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Tianzhushania spinosa and other large acanthomorphic acritarchs of Ediacaran Period from the Infrakrol Formation, Lesser Himalaya, India

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ABSTRACT

Covering a time span from Ediacaran (base of Blaini pink carbonates) to Early Cambrian (base of Tal Group), the Krol belt in the Lesser Himalaya (India), occurs as a series of synclines from Solan, Himachal Pradesh in the north-west to Nainital, Uttarakhand in the south-east. Various lithostratigraphic divisions of this belt reveal many palaeobiological entities, namely cyanobacteria, algae, acritarchs, small shelly fossils and trace fossils. Globally, large acanthomorphic acritarchs of the Ediacaran Period are used as significant biostratigraphic tools for global correlation. In the Krol belt, reports of acanthomorphic acritarchs from the Infrakrol and Krol 'A' formations of the Krol Group have further supported this notion. This paper reports well-preserved microfossils including acanthomorphic acritarchs, sphaeromorphic acritarchs, coccoids namely *Tianzhushania spinosa*, *T. polysiphonia*, *Papillomembrana compta*, *Schizofusa* sp., *Gloeodiniopsis lamellosa*, *Sphaerophycus medium*, and the unnamed forms A, B and C from the chert nodules of the Infrakrol Formation exposed in the Nainital Syncline of the Kumaun Lesser Himalaya. A biostratigraphic correlation based on acanthomorphic acritarchs suggests that the Infrakrol Formation is coeval to the lower *Tianzhushania* assemblage zone of the Doushantuo Formation of south China. *Tianzhushania* and *Papillomembrana* are significant additions to the previous record of the Ediacaran acanthomorphic acritarchs from the Lesser Himalaya of India and provide an independent evidence for construction of both biozonation scheme and paleogeography.

1. Introduction

Ediacaran Period, the terminal part of Neoproterozoic, begins with the close of the last global glaciation of the Cryogenian Period (635 Ma) and ends with the beginning of the Cambrian Period (542 Ma) (Amthor et al., 2003; Bowring et al., 1993; Condon et al., 2005; Grotzinger et al., 1995). A negative excursion in the carbon isotopic records in the beginning and in the end, records of unusual biogeochemical events in carbonate rocks, and sedimentary organic matter are also observed during this period. The lower and middle parts of the Ediacaran Period are characterized by cyanobacteria, microalgae, multicellular algae and acritarchs (Grey, 2005; Moczydlowska, 2008a,b; Xiao and Dong, 2006; Zang and Walter, 1992) and the upper part by extraordinary soft bodied metazoans, the earliest skeletal metazoans and tubulous metazoans (Cortijo et al., 2010; Fedonkin et al., 2007; Gehling, 1999; Germs et al., 2009; Glaessner, 1984; Grazdhankin, 2004; Narbonne, 2005).

It has been noted worldwide that the characteristic Large Acanthomorphic Acritarchs (LAAs) radiated and diversified in the lower and middle parts of the Ediacaran Period (i.e. between ~635 and ~551 Ma) (Grey et al., 2003, Grey, 2005; Liu et al., 2013; Zhou et al., 2007). These LAAs are now known from South China, Australia, Eastern European Platform, Siberia, India and Svalbard (Grey, 2005; Knoll and Ohta, 1988; Knoll, 1992; Liu et al., 2013, 2014; Moczydlowska et al., 1993; Moczydlowska and Nagovitsyn, 2012; Nagovitsyn et al., 2004; Sergeev et al., 2011; Shukla and Tiwari, 2014; Tiwari and Knoll, 1994; Tiwari and Pant, 2004; Veis et al., 2006; Vidal, 1990; Vorob'eva et al., 2009a, 2009b; Willman, 2006; Willman and Moczydłowska, 2008,2011; Xiao, 2004; Yin and Li, 1978; Yin, 1987, 1999; Yin and Liu, 1988; Yin et al., 2011; Yuan and Hofmann, 1998; Xiao et al., 2014; Zang and Walter, 1992; Zhang et al., 1998; Zhou et al., 2001, 2007). The presence of these LAAs has shown their great potential in biostratigraphic zonation and global correlation of Ediacaran strata in spite of various complications such as facies control, taxonomic differences due to identification of the same forms in different lithologies (e.g. chert and shale) and different processing techniques (thin

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Table 1
Generalised stratigraphic succession of the area based on Shanker et al. (1993).

