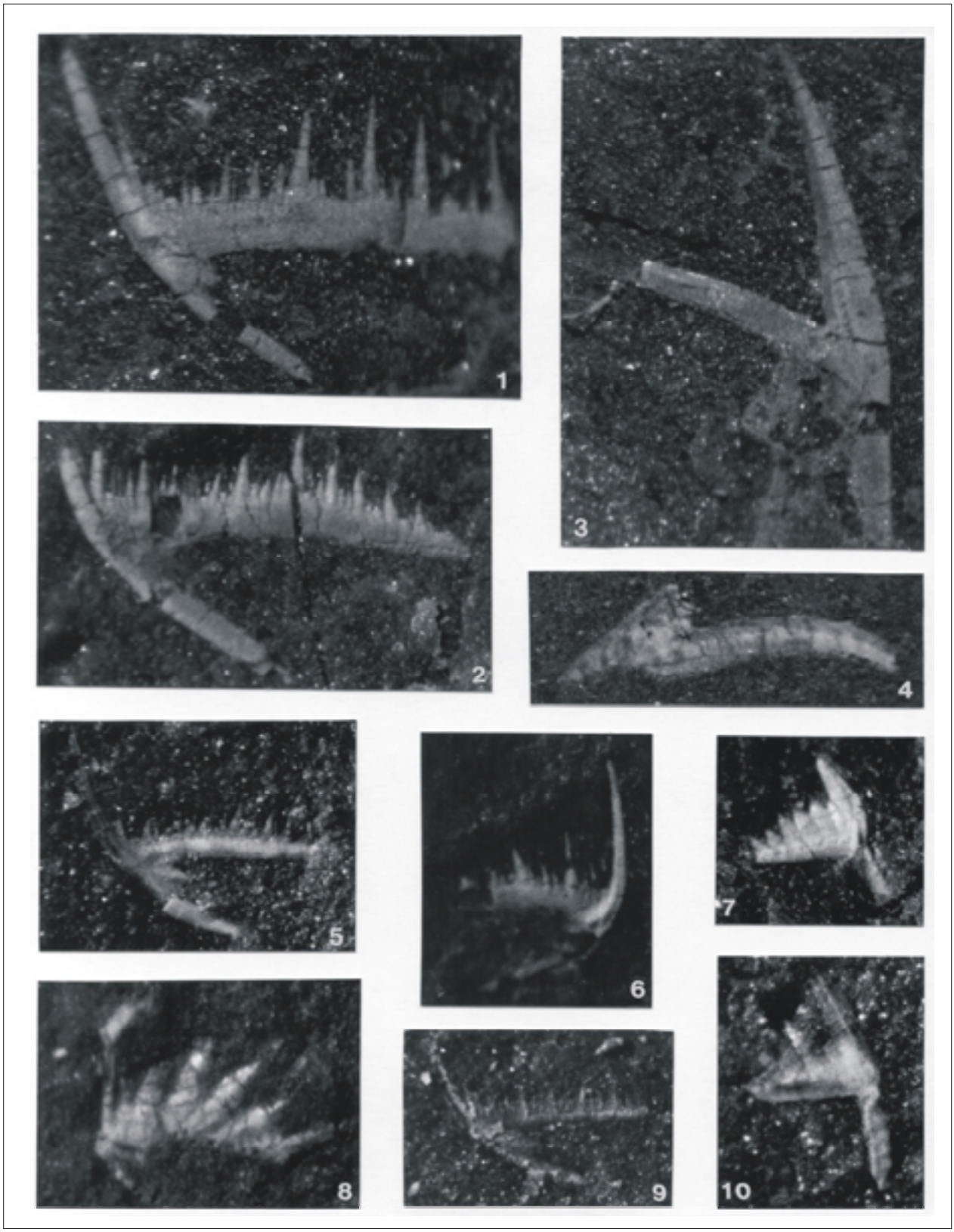

Plate 1 Photomicrographs of conodonts from the Leadhills -Abington - Crawford area, *Oepikodus evae* Biozone.

