# The Ediacaran Period: A New Addition to the Geologic Time Scale

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Submitted on Behalf of the Terminal Proterozoic Subcommission of the International Commission on Stratigraphy

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## Introduction

In *The Origin of Species*, Charles Darwin (1859) explained the apparently sudden appearance of complex animals in Cambrian rocks as the stratigraphic product of massive record failure. Charles Doolittle Walcott (1914) later formalized this view, defining the Lipalian Interval as the unrecorded period of time reflected in the unconformity between lowermost Cambrian strata and the (commonly deformed) rocks that lay beneath them. Although the Lipalian concept enjoyed early popularity, stratigraphers working in some parts of the world already knew that, regionally, Cambrian successions lay more or less conformably atop well preserved sedimentary successions, some of them thousands of meters thick. Regional characterizations (and names) of immediately sub-Cambrian strata proliferated. By 1960, however, Termier and Termier could speak in terms of a global "Ediacarien" interval that not only recorded immediately pre-Cambrian time, but contained simple animal fossils, as envisioned by Darwin.

Already in 1952, Boris Sokolov had proposed the name Vendian for a discrete system of siliciclastic rocks underlying Lower Cambrian strata on the Russian Platform and in the Ural Mountains. Initially restricted to rocks deposited during and after the Redkino transgression, Sokolov later expanded the Vendian System to include the Laplandian glacial level, best known from Uralian exposures (summarized in Sokolov, 1984, 1997). By the 1960s, both continental glaciation (Harland and Rudwick, 1964) and Ediacaran fossils (Glaessner, 1966) were known to occur globally, and both loomed large in attempts to understand regional and global correlations. With these in mind, Harland and Herod (1975; Harland et al., 1990) proposed the Ediacaran as an epoch within the Vendian Period. Cloud and Glaessner (1982), in turn, proposed that the Ediacarian (note spelling) be recognized as a period, its beginning marked by the base of the cap carbonate that overlies Marinoan diamictites in South Australia. Jenkins (1981) had earlier proposed an etymologically similar but conceptually distinct Ediacaran Period, its base placed somewhat higher, near the first appearance of Ediacaran fossils in South Australian sections.

In 1991, in a radical departure from Phanerozoic convention, the International Commission on Stratigraphy ratified a series of Proterozoic periods based strictly on geochronometric subdivision of the eon (Plumb, 1991). Three eras and eight periods were defined, but the terminal Proterozoic period – the time interval immediately prior to the Cambrian – was left for later definition and characterization in the thought that this youngest Proterozoic time interval, at least, might combine geochronological and geochronometric criteria, thereby providing a conceptual join between Proterozoic and Phanerozoic time scales (e.g., Knoll, 2000). After more than a decade of research and debate (see below), the ICS Subcommission on the Terminal Proterozoic Period has voted to define the initial GSSP for the terminal Proterozoic period, herein named the Ediacaran Period, at the stratigraphic level originally proposed by Cloud and Glaessner.

***The new Ediacaran Period reflects the subcommission's identification of an initial GSSP that can be correlated with confidence throughout the world. But it does more than that. The Ediacaran Period encompasses a coherent (and remarkable) interval of Earth history. The period begins with the termination of the last great global glaciation of the Neoproterozoic Era, an extraordinary interval when continental glaciers reached sea level in tropical latitudes -- even the name of the preceding period, the Cryogenian, reflects the centrality of glaciation to the interval that bounds the Ediacaran from below. The end of the***

***period is marked by the initial GSSP of the Cambrian Period, again marking the beginning of a biologically distinct world characterized by diverse skeletal fossils of bilaterian animals. The beginning and the end of the Ediacaran Period are also marked by remarkable negative excursions in the carbon isotopic records, unusual biogeochemical events recognized globally in both carbonate rocks and sedimentary organic matter. And in between, we find the extraordinary fossils that give the period its name – the Ediacaran fossil assemblage known globally from terminal Proterozoic rocks (and either absent or of trivial ecological importance both earlier and later). As generations of stratigraphers have recognized, the Ediacaran is a distinctive period of time that is bounded above and below by equally distinctive intervals – the Ediacaran, thus, deserves formal recognition as a period, and it is fitting that its name reflects the central biological feature of the interval.***

## Issues and Opportunities

In recent years, the Phanerozoic time scale has been reformulated in terms of Global Stratotype Sections and Points that precisely define the beginnings of periods or other time intervals (e.g., Chlupac and Vacek, 2003). Accepted convention for boundary definition stresses the first appearances of animal fossils and frowns on GSSP placement at unconformities, where biostratigraphic ranges may be truncated.

Despite the preference for fossils in GSSP placement, it is widely recognized that carbon (and, less completely realized, sulfur and strontium) isotopic chemostratigraphy offers complementary tools for correlation, and even boundary definition, especially at the three great era bounding events of Phanerozoic history: the beginning of the Cambrian Period, the Permian-Triassic mass extinction, and mass extinction at the Cretaceous-Tertiary boundary. During these intervals of Earth-altering environmental perturbation, chemostratigraphy likely permits interbasinal correlations at least as precise as those offered by invertebrate fossils.

The tools for Proterozoic correlation also include fossils and chemostratigraphy (e.g., Knoll and Walter, 1992). Ediacaran animal fossils and acritarchs both provide excellent means of recognizing and characterizing terminal Proterozoic rocks. As bases for GSSP placement, however, their usefulness is limited -- known fossil occurrences are simply too sparse to support correlations that are accurate to within a million years or less.

GSSP definition for the terminal Proterozoic period (or any earlier period defined geochronologically) will necessarily rely on the physical and chemical records of major events in Earth history. Fortunately, Neoproterozoic time offers several events of the required magnitude -- the great ice ages that wracked the later Neoproterozoic world. Because these events were global in impact, and because they are associated with carbon isotopic excursions larger than any recorded in Phanerozoic rocks, the glaciations offer what are undoubtedly our best opportunities for the subdivision of Neoproterozoic time. Prominent unconformities are present at the base of many Neoproterozoic glacial units, particularly around the margins of sedimentary basins, in platform interiors, and at locations where ice was grounded on its substrate. Generally more subtle unconformities are observed locally also at the tops of these units, perhaps as a result of isostatic rebound following retreat of the ice. For these geochemical and stratigraphic reasons, a GSSP placement that reflects deglaciation maximizes confidence in correlation and minimizes the uncertainties commonly associated with unconformities.