Group	Formation	Lithology
Tal	Dhaulagiri	Argillo-arenaceous rocks
	Deo ka Tibba	Chert phosphorite, argillo-arenaceous and calcareous rocks
Krol	Kauriyala (Krol C,D,E)	Massive dark grey and blue dolomite, rhythmic alteration of thinly bedded black shale with marl and carbonaceous and cherty dolomite
	Jarashi (Krol B)	Red to purple coloured shales with intercalated green shale layers
	Mahi (Krol A)	Grey to greenish-grey calcareous shales to siltstones and argillaceous sandstone
Baliana	Infrakrol	Dark carbonaceous shales/siltstones with chert nodules
	Blaini	Diamictite grading into carbonate beds

sections or macerated slides) (Grey, 2005; Grey et al., 2003; Grey and Willman, 2009; Liu et al., 2013, 2014; Moczydlowska and Nagovitsin, 2012; Sergeev et al., 2011; Vorob'eva et al., 2009a, 2009b; Willman and Moczydlowska, 2008, 2011). Such taphonomic variations are well evident in the Ediacaran acritarch assemblages of Australia and South China (Grey, 2005; Grey and Willman, 2009; Zhou et al., 2007).

In India, microfossils including characteristic LAAs are reported from the Krol belt of the Lesser Himalaya. The Krol belt extends from Solan in the north-west to Nainital in the south-east in the form of several synclines. This belt embraces Neoproterozoic to Cambrian succession of the Baliana, Krol and Tal groups (Table 1). Various lithostratigraphic divisions of these groups reveal several palaeobiological entities, including small shelly fossils, trace fossils, acritarchs, cyanobacteria and algae (Shukla and Tiwari, 2014 and references therein). The fossil reports and sequence stratigraphic studies in the Krol Belt (Kaufman et al., 2006 and references therein) show that the succession that includes pink carbonate of Blaini Formation (related to Marinoan glaciation; Jiang et al., 2003a; Condon et al., 2005; Zhang et al., 2005) and overlying Infrakrol Formation and Krol Group is designated as Ediacaran succession. Here, in the lower part of the Ediacaran Period in the Krol belt well-preserved microfossils from the Baliana Group and the Krol Group were reported. These microfossils include large acanthomorphic acritarchs, cyanobacteria and multicellular algae viz. *Asterocapsoides sinensis*, *Asterocapsoides* sp., *Cymatiosphaeroides yinii*, *Knollisphaeridium maximum*, *Eomicrocoleus crassus*, *Ericiasphaera spjeldnaesii*, *Leiosphaeridia crassa*, *Melanocyrillium horodyskii*, *Myxococcoides* sp., *Obruchevella magna*, *O. parva*, *Oscillatoriopsis media*, *Polybessurus crassus*, *Polytrichoides lineatus*, *Siphonophycus inornatum*, *S. kestron*, S. *punctatum*, *S. robustum*, *S. typicum*, *Salome hubeiensis* and *Wengania globosa* from Infrakrol Formation (Krol Group) (Tiwari and Azmi, 1992; Tiwari and Knoll, 1994; Tiwari and Pant, 2004) and from Mahi Formation/Krol A (Krol Group) include *Appendisphaera fragilis*, *A. grandis*, *Asterocapsoides* sp., *Asterocapsoides* sp. B, *Cavaspina acuminata*, *C. basiconica*, *Eotylotopalla dactylos*, *Knollisphaeridium* sp., *Papillomembrana* sp., *Weissiella* cf., *W. grandistella* from Krol A Formation (Shukla and Tiwari, 2014). These microfossils have been reported exclusively from the early diagenetic chert nodules of the Infrakrol Formation in the Pachmunda, Krol Hill synclines in the north-western part and Nainital Syncline in the south-eastern part of the Krol Belt (Tiwari and Knoll, 1994; Tiwari and Pant, 2004) and from chert nodules and chert bands of the Krol A Formation of the Khanog and Rajgarh synclines, in the north-western part of the Krol belt (Shukla and Tiwari, 2014).

