A SUMMARY OF NEW CONODONT BIOSTRATIGRAPHY AND CORRELATION OF THE ANISIAN (MIDDLE TRIASSIC) STRATA IN BRITISH COLUMBIA, CANADA

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Abstract – New conodont collections from both outcrop sections and subsurface drill core improve the correlation of Anisian (Middle Triassic) strata in British Columbia. New conodont species and morphotypes identified in these collections are used to define new informal conodont faunal assemblages. This preliminary biostratigraphical scheme allows correlation of the Anisian between surface and subsurface sections in British Columbia for the first time, as illustrated by four of the sections studied. Improved correlation has led to a revision of the interpretation of the depositional environment of Anisian rocks in British Columbia, from that of a continental margin to that of a restricted basin. The recognition of some of the new conodont taxa in collections from Nevada and the Canadian Arctic indicates that some of the faunal assemblages may prove useful for regional correlation and placement of the sub-stage boundaries of the Anisian.

INTRODUCTION

This paper introduces new conodont taxa from the Anisian of northeastern British Columbia, and new biostratigraphical correlations based on their distribution. This work both summarises and expands upon observations and conclusions made by Golding (2014).

Ammonoids and conodonts are the two most useful and widely used taxonomic groups for biostratigraphical subdivision of the marine Anisian. The base of the Anisian has not yet been defined by a Global Boundary Stratotype Section and Point (GSSP; Ogg et al., 2014). The only candidate section so far proposed is at Desli Caira in Romania, where the boundary has been proposed at the first appearance of the conodont Chiosella timorensis (Nogami) (Gradinaru et al., 2007; Orchard et al., 2007a). However, the first appearance of this species is now known to occur with Spathamian (upper Olenekian) ammonoids of the Neopopanoceras haugi Zone in Nevada and China (Ovtcharova et al., 2010; Goudemand et al., 2012), therefore its use as a definitive index species for the base of the Anisian is questionable, and would require the Neopopanoceras haugi Zone to be re-defined as Anisian in part. The complementary section at Guandao in China (Lehrmann et al., 2006) provides a superior conodont record (Orchard et al., 2007b), but lacks good ammonoid control.
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(Ogg et al., 2014). The upper boundary of the Anisian is formally defined by the first appearance of the ammonoid *Eoprotrachyceras curionii* (Mojsisovics) at the base of the Ladinian, in the section at Bagolino in Italy (Brack et al., 2005).

In British Columbia, the Anisian ammonoid record is fairly well developed, with eight ammonoid zones and two subzones recognized (Fig. 1; Tozer, 1967, 1994; Silberling & Tozer, 1968; Bucher, 2002). However, the Anisian sequence in British Columbia appears rather incomplete by reference to that of Nevada, where 13 ammonoid zones and 31 subzones are recognized (Silberling & Wallace, 1969; Silberling & Nichols, 1982; Bucher, 1988, 1989, 1992 a, b, 1994; Bucher & Orchard, 1995). Lowermost Anisian ammonoids appear to be missing in British Columbia, and there are large gaps in the ammonoid record of the Middle and Upper Anisian (Monnet & Bucher, 2005). The reasons for this discrepancy between the two areas are unclear, but may be due to unconformities in the Anisian succession of British Columbia, or the difference may simply be a reflection of the higher ammonoid diversity in Nevada (Monnet & Bucher, 2005).

The conodont record of the Anisian in British Columbia is generally poor in resolution compared with that of the ammonoids. Eleven partially overlapping conodont zones have been outlined for the Anisian (Orchard & Tozer, 1997), although several of these were based on undescribed taxa. In the upper part of the Middle Anisian and in the Upper Anisian the precision of the existing conodont zonation is comparable to that of the ammonoids, however, within the Lower Anisian and lower part of the Middle Anisian, the precision is not as good (Fig. 1).

The deficiency in the existing conodont biozation is due, in part, to an underdeveloped taxonomy for Anisian conodonts in North America, particularly the ubiquitous Neogondolellins and Paragondolellins (sensu Orchard, 2005). In an attempt to improve the stratigraphic utility of the conodonts, new conodont samples were collected from both surface outcrop and subsurface drill core in British Columbia, and examined together with existing collections which are calibrated with ammonoid zones (Orchard & Tozer, 1997). This has resulted in the taxonomic revision of a number of conodont species groups, the refinement of the faunal succession that is tied to the existing ammonoid biozonation, and improved correlation between outcrop and subsurface Triassic.

**GEOLOGICAL SETTING**

The Anisian rocks of British Columbia belong to two major tectonic settings: some were deposited on the continental margin of North America, whilst others were deposited on pericratonic and exotic terranes that lay to the west of the continent during the Triassic. These terranes have subsequently accreted onto the margin of North America, and rocks of Anisian age are preserved throughout British Columbia (Orchard, 1991). Those that were deposited on the continental margin form a near-continuous outcrop belt running along the eastern margin of the Canadian Rocky Mountains (Fig. 2). To the east of this outcrop belt, Anisian rocks are present in the subsurface of British Columbia and the neighboring province of Alberta.