Texturally unusual carbonate beds (cap carbonates) and extraordinary C-isotopic excursions provide universal signatures of ice age termination that are not only unambiguously recognizable, but also stratigraphic reflections of rapid, and according to some, even catastrophic deglaciation (Kennedy, 1996; Hoffman and Schrag, 2002; Halverson, 2002). Thus, temporal uncertainties in the correlation of isotopic signatures in the cap carbonates above Marinoan glacial deposits are lower than those for any other known Proterozoic events. Indeed, it is likely that they allow time resolution of much less than one million years, similar to or better than the temporal resolution that any reasonable understanding of biology permits us to place on the fossil-based GSSPs of Paleozoic periods.

The number and correlation of Neoproterozoic glacial intervals has been a subject of debate (e.g., Kaufman et al., 1997; Kennedy et al., 1998), but recent progress on radiometric dating and chemostratigraphy now suggests two truly global ice ages. Uranium-lead zircon dates of 713 ± 1 Ma (Bowring et al., 2003), 709 ± 5 Ma (Fanning and Link, 2003) and 684 ± 4 Ma (Lund et al., 2003) on volcaniclastic sandstone, an ash bed and a rhyolite flow within glacial units, respectively, and 667 ± 5 Ma from an ash bed immediately above glacial rocks (Fanning and Link, 2003) constrain the time placement if not the full duration of Sturtian glaciation. Recent U-Pb dates of ca. 635 Ma (Bowring et al., 2003) and 663 ± 4 (Xiao et al., 2003), from ash beds within and beneath glacial strata, respectively, and a 599 ± 4 Ma Pb-Pb phosphorite whole rock age from stratigraphically above (Barfod et al., 2002) do the same for the Marinoan ice age. U-Pb dates also indicate later glaciation of regional extent (Bowring, et al., 2003).

Patterns of C-isotopic variation as well as the lithological features of cap carbonates serve to distinguish among glacial deposits of differing ages (Kennedy et al., 1998; Halverson, 2002). Thus, GSSP placement above a Marinoan diamictite-bearing unit in South Australia does not introduce intractable problems of correlation—quite the opposite. Records of Marinaon glaciation outside of Australia include the Nantuo Formation in China (Wang et al., 1981; Jiang et al., 2003a, 2003b), Laplandian deposits in Russia (Chumakov, 1990), the Ghaub Formation in Namibia (Hoffman et al., 1998; Kennedy et al., 1998), the Wilsonbreen Formation in Spitsbergen (Fairchild and Hambrey, 1995), at least the upper part of the Blaini Formation in India (Gupta and Kanwar, 1981; Kumar et al., 2000; Jiang et al., 2003b), and the Ice Brook Formation in northwestern Canada (Aitken, 1991; Narbonne and Aitken, 1995; James et al., 2001). In contrast, the Moelv (Nystuen, 1976; Knoll, 2000) and upper Varanger diamictites in Scandinavia and the Gaskiers Formation (Eyles and Eyles, 1989) in Newfoundland appear to record a younger, regional event centered on the peri-North Atlantic (Halverson, 2002); U-Pb dates on ash beds below, within, and above the Gaskiers Formation, indicate that this short-lived event took place about 580 million years ago (Bowring et al., 2003).

***Biostratigraphy***

The potential tools for correlation in terminal Proterozoic successions, thus, include biostratigraphy, chemostratigraphy, magnetostratigraphy, and event stratigraphy, especially high amplitude shifts in global climate. There is broad agreement that Ediacaran fossils provide compelling characterization of the terminal Proterozoic interval. Save for small discoidal structures of uncertain origin in northwestern Canada (Hofmann et al., 1990), Ediacaran-type megafossils are unknown in pre-Marinoan successions. Equally, only a few taxa of Ediacaran-grade organisms are known to have survived into the Cambrian Period. Diverse and structurally complex Ediacaran fossils have been discovered in some 25 localities and areas distributed globally, and the presence of diverse Ediacarans reliably indicates a terminal Proterozoic age (Fedonkin, 1990; Narbonne, 1998). On the other hand, 25 occurrences in 32 million years is a sparse stratigraphic distribution. Statistical methods are available to place error bars on first and last appearances of fossil taxa (e.g., Strauss and Sadler, 1989; Marshall, 1990), and applied even in general fashion to the Ediacaran fossil record, these indicate a stratigraphic uncertainty in the first appearance of diverse Ediacaran assemblages of many millions of years beyond their first documented occurrence 575 million years ago (Narbonne and Gehling, 2003; Bowring et al., 2003). Clearly, then, while Ediacaran fossils compellingly characterize the terminal Proterozoic Period, they do not provide sharp tools for initial GSSP definition.

Much the same can be said of other biostratigraphic indicators. The oldest unambiguous records of animal life are eggs, embryos and camerate tubes found in phosphorites of the Doushantuo Formation, China, that lie stratigraphically above Nantuo diamictites (Xiao and Knoll, 2000; Xiao et al., 2000); Barfod et al. (2002) obtained a Pb-Pb date of 599±4 million years for the fossiliferous beds. Trace fossils and calcified megafossils are widely distributed in younger rocks of terminal Proterozoic age, but have not been identified unequivocally in rocks older than 555 million years (Martin et al., 1999). While they may in time prove useful in the subdivision of the terminal Proterozoic Period, these remains do not help to define its beginning. Diverse assemblages of morphologically complex acritarchs are also known from older terminal Proterozoic rocks on several continents (Vidal, 1990; Jenkins et al., 1992; Zang and Walter, 1992; Zhang et al., 1998), and in Australia, at least, their stratigraphic distribution allows for the recognition of several assemblage zones (Grey, 1998; Grey, in press). But, once again, statistical evaluation of first appearances yields large error bars. Stromatolites, seaweeds, and prokaryotic microfossils all occur in terminal Proterozoic rocks, but none provides a high resolution guide to boundary definition. In summary, then, fossils provide an increasingly refined view of life just before the Cambrian explosion, and they suggest ways that the terminal Proterozoic period might be subdivided, but biostratigraphy does not provide a strong basis for boundary definition at present, and the prospect that it will do so in the future is small.