Figures 1–10. *Oepikodus evae* (Lindström, 1955)

1) S element, Raven Gill, 16E788, x50
2) S element, Raven Gill, 17E117, x50
3) M element, Radio mast track, 16E789, x50
4) M element, Raven Gill, 16E766, x50
5) S element, Radio mast track, 16E802, x50
6) S element, Radio mast track, 16E793, x50
7) P element, Raven Gill, 17E107, x50
8) P element, Raven Gill, 17E108, x50
9) S element, Raven Gill, 17E118, x50
10) P element, Raven Gill, 16E759, x50

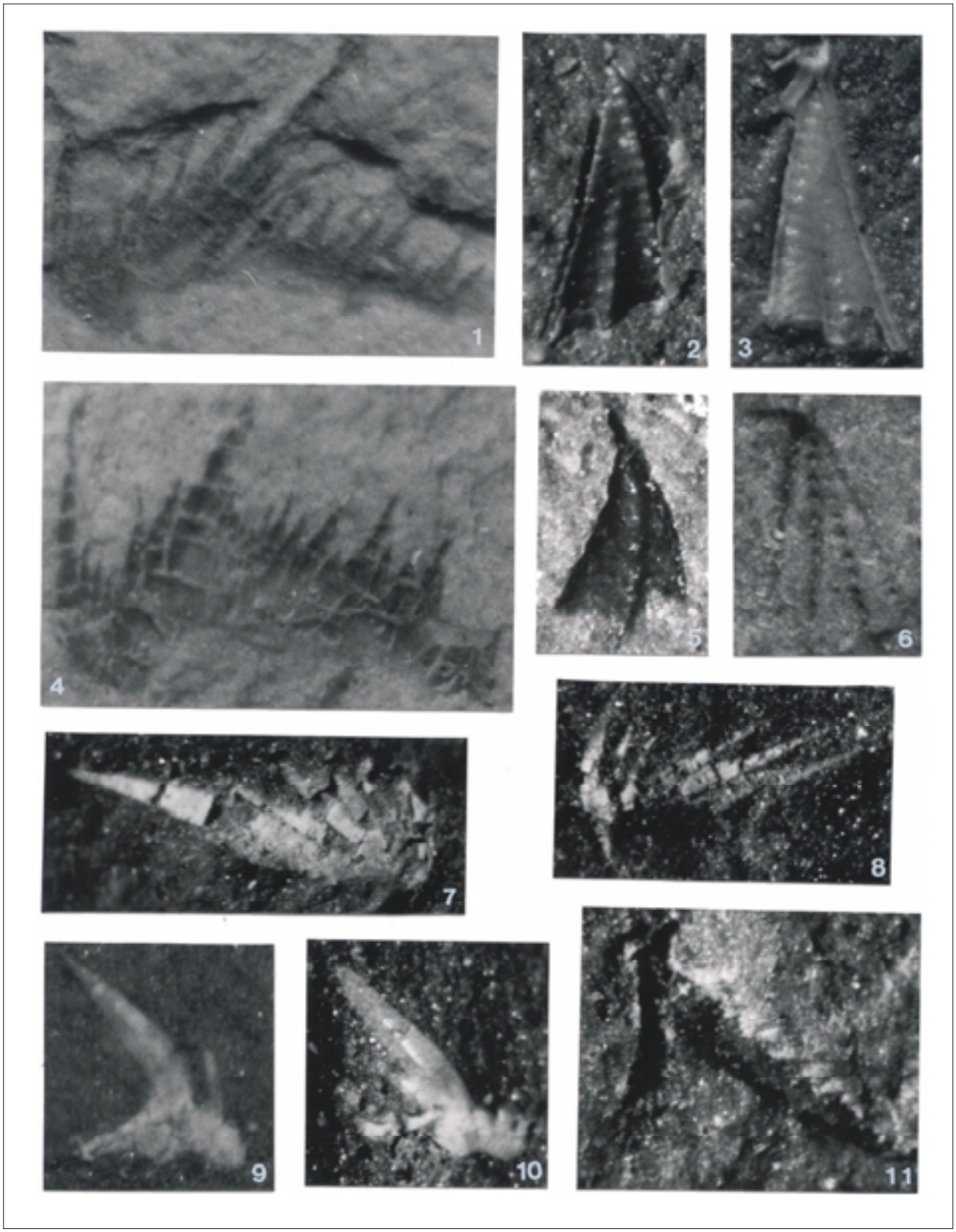

Plate 2 Photomicrographs of conodonts from the Lead-hills –Abington –Crawford area.