The Anisian rocks of the subsurface and eastern outcrop belt were deposited in the Western Canada Sedimentary Basin (WCSB), which was made up of a complex series of sub-basins formed by a combination of transtension and extension (Davies, 1997). The basin initiated during the Mesoproterozoic and persisted as a continental margin basin until terrane accretion began in the Triassic (Ross et al., 1989; Beranek and Mortensen, 2011). During the Anisian, the WCSB was located on the western margin of North America at mid-latitudes (Smith et al., 1995), and experienced an arid climate influenced by trade winds and upwelling (Davies, 1997).

Anisian rocks of the outcrop belt belong to the Toad Formation. This unit was named by Kindle (1944) and it consists of up to 800 m of siltstone, shale, fine-grained sandstone and carbonate (Gibson, 1975). The formation is thought to range in age from the Smithian (lower Olenekian) to the Ladinian on the basis of ammonoid and conodont collections (Tozer, 1961, 1994; Orchard & Tozer, 1997; Zonneveld, 2010). In the subsurface, the Anisian rocks belong to the Montney and Doig formations, both defined by Armitage (1962). The Montney Formation consists of up to 450 m of siltstone and sandstone with very minor amounts of shale and carbonate (Armitage, 1962; Davies et al., 1997). The formation is thought to range in age from Changhsingian to Anisian (Zonneveld, 2010; Zubin-Stathopoulos et al., 2012). The Doig Formation unconformably
overlies the Montney Formation, and consists of up to 150 m of siltstone, fine sandstone and carbonate (Armitage, 1962; Evoy & Moslow, 1995). The age of this formation is uncertain, but has been estimated as Spathian to Ladinian (Hunt & Ratcliffe, 1959; Qi, 1995; Zonneveld, 2010). Both the Montney and Doig formations contain economically important reserves of natural gas (Adams, 2013).

A total of 42 conodont collections from 11 outcrop sections and 7 subsurface wells, all representing the ancestral North American continental margin, were examined for this study; the location of those discussed in this paper are shown in Fig. 2. A full description of all of the localities is available in Golding (2014).

NEW CONODONT SPECIES

Previously, the majority of conodont species from the Anisian of North America have been assigned to one of six named species: Neogondolella regalis Mosher, N. constricta (Mosher and Clark), N. bulgarica (Budurov and Stefanov), N. shoshonensis Nicora, N. mombergensis (Tatge), and Paragondolella excelsa Mosher (Mosher & Clark, 1965; Mosher, 1973; Nicora, 1976, 1977; Nicora & Kovács, 1984; Ritter, 1989; Orchard, 1994), although Nicora et al. (1980) and Orchard (2010) also differentiated several other less common taxa from Nevada. The current taxonomic revision has resulted in the recognition of a number of new morphotypes of some of the common species from British Columbia, which have been re-classified as species groups. Previous reports of N. mombergensis, the type species of Neogondolella, from North America (e.g. Ritter, 1989) are regarded as erroneous, and the existence of this species outside of Tethys is questioned (Bucher & Orchard, 1995; Orchard & Rieber, 1999). In addition to 18 new morphotypes of four species groups assigned to Neogondolella and Paragondolella, a further nine new species of Neogondolella have been differentiated; these new taxa will all be fully described in future publications. A selection of some of the most stratigraphically important new taxa are shown in Fig. 3.

The Canadian succession of these new conodont taxa has allowed the recognition of 11 new, informal faunal assemblages that are useful for local correlation. These assemblages are groups of species that will hopefully define biozones, once the variations in morphology, and geographic and stratigraphic ranges of the constituent species have been fully determined. Seven of these assemblages are introduced informally here to illustrate their use in correlation (Fig. 4). Currently, the new biostratigraphical scheme is a hybrid, with the N. ex gr. shoshonensis faunal assemblage equivalent in concept to an assemblage biozona, whilst the others are akin to interval biozones, defined by first appearances of taxa.

CORRELATION OF THE ANISIAN IN B.C.

In order to demonstrate the utility of the new conodont faunal assemblages in the correlation of the Anisian of northeastern British Columbia, four sections are chosen. Two of these are outcrop sections located on the Alaska Highway, at Mile Post 375 East and Mile Post 375 West (Fig. 2). The Toad Formation is exposed at these sections on the two limbs of an anticline, and they represent the type sections of the Lenotropites caurus, Hollandites minor, and Eogymnotoceras deleeni ammonoid Zones (Tozer, 1967, 1994); Bucher (2002) also differentiated the Paracrochodiceras americanum beds at the Mile Post 375 East section. At these sections, the age of the conodont faunal assemblages has been directly tied to the ammonoid biozonation (Fig. 4). The other two sections are drill core from hydrocarbon wells drilled in the vicinity of Fort St. John, named Talisman Altaraes 16-17-083-25W6 and Murphy Swan d-054-B-093-P-09 (Fig. 2). The drill core from these wells belongs to the Montney and Doig formations, and conodont collections from the wells can be assigned to the same faunal assemblages as in the outcrop sections. However, no ammonoids were collected from the drill core. The correlation between this drill core and the outcrop sections is shown in Fig. 4. The stratigraphy and conodont zonation of the Talisman Altaraes 16-17-083-25W6 well is discussed in detail in another manuscript (Golding et al., in press).