### *Chemostratigraphy*

The remarkable stratigraphic variation in C-isotopic compositions of Neoproterozoic carbonates and organic matter was first identified nearly two decades ago (Knoll et al., 1986), and since that time, numerous studies have refined our understanding of secular changes in the Neoproterozoic carbon cycle (for a recent summary, see Walter et al., 2000). In particular, the isotopic record of terminal Proterozoic carbonates is well-established (Kennedy, 1996; Kaufman et al., 1997; Halverson, 2002). It begins with $\delta^{13}C$ values of ca. +1 to -3‰ that decline upsection within post-Marinoan cap carbonates to values as low as -8‰ before beginning a climb to values as high as +8‰. In combination with unique carbonate depositional textures, barite deposition, and rising $^{87}Sr/^{86}Sr$, this C-isotopic pattern provides a unique geological signature of Marinoan deglaciation (Kennedy et al., 1998; Halverson, 2002; Jiang et al. 2003a). Even meter thick caps deposited at high latitudes contain the full range of C-isotopic variation documented in thick, low latitude sections, suggesting that the variable thicknesses of cap carbonates in different areas commonly reflect variations in depositional rate rather than a measurably later onset of precipitation (Porter et al., in press). Geochemical controls on post-glacial isotopic variation remain contentious (e.g., Grotzinger and Knoll, 1995; Hoffman and Schrag, 2002; Jiang et al., 2003a; Ridgwell et al., 2003), but all proposed explanations involve geologically rapid glacial decay. Given mixing times on the order of $10^3$ years for ocean water (Broecker and Peng, 1982), the large isotopic variations seen globally suggest a level of synchroneity that rivals the best available for Phanerozoic biostratigraphy.

## The Global Stratotype Point and Section for the Initial Boundary of the Ediacaran Period

### *Formal Statement of Name and GSSP Placement*

***We propose that the beginning of the terminal Proterozoic period be defined as the base of the Marinoan cap carbonate (Nuccaleena Formation) in the Enorama Creek section of the central Flinders Ranges, Adelaide Rift Complex, South Australia (Figs. 1-3). We further propose that this time interval be known as the Ediacaran Period, in recognition of its transcendent characteristic, the Ediacara Biota.***

The Nuccaleena is the lowermost division of the 3-km-thick terminal Proterozoic Wilpena Group in the Flinders Ranges (Fig. 2). It overlies a varied assemblage of glacial, glacial-marine and associated deposits assigned to the Elatina Formation (and correlative units) at the top of the Umberatana Group (Preiss, 1987). The entire section, more than 8 km thick, from Sturtian glacial deposits in the lower part of the Umberatana Group, to the base of the Cambrian (top of the Wilpena Group), is exposed in a single west-dipping homocline, encompassing the Enorama Creek locality (Figs. 1 and 3; Preiss, 1999; Reid and Preiss, 1999).

The main advantages of this section are clear paleontological, sedimentological and carbon isotopic context; expanded stratigraphic thickness; simple structure well known from both regional and local geological mapping; excellent exposure in semi-arid terrain; historical significance; and ease of access. In common with all of the prime candidates for a terminal Proterozoic GSSP, the main limitation of the Flinders Ranges is the absence of datable igneous rocks in the relevant portion of the stratigraphy. However, precise global correlation at the cap level using carbon isotopic data should eventually make it possible to constrain the age of the proposed GSSP. At present, the end of Marinoan glaciation is most closely constrained by a ca. 635 Ma U-Pb zircon age for an ash bed within glacial strata in Oman (Bowring et al., 2003). Post-glacial phosphorites in China have yielded a Pb-Pb age of 599 ± 4 Ma (Barfod et al., 2002), and a $^{40}Ar/^{39}Ar$ hornblende age of 580 ± 7 Ma dates a volcanic flow just above the Marinoan glacial level in the western U.S. (see Christie-Blick, 1997).

### *Detailed Description of GSSP*

The cap carbonate at the base of the Nuccaleena Formation is well exposed and easily recognized throughout the Flinders Ranges. From a practical point of view, it makes little difference which section is selected for a stratotype. Among the best candidates are Chambers Gorge, Trezona Bore and Enorama Creek.

The most spectacular exposures of the cap carbonate are those at Chambers Gorge on the eastern side of the Flinders Ranges (COPLEY 1:250,000 map sheet). Trezona Bore and Enorama Creek on the western flank of the ranges (PARACHILNA 1:250,000 map sheet; Reid and Preiss, 1999) have the advantages of a very simple structural setting, a full stratigraphic context, ease of access, and the protection afforded by a location within the Flinders Ranges

**Figure 1. Location map of the Enorama Creek locality (from Reid and Preiss, 1999), with insets showing an enlargement of the proposed GSSP site and location within a broader area of South Australia.**