Plate 2 Explanation

Figures 1, 4 *Periodon aculeatus* (Hadding, 1913)
1) S element, Gripps Shaft, 17E272, x50
4) S element, Gripps Shaft, 17E309, x50

Figures 2, 3, 5, 6, 11 *Pygodus anserinus* Lamont and Lindström, 1957
2) Pa element, White Heather Burn, 15E6592, x50
3) Pa element, White Heather Burn, 15E6593, x50
5) Pb element, Gripps Shaft, 17E141, x50
6) Pa element, Gripps Shaft, 17E137, x50
11) Pc element, Gripps Shaft, 17E151, x50

Figure 8 *Periodon flabellum* (Lindström)
8) S element, Raven Gill, 17E108, x50

Figures 7, 10 *Periodon aculeatus* (Hadding, 1913)
7) S element, Glencaple Burn, 16E863, x50
10) Pb element, Glencaple Burn, 16E851, x50

Figure 9 *Bergstroemognathus extensus* (Graves and Ellison, 1941)
9) S element, Glencaple Burn, 16E862, x50

Table 1 Conodont localities Leadhills–Abington area (Sheet 15e).

Locality and NGR	*Fossils*	*Locality name*	*Lithology*	*Lithostratigraphy*	*Biozone and age*
JF 166 NS 9373 2175	15E6599–6602 16E789–808 16E2881–2884	Track to radio mast, Crawford	red mudstone	Crawford Group, Raven Gill Formation, Castle Hill Member	*Oepikodus evae* Arenig
JF 175 NS 9255 1989	16E835–875	Glencaple Burn, Abington. E bank	red mudstone	Crawford Group, Raven Gill Formation, Castle Hill Member	*Oepikodus evae* Arenig
JF 175A NS 9255 1989	16E2885–2888	Glencaple Burn, Abington. E bank	red mudstone	Crawford Group, Raven Gill Formation, Castle Hill Member	*Oepikodus evae* Arenig
JF 175B NS 9255 1989	16E2863–2880 17E91–99	Glencaple Burn, Abington. E bank	red mudstone	Crawford Group, Raven Gill Formation, Castle Hill Member	*Oepikodus evae* Arenig
JF 176 NS 9204 1989	16E758–788	Raven Gill, Glencaple	brown mudstone	Crawford Group, Raven Gill Formation	*Oepikodus evae* Arenig
JF 176A NS 9204 1989	17E100–110	Raven Gill, Glencaple. NW side of gully	brown mudstone	Crawford Group, Raven Gill Formation	*Oepikodus evae* Arenig
JF 176B NS 9204 1989	17E111–122	Raven Gill, Glencaple. NE side of gully	brown mudstone	Crawford Group, Raven Gill Formation	*Oepikodus evae* Arenig
JF 176C NS 9204 1989	17E123–126	Raven Gill, Glencaple. SE side of gully	brown mudstone	Crawford Group, Raven Gill Formation	*Oepikodus evae* Arenig
JF 177 NS 8708 1568	16E809–834 17E127–136	'Hunt Law Cleuch', Snar Water	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 227A NS 8843 1652	17E137–156	Gripps Shaft, Leadhills. NE bank of channel	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 227B NS 8843 1652	17E157–232	Gripps Shaft, Leadhills. NE side of channel	black indurated mudstone (c. 0.4m) interbedded with grey cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn - Caradoc
JF 227C NS 8843 1652	17E233-238	Gripps Shaft, Leadhills. N bank Glengonnar Water.	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 227D NS 8843 1652	17E239–244	Gripps Shaft, Leadhills. NE of channel	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 227E NS 8843 1652	17E245–252	Gripps Shaft, Leadhills. SW side of channel	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 233 NS 8752 1606	17E253–321	Glenkip Head, Leadhills.	pink-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 246B NS 8829 1713	17E322–348	'Gripps Cleuch', Glengonnar, Leadhills.	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 257 NS 9151 1961	17E349–365	'Kirk Gill Cleuch', Abington.	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 258 NS 9150 2070	17E366–368	Kirk Gill, Abington. Cliff on W bank of burn	dark grey mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc

Locality and NGR	*Fossils*	*Locality name*	*Lithology*	*Lithostratigraphy*	*Biozone and age*
JF 260 NS 8991 1815	17E369–386	Clow Gill. Cliff on E bank, near head of burn	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
JF 262 NS 8914 1845	17E390–391	Clow Gill. Wood below moorland	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn - Caradoc
HB 339 NS 9779 2460	17E392-398	Black Grain. Top of gully, northern tributary	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
HB 383 NS 9850 2533	17E399–412	Lead Burn. Small trackside quarry to NE of burn	red mudstone; grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
HB 384 NS 9870 2516	17E413–418	Lead Burn. Trackside outcrop to NE of burn	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Llanvirn–Caradoc
HB 385 NS 9858 2528	17E419–426	Lead Burn. Trackside outcrop to NE of burn	grey-buff mudstone between grey bedded cherts	Crawford Group, Kirkton Formation	*Pygodus anserinus* Biozone (+ graps) Llanvirn–Caradoc