The geographical separation of these sections is quite large, nevertheless it is possible to draw firm correlations between them, particularly around the Lower-Middle Anisian boundary. This is placed between the Paracrochodiceras americanum and Buddhaites hagei ammonoid zones (Tozer, 1994) and, although no conodont fauna was recovered from the Buddhaites hagei Zone (the presence of which was reported from the Mile Post 375 East section by Bucher, 2002), the division between the Neogondolella ex gr. regalis morphotype D and the Neogondolella ex gr. regalis morphotype B faunal assemblages is inferred to approximate the boundary. The recognition of these faunal assemblage in the subsurface drill core allows the correlation of the Lower-Middle Anisian boundary between the outcrop and the subsurface (Fig. 4).

IMPLICATIONS OF THE NEW CORRELATION

The correlation of the Anisian using new conodont faunal assemblages allows some of the previously accepted ideas about the Anisian of British Columbia to be tested. The boundary between the Montney and Doig formations has previously been thought to be diachronous, with estimates for its age ranging from Spathian to Ladinian (Hunt & Ratcliffe, 1959; Qi, 1995; Zonneveld, 2010), however neither the degree nor pattern of diachronity has been well understood. The new correlation described herein shows that the formational boundary is oldest in the center of the study area, just west of Fort St. John, and becomes younger both to the west and to the east (Golding, 2014). The base of the Doig Formation is Spathian in age in the Altaraes area of British Columbia, and ranges into the Middle Anisian in the Dawson area. This pattern of diachronity is not what would have been expected if the sediment of the Montney and Doig formations was deposited on a west-facing continental margin. Instead, it implies that the depositional basin was restricted during the Anisian, with localized palaeo-highs present to the west as well as to the east of the depocentre (Golding, 2014). The new correlation also shows that the basal Doig Formation is condensed, with
the highest degree of condensation occurring where the base of
the formation is youngest, and the least where it is oldest. This
pattern of condensation again suggests the presence of localized
paleo-highs within the basin (Golding, 2014).

The large number of new conodont species and morphotypes
used to define the new faunal assemblage scheme currently
precludes correlation beyond the local area. Anisian collections
of conodonts from Nevada contain rich faunas of Neogondolella
ex gr. constricta, and it is probable that some of the new species
recognized in British Columbia can also be recognized amongst
this diverse fauna. Morphotypes of Neogondolella ex gr. shoshonensis
have been identified in Nevada (Nicora, 1976) and may be useful
for stratigraphic correlation between the two areas; this species
group appears to be restricted to the Middle and Upper Anisian
(Nicora, 1976; Golding, 2014). Neogondolella n. sp. C sensu
Orchard, 2008 appears in the Lower Anisian in British Columbia
and similar forms seem to occur at the same level in Nevada and
in the upper Spathian of the Canadian Arctic (Orchard, 2008). Further investigation of Anisian faunas from Nevada and the
Canadian Arctic is required to determine the degree to which
these new faunal assemblages are suitable for regional correlation,
or to what extent they may be useful for correlation with sub-stage
boundaries used in Tethys.

**Figure 4** – Correlation of the sections at Mile Post 375 East, Mile Post 375 West, Talisman Altares 16-17-083-25 W6 and Murphy Swan d-054-B/093-P-09 using seven of the new conodont faunal assemblages, that are in turn calibrated to the existing ammonoid biozonation. Dashed line between Paracrochordiceras americanum and Tetsaceras hayesi zones indicates the absence of the Buddhaites hagei Zone. N. = Neogondolella, P. = Paragondolella. In outcrop sections, the scale is in meters above the base of the section, and in subsurface drill core, the scale is in meters below kelly bushing.
CONCLUSIONS

The recognition of new conodont taxa from the Anisian of British Columbia has improved the resolution of the conodont biozonation for this time period. The new faunal assemblages allow more precise correlation between sections, including from the outcrop to the subsurface for the first time. The correlation of the subsurface sections has allowed the depositional environment of the Anisian rocks to be reassessed; it is suggested that these rocks were not deposited on a continental margin, but within a semi-restricted basin. A number of the new conodont taxa identified within the Anisian of British Columbia are also present in Nevada and the Canadian Arctic, suggesting the potential for recognizing the conodont faunal assemblages throughout North America.

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