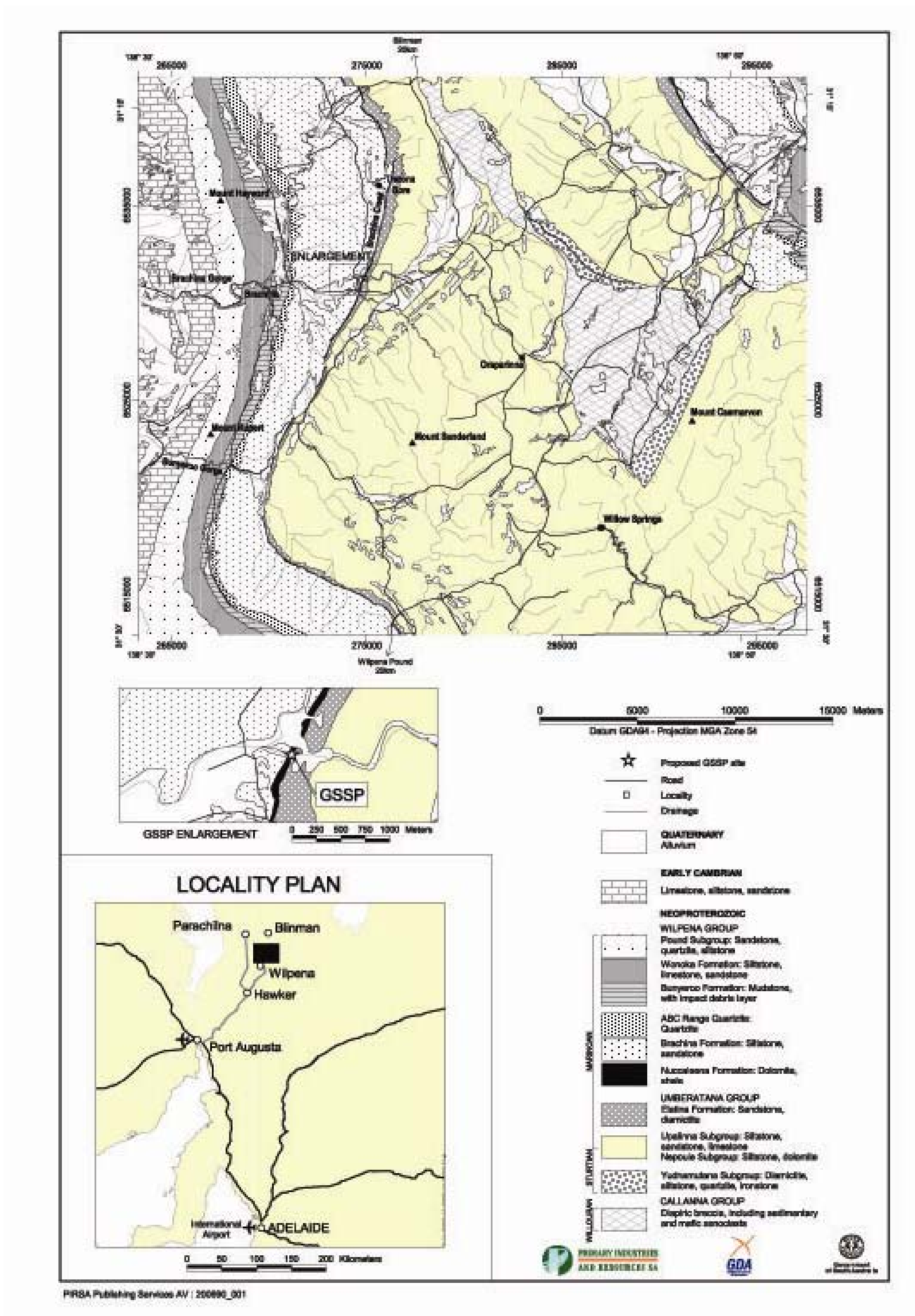


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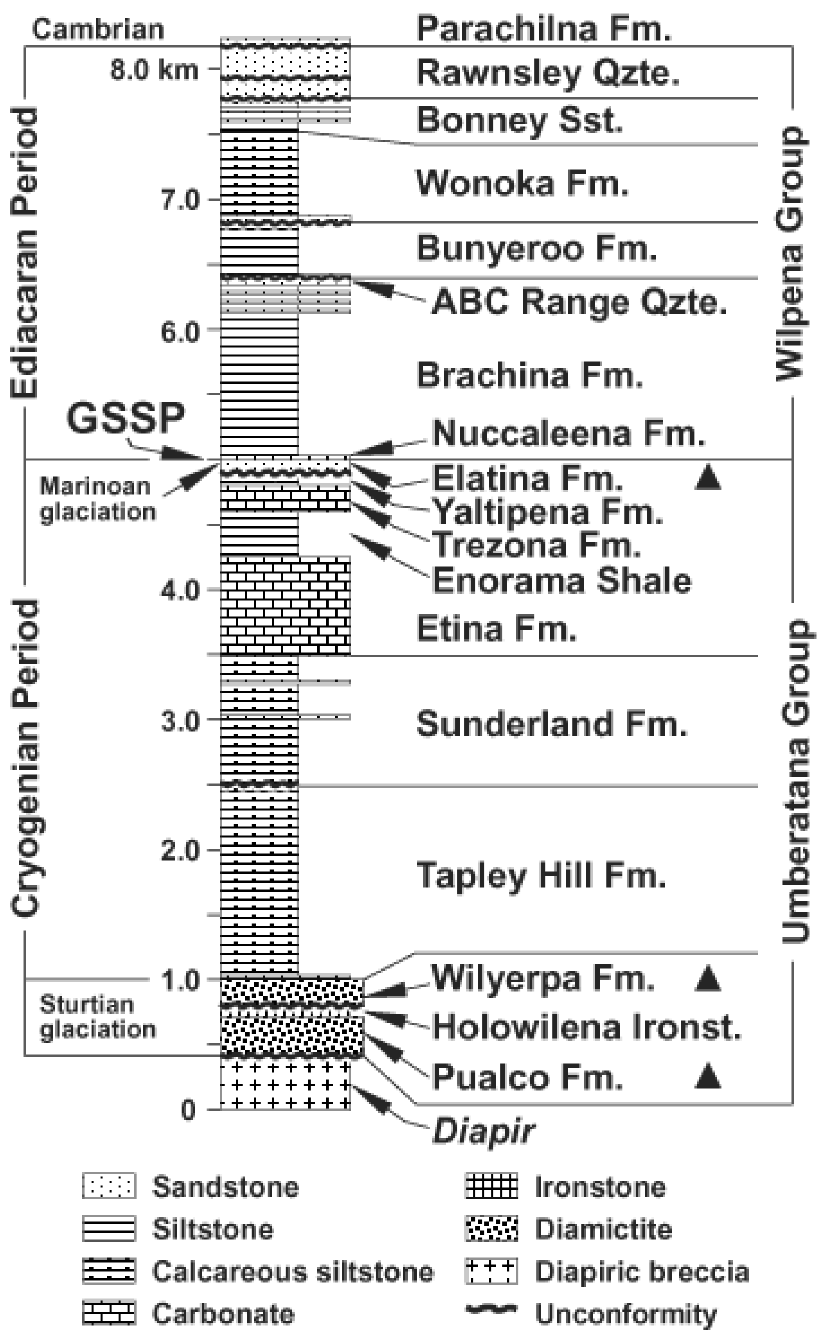
**Figure 2. Generalized stratigraphic section for the Umberatana and Wilpena groups of the central Flinders Ranges, South Australia, essentially as exposed in the homocline that contains the GSSP. Diagram indicates the stratigraphic placement of the GSSP within the broader upper Neoproterozoic stratigraphy of the region.**



National Park (Figs. 1 and 3). The west-dipping homocline of the west-central Flinders Ranges is dissected by both east-west and north-south valleys. Expanded sections of pre-glacial Trezona and Yaltipena formations, glacial Elatina Formation and post-glacial Brachina Formation are well exposed and documented in a salt-withdrawal syncline (Preiss, 1987; Lemon and Gostin, 1990; Christie-Blick et al., 1995; Lemon and Reid, 1998; Sohl et al., 1999; Sohl, 2000). The most favorable section overall at this stratigraphic level is a composite section in the vicinity of Trezona Bore, but the greater thickness of the cap carbonate and accessibility of the Enorama Creek locality by road lead us to designate that section as the GSSP (Fig. 3). The location, determined by stand-alone Global Positioning System, is Zone 54, 274825 ± 5 mE, 6531235 ± 5 mN (GDA 94), or 31° 19' 53.2" S, 138° 38' 0.2" E.

Access to Enorama Creek is by paved road from Adelaide, the closest city with an international airport, 400 km to the south, and by well-maintained unpaved roads within the Flinders Ranges National Park. It is less than a day's drive from Adelaide. The Flinders Ranges is a tourist region visited by tens of thousands of people every year. Motels, hotels, camping grounds and shops are available in several places. The tourist resort at Wilpena Pound provides a convenient local base.

### *Geological Location*

The Flinders Ranges are made up of rocks of the Neoproterozoic to Middle Cambrian Adelaide Rift Complex (formerly Adelaide Geosyncline). The geology of this region has been studied intensively for more than a century. Geological maps at 1:250,000 and 1:63,360 scale (Dalgarno et al., 1964; Dalgarno and Johnson, 1965, 1966) are currently available from the Geological Survey of South Australia (now Primary Industries and Resources South Australia) and elsewhere. The recently published second edition of the PARACHILNA 1:250,000 geological map (Reid and Preiss, 1999) with Explanatory Notes (Preiss, 1999) incorporates the area of the proposed GSSP. There is a large published literature on the region, including numerous monographs. This has recently been synthesized in a series of volumes (Preiss, 1987, 1990, 1993). Color aerial photographs and satellite imagery are readily available.

The Ediacara assemblage of fossils is generally regarded as the prime distinguishing characteristic of the terminal Proterozoic (no matter how such a unit might be defined). With the single possible exception of a dubious pennatulid-like fossil found 26 m below the base of the Nuccaleena Formation at Horrocks Pass near Wilmington (Dyson, 1985), subsequently regarded as inorganic (Jenkins, 1986), and the contentious structure *Bunyerichnus dalgarnoi* Glaessner low in the Wilpena Group (see Fig. 2 for stratigraphic units), all known examples of the Ediacara assemblage in South Australia have been described from the upper part of the Wilpena Group (Jenkins, 1995), with the best known members of the assemblage restricted to the Pound Subgroup in the upper part of the Wilpena Group.

Searches for pre-Marinoan metazoan fossils in this region and in central and northern Australia have a history extending to early in the 20th Century, and over the last 30-40 years in particular such searches have been repeated and intensive. No fossils have been found at these lower stratigraphic levels; nor have sedimentological studies conducted over the same period revealed any convincing reason why such fossils should go unpreserved. Thus it is reasonable to conclude that megascopic metazoans were rare or absent prior to the time of deposition of the Wilpena Group. Selection of a GSSP at or near the base of the Wilpena Group would therefore include in the terminal Proterozoic System all definite megascopic metazoan fossils known in

**Figure 3. Stratigraphic sections at Enorama Creek and Trezona Bore (5 km to north), with carbon isotopic profile for Enorama Creek (M.J. Kennedy, unpublished isotopic data). Note that the Nuccaleena Formation formally includes an interval of greyish red siltstone with thin beds of dolomite in the transition to the overlying Brachina Formation. A nearly complete composite section may be pieced together for the Neoproterozoic in this part of the Flinders Ranges, starting in the upper part of the Sturtian glacial succession.**

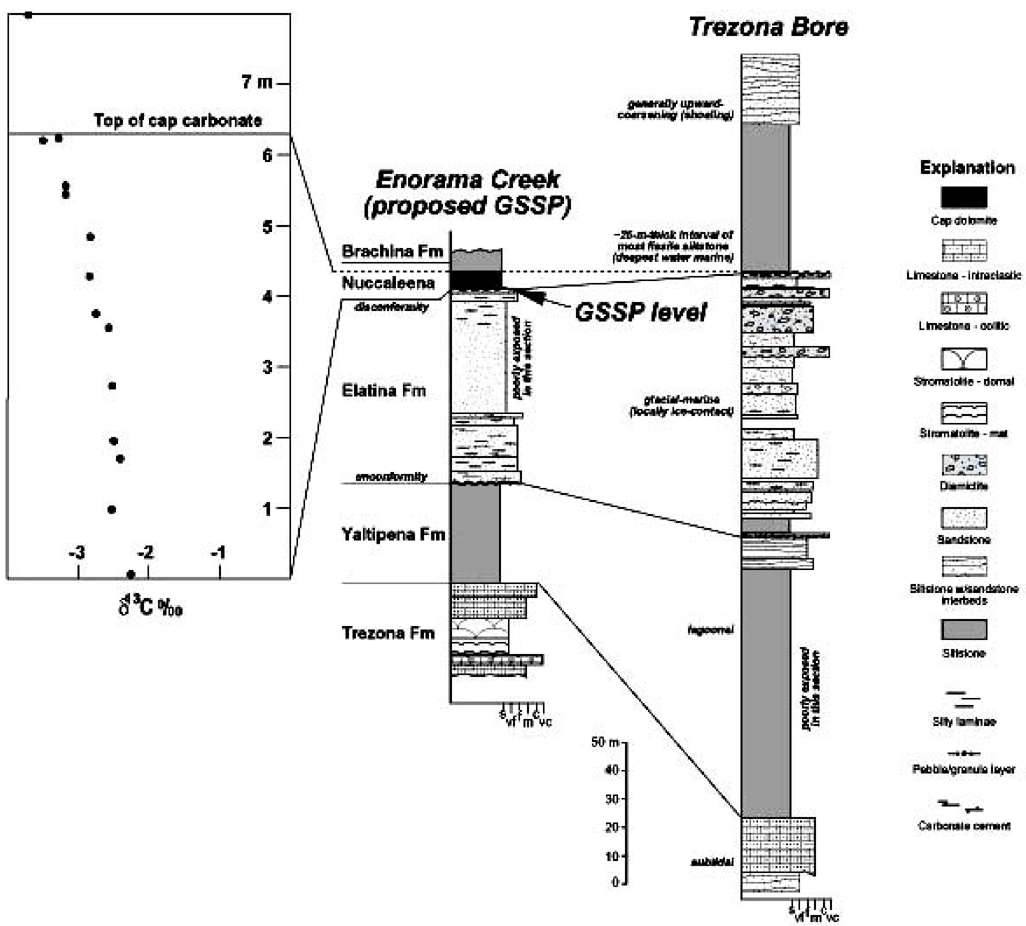


**Figure 4. Outcrop view of Enorama Creek section, showing the Nuccaleena cap carbonate overlying the uppermost diamictites. The right foot of the geologist stands on the top of the uppermost diamictite bed; his left foot rests on the top of the lowermost portion of the cap carbonate. The GSSP is at the base of the layer on which the left foot rests.**

Australia and all global occurrences of the Ediacara assemblage as conventionally recognized.

Also encompassed by such a definition of the terminal Proterozoic is the very distinctive acritarch assemblage of the Pertatataka Formation in the Amadeus Basin and correlative levels in the Officer Basin and on the Stuart Shelf of the Adelaide Rift Complex (Jenkins et al., 1992; Zang and Walter, 1992; Grey, 1998; Grey, in press; Grey et al., 2003). This assemblage includes some 50 taxa, mostly very large and many highly ornamented. It has not been recognized in the Flinders Ranges, partly because of deeper burial and thermal alteration of the sediments, but largely because of a lack of fresh drill core. The acritarch-bearing interval is considered to correspond with the Bunyeroo and Wonoka formations in the middle part of the Wilpena Group. Correlations with the Officer Basin are well established, especially at the level of the impact ejecta layer in the lower part of the Bunyeroo Formation, a distinctive deposit that has been linked to an impact structure at Lake Acraman in the Gawler Ranges west of the Flinders Ranges (Gostin et al., 1986; Williams, 1986; Wallace et al., 1989). Acritarchs have also

**Figure 5. Closer view of GSSP level within Enorama Creek section. GSSP level is at the base of the carbonate unit marked by the vertical pencil. (photo courtesy of T. Raub).**

been found in the preserved portion of this same interval on the intervening Stuart Shelf, where the rocks are undeformed and have never been deeply buried, and abundant drill core is available (Zang, 1997; Grey, 1998). Most, and perhaps all, convincing glaciogenic deposits known from the Flinders Ranges and correlative units elsewhere in Australia underlie the Wilpena Group and its equivalents. The well known Sturtian glacial deposits substantially pre-date the Wilpena Group (Preiss, 1987, 1990; Young and Gostin, 1991; Preiss, 1993), and the Marinoan glacial deposits immediately underlie it (Mawson, 1949; Preiss et al., 1978; Preiss, 1987, 1990, 1993; Lemon and Gostin, 1990).

The Marinoan Elatina Formation is of particular significance for yielding the most convincing evidence to date for continental glaciation at low latitude (7.5° N. with error limits of 1.0° to 14.5° N.; Schmidt and Williams, 1995; Sohl et al., 1999). One of three key palaeomagnetic reference sections is located 5 km north of the proposed GSSP near Trezona Bore (Figs. 1 and 3).

The Marinoan is the last truly global glaciation of the Neoproterozoic, and as such marks a critical boundary in Earth evolution. DiBona (1991) reported diamictite and lonestones in laminated siltstone in the upper part of the Wilpena Group of the northern Flinders Ranges, and inferred that they might be of glacial origin. However, the restricted distribution of these deposits and their sediment gravity flow association cast doubt on the glacial interpretation. Grey and Corkeron (1998) proposed that the youngest glaciation in the Kimberley region of northwestern Australia could be post-Marinoan, on the basis of correlation using the distinctive stromatolite *Tungussia julia.* This correlation, however, requires testing.

The Marinoan cap carbonate is a distinctive stratigraphic unit located at the base of the Nuccaleena Formation and locally within the correlative Seacliff Sandstone. It is well exposed and readily mapped in the Flinders Ranges over many hundreds of square kilometers. The carbonate is typically no more than a few meters thick and is composed primarily of finely laminated cream and pink microspar and dolomicrite (Plummer, 1979; Williams, 1979; Preiss, 1987, 1990, 1993; Lemon and Gostin, 1990; Dyson, 1992; Kennedy, 1996; Calver, 2000). The most common facies consists of normally graded event layers (turbidites), in places arranged into constructional meter-scale tepee-shaped structures aligned parallel with paleocurrents. Less common, but found widely within the Nuccaleena and cap carbonates in general, are facies characterized by abundant sheet cracks, bedding disruption, brecciation, multiple generations of isopachous fringing cements and internal sediments, stromatolites, formerly aragonite and barite crystal fans and tube-like structures – features that have been attributed recently to the development of cold methane seeps at the cap level (Kennedy et al., 2001b; see also Jiang et al., 2003a). In contrast to early interpretations of the carbonate as locally peritidal (Plummer, 1979), the Nuccaleena is now thought to have accumulated in many tens to perhaps hundreds of meters of water. Shallow-water indicators are absent. The lower contact of the Nuccaleena is a disconformity tentatively attributed to post-glacial isostatic rebound (Christie-Blick et al., 1995). The carbonate is interpreted to represent a short-lived chemical oceanographic event accompanying Marinoan deglaciation and sea-level rise, and to be of global extent. This interpretation, foreshadowed by the work of R.P. Coats (Geological Survey of South Australia) in the 1960s and 1970s (Preiss et al., 1978; Coats and Preiss, 1980), is now supported by the recognition in the cap carbonate of a very distinctive carbon isotopic signature, with $\delta^{13}C$ values that decrease upwards from close to 0‰ at the base to values of –5‰ or lower (Kennedy, 1996; Calver, 2000; Walter et al., 2000; McKirdy et al., 2001). The emerging picture of cap carbonates as high-resolution global markers (Preiss et al., 1978; Williams, 1979; Coats and Preiss, 1980, 1987; Knoll et al., 1986; Kaufman et al., 1993, 1997; Narbonne et al., 1994; Grotzinger and Knoll, 1995; Narbonne and Aitken, 1995; Kennedy, 1996; Hoffman et al., 1998; Kennedy et al., 1998, 2001a,b; Calver, 2000; Calver and Walter, 2000; Walter et al., 2000) makes the Marinoan cap extremely attractive for defining a GSSP.

Although carbonate rocks are only locally developed within the Umberatana and Wilpena groups of the Flinders Ranges below and above the Marinoan cap level, the carbon isotopic systematics of these units have been studied independently by at least three different research groups over the past decade, and are now well known (see summaries by Calver, 2000; Walter et al., 2000; McKirdy et al., 2001; and the discussion by M.J. Kennedy in 12th Circular, 1999).

### *Stratigraphic Level of GSSP*

If the cap carbonate represents in the order of $10^3$ to $10^4$ years, as some have suggested (Kennedy and Christie-Blick, 1998; Kennedy et al., 2001b), at the age resolution usually achievable in Proterozoic rocks the precise level selected within the cap is of little consequence. We now advocate the base of the Nuccaleena Formation (Fig. 3), as suggested by Cloud and Glaessner (1982) and Christie-Blick et al. (1995), for the following reasons. 1) The base of the Nuccaleena is a well-defined surface, and easily recognized throughout the Flinders Ranges. If related to glacial-isostatic rebound, the associated hiatus is likely to be limited in most places compared, for example, with the erosion surface beneath the Marinoan glacial rocks, because deglaciation was clearly associated with a marked rise in sea level. In most places, the glacial-eustatic rise rapidly overcame the local stratigraphic signature of the retreating ice sheet, as might be expected for a site at low palaeolatitude. 2) The lateral variability of absolute $\delta^{13}C$ values in the cap carbonate is sufficiently great to cast doubt on whether nuances in isotopic data can be used objectively to establish time relations within the carbonate, although, globally, most sections preserve a record of comparable *stratigraphic trends* in secular variation. Although $\delta^{13}C$ values attain a minimum near the top of the cap carbonate in those sections elsewhere in which carbonate rocks persist up section above the cap level (e.g., northern Namibia and southern China), that minimum tends to be stratigraphically broad (tens of meters), and not useful for precise correlation. 3) The cap carbonate is thought to represent a chemical oceanographic event, and not simply a sea-level rise. There is no reason for regarding an interval of maximum flooding (deepest water) within shales above the cap to have more than regional temporal significance. Nor is it possible to locate any particular distinctive horizon within that interval more objectively than the base of the carbonate.

Taken together, these considerations suggest the base of the Nuccaleena as the level with greatest potential for global correlation. However, a conceptual issue arises with the selection of a disconformity. Would the GSSP correspond in time with the base of the cap carbonate, with the top of the underlying glaciogenic Elatina Formation, or with some point within the span of time not represented at the site selected? The most practical solution is to regard the GSSP as marking the *onset* of cap carbonate deposition. That is undoubtedly slightly younger than the age of the genetically correlative conformity of the disconformity (Christie-Blick, 2001), but it is the criterion of greatest practical utility.

### *Provisions for Conservation, Protection, and Accessibility*

The proposed GSSP is located within the Finders Ranges National Park and so has special legal protection. The Parks and Wildlife Service of South Australia administers the park and provides rangers to enforce conservation measures. Permission must be obtained for rock and fossil sampling. If our proposal is ratified we will seek advice from the Park Service on extra conservation measures including access and signposting. Current access is by a well-maintained unsealed road that passes within 100 m of the GSSP.

### *Principal Correlation Events at the GSSP Level*

Three distinct but causally related events mark the initial GSSP of the Ediacaran Period. First is the rapid decay of Marinoan ice sheets, clearly observed locally but documented globally. Second is the onset of sedimentologically, texturally, and chemically distinct cap carbonates, again recorded clearly in the GSSP but observed throughout the world. And third is the beginning of the distinctive pattern of secular change in carbon isotopes recorded in the cap carbonates, like the other events documented globally.

***Demonstration of Regional and Global Correlation***

The level of the GSSP is recognizable throughout the central and northern Flinders Ranges of South Australia as the base of the Nuccaleena cap carbonate (Preiss, 1987). In the southern Flinders Ranges and Mount Lofty Ranges near Adelaide, the Nuccaleena passes laterally into the Seacliff Sandstone and correlative strata, which are thought locally to occupy incised valleys cut into the underlying glacial deposits (Dyson and von der Borch, 1994; Christie-Blick et al., 1995). In those sections, according to the way in which the GSSP is defined above, the base of the Ediacaran System corresponds approximately with the lowest dolomite, typically no more than a few meters to tens of meters below the top of the Seacliff Sandstone. In the Amadeus basin of central Australia, the level of the GSSP corresponds with the base of the cap carbonate at the top of the glaciogenic Olympic Formation (Preiss et al., 1978; Kennedy, 1996), and where the cap is missing, approximately with the base of the Pertatataka Formation (marine siltstone comparable to the Brachina Formation in the Flinders Ranges). In the eastern Amadeus Basin, where the Olympic Formation intertongues lithically with the Gaylad Sandstone (Field, 1991; Freeman et al., 1991), the cap carbonate is cut out by an unconformity that traces laterally into the Gaylad. This same stratigraphic level corresponds in the Ngalia basin of central Australia with the cap carbonate in Mount Doreen Formation. Correlation with the Kimberley region of northwestern Australia is currently unresolved (Grey and Corkeron, 1998).

A decade of intensive research on the cap carbonates that lie above Neoproterozoic glacial deposits has revealed consistent patterns of sedimentology, petrology and geochemistry that serve to unite caps of similar age and separate caps related to the Sturtian, Marinoan and Moelv/Gaskiers ice ages (Kennedy et al., 1998; Halverson, 2002). Marinoan-age glacial deposits lie above older Neoproterozoic successions characterized by distinctive microfossils (Knoll, 2000), carbonate C-isotope compositions that change stratigraphically from unusually positive values (to +10‰) to negative values (-5 to -7‰) just beneath the diamictites (Hoffman and Schrag, 2002; Halverson, 2002), and relatively low $^{87}Sr/^{86}Sr$ (Kaufman et al., 1993). Strata above Marinoan-age glacial deposits contain different, but equally distinctive microfossils (Knoll, 2000), all known diverse Ediacaran macrofossil assemblages (Narbonne, 1998), distinctive C-isotopic profiles (Kaufman et al., 1997; Walter et al., 2000), and much higher $^{87}Sr/^{86}Sr$ (Kaufman et al., 1993). Cap carbonates associated with Marinoan-age glacial deposits characteristically have C-isotopic profiles that decline upsection from their base; an upsection transition from pinkish dolomites to limestones, with barite deposits at the transition between lithologies; unusual sedimentary features that include peloidal laminae, "pseudo-tepees" interpreted by some as aggradational oscillation megaripples, and macroscopic crystalline precipitates (Kennedy, 1996; James et al., 2001; Hoffman and Schrag, 2002). Caps associated with Sturtian glacial deposits do not exhibit these features, nor do caps (where present) above younger glacial deposits such as the Gaskiers Formation in Newfoundland (Kennedy et al., 1998; Myrow and Kaufman, 1999).

With these features in mind, the Ediacaran Period can be recognized beyond Australia as follows (see Fig. 6 and references cited therein): (1) the cap carbonate above the Nantuo Formation and the succeeding Doushantuo and Dengying formations up to the point of the previously recognized base of the Cambrian, (2) the cap carbonate at the top of the Blaini

Formation and the succeeding Infra Krol Formation and Krol Group up to the previously recognized base of the Cambrian in subhimalayan India, (3) the Yudoma Group in Siberia and the Vendian succession in the Ukraine, both of which begin with transgression within the Ediacaran Period, (4) the cap carbonate above the Ghaub Formation in Namibia, succeeding strata of the Tsumeb Subgroup and the Witvlei and Nama groups, up to the previously recognized unconformity marking the base of the Cambrian, (5) the cap carbonate above the Wilsonbreen Formation in Svalbard and its correlatives in East Greenland and succeeding strata beneath the sub-Cambrian disconformity, (6) the cap carbonate above the Ice Brook Formation in northwestern Canada and succeeding strata of the upper Windermere Subgroup, up to the previously recognized beginning of the Cambrian Period, (7) the Avalon succession in Newfoundland, from the angular unconformity at the base of the Conception Group to the previously recognized base of the Cambrian, and (8) the cap carbonate above the Smalfjord Formation in northern Norway and overlying strata up to the beginning of the Cambrian.

### *Age of the GSSP*

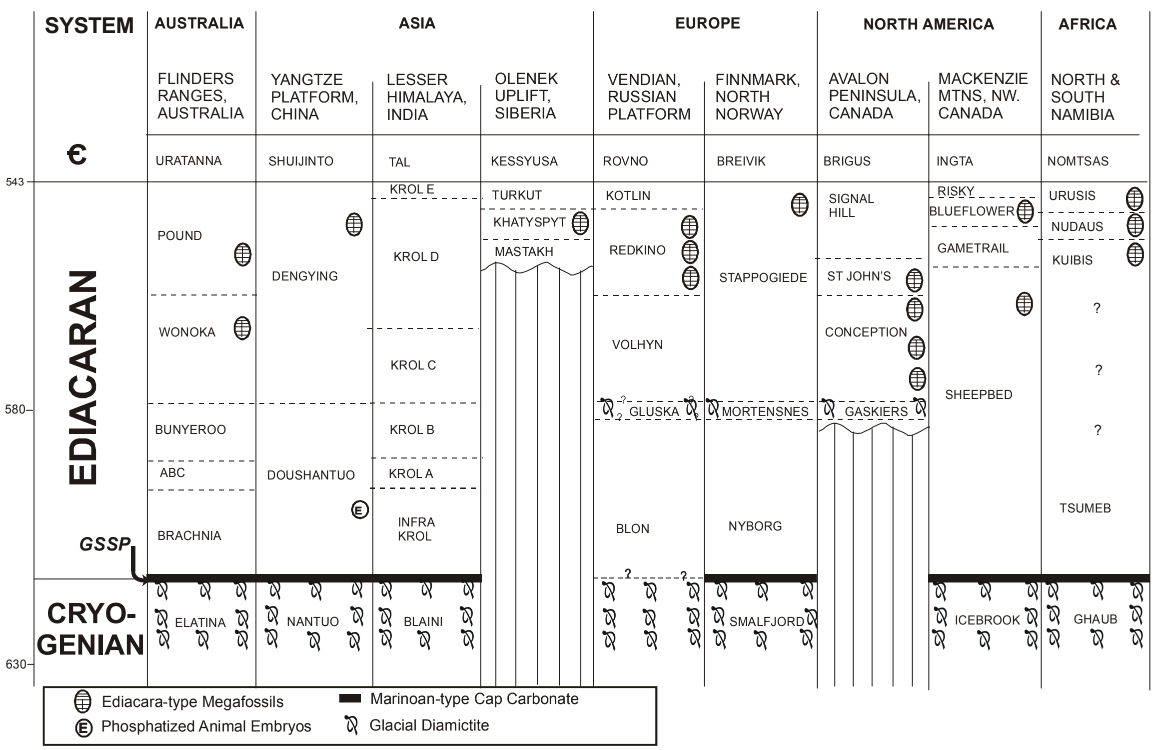
Datable igneous rocks have not been identified in the terminal Proterozoic succession of the Flinders Ranges. Attempts have been made to employ Rb/Sr systematics on fine-grained siliciclastic rocks from the adjacent Stuart Shelf, but the results are associated with large errors and are in any case likely to reflect maximum ages of deposition owing to the presence of detrital minerals. Shale dates from the deformed rocks of the Flinders Ranges generally reflect the 526-480 Ma Delamerian Orogeny (Chen and Liu, 1996; Flöttmann et al., 1998). Probable ash beds in the Bunyeroo Formation have not yielded zircons (S.A. Bowring and V. Gostin, personal communication). As noted above, however, recent dating in Oman and southern China suggest an age for the GSSP younger than 635 Ma, but older than 600 Ma.

### *The Name of the Period*

Termier and Termier (1960) proposed the name l'Ediacarien for the earliest stage of animal evolution, but no stratotype was defined. Many authors followed this usage. Cloud and Glaessner (1982) defined the Ediacarian as a system and period. Like Jenkins' (1981) definition of the Ediacaran, their proposed stratotype of the Ediacarian is located in Bunyeroo Gorge in the central Flinders Ranges, approximately 10 km south-southwest of the currently proposed Enorama Creek locality. The Ediacarian of Cloud and Glaessner encompasses the entire Wilpena Group, consistent with our proposed terminal Proterozoic GSSP, whereas Jenkins' Ediacaran was and is represented by only the upper part of the Wilpena Group. Our proposal can be seen as an extension of the Termier and Termier concept of 1960, and a refinement of that of Cloud and Glaessner (1982). However, we have adopted the name Ediacaran, believing this to be the etymologically correct form.

The name "Idiyakra" or "Ediacara" is Australian Aboriginal in origin and can be traced back to 1859 or a little earlier, when the first white pastoralists took up lands in the far north western Flinders Ranges. Its etymology links it to a place where water is or was present close by or about, either in the sense of the present or extending distantly into past wetter times. As water is synonymous with life in the harsh, arid lands of Australia, it is a fitting name for a time when the first megascopic marine animals evolved. As the records of early surveyors and State Parliamentary records show, the ending of the name sounded as a "kra", "ker" or "ka", and hence

**Figure 6. Correlation of GSSP with other terminal Proterozoic successions, showing the relationship of the proposed Ediacaran period to regional stratigraphic units. "Cambrian" refers to the lowest Cambrian unit overlying the Ediacaran. Sections and correlations from the following sources and references therein: Australia (this report); Yangtze Platform and Lesser Himalaya (Jiang et al., 2003b); Olenek Uplift (Knoll et al., 1995); Vendian type area and Finnmark (Chumakov, 1990; Fedonkin, 1990; Sokolov, 1997; Martin et al., 2000); Avalon Peninsula (Narbonne and Gehling, 2003; Bowring et al., 2003); Mackenzie Mountains (Narbonne and Aitken, 1995); Namibia north (Hoffman et al., 1998) and south (Grotzinger et al., 1995). See these papers, as well, for the positions of unconformities within these successions.**



the appropriate name of the Period is "Ediacaran" (quoted from R. J. F Jenkins, unpublished note, 2003).

The Flinders Ranges region has come to be regarded as the type area for the Ediacara Biota, despite the fact that elements of it were first recognized in 1872 in Newfoundland by E. Billings, and later in Namibia (see Gehling et al., 2000). Sprigg (1947) contributed the first of a long series of publications about the biota from Australia after his discovery of metazoan impressions in the Ediacara Hills, just to the west of the Flinders Ranges

## The Process of GSSP Selection

The ICS Working Group on the Terminal Proterozoic Period (now Subcommission) was established at the IGC in Washington in 1989. Over the succeeding decade and a half, the Terminal Proterozoic Working Group/Subcommission formally visited terminal Neoproterozoic sections in Ukraine (1990), the Yangtze Platform (1992), Flinders Ranges (1993 and 1998), central Australia, (1993), Finnmark (1994), Lesser Himalaya (1994), Namibia (1995), and Newfoundland (2001), with additional visits by smaller groups to the White Sea (1995) and the Ural Mountains (1996). The Mackenzie Mountains of northwestern Canada and the Olenek Uplift of Siberia contain