The present paper describes additional three dimensionally preserved microfossils including LAAs: *Tianzhushania spinosa*, *T. polysiphonia*, *Papillomembrana compta*; sphaeromorphic acritarch: *Schizofusa* sp., and coccoidal cyanobacteria: *Paratetraphycus giganteus*, *Gloeodiniopsis lamellosa, Sphaerophycus medium* along with unnamed forms A, B and C preserved within chert nodules of the Infrakrol Formation exposed in the Takula–Khurpatal road and Hanumangarhi sections in the Nainital Syncline. This data confirms the presence of *Tianzhushania spinosa* in India and also validates the potential of Ediacaran acritarchs in biostratigraphic correlation worldwide. However, in order to establish biozones within the Ediacaran deposits of the Krol belt, a high resolution biostratigraphic study with documentation of more taxa of large acanthomorphic acritarchs from different stratigraphic lithounits of the Krol Group is still required.

2. Geological Setting

The Krol Belt of the Lesser Himalaya, India is exposed in the form of various doubly plunging synclines from Solan in the north-west to Nainital in the south-east (Bhargava, 1979). In the Nainital syncline, the southeastern part of the Krol belt, well-exposed Baliana-Krol-Tal groups of rocks are present (Figs. 1 and 2). The Baliana Group is represented by the Blaini and Infrakrol formations. Earlier workers included the Infrakrol within the Blaini Formation (Auden, 1934; Bhattacharya and Niyogi, 1971; Fuchs and Sinha, 1974; Kumar, 1984; Rupke, 1974; Valdiya, 1980). Later on Shanker et al. (1993) grouped the Blaini and Infrakrol formations into the Baliana Group, after the type area in the Baliana nala section of Himachal Pradesh. The Blaini Formation consists of a lower diamictite at the base and an upper diamictite with limestone at the top; its middle part comprises alternating sandstone and shale (Brookfield, 1987). The diamictite consists of pebble and boulder-sized clasts of wacke, slates, phyllites, sandstones, shales and limestone set in a grey, carbonaceous pelitic matrix. The diamictite beds bear striations and abrasion marks and at a few localities contain distinct glacial fabrics of elongated clasts (Jain, 1981). Above the diamictites lies a few meter thick pink carbonate ($\sim$5–15 m thick) consisting of thinly laminated iron rich muddy dolomite, interbedded with thin shale in the upper part. This pink carbonate is conformably overlain by the Infrakrol Formation ($\sim$120–200 m thick) that includes siltstone and bleached shale, dark black carbonaceous shale with chert nodules in its upper part. The chert nodules are wrapped around by the carbonaceous shale layers (Fig. 3). A few lensoid patches of carbonates are also seen in some sections. The Infrakrol Formation is overlain by the Mahi (designated as Krol A), Jarashi (Krol B) and Kauriyala (Krol C, D, E) formations (900–1200 m thick) of the Krol Group. The Mahi/Krol A Formation consists of carbonaceous shale at the base, with calcareous limestone and minor gypsum in some places which is overlain by the Jarashi/Krol B Formation comprising red and ferruginous shale interbedded with biohermal stromatolitic dolomite. The overlying Kauriyala/Krol C, D, E Formation includes massive dark grey and blue dolomite, rhythmic alterations of thinly bedded black shale with marl and carbonaceous and cherty dolomite (Shanker et al., 1993; Valdiya, 1980). It is succeeded by the carbonaceous shale and chert-phosphorite of the lower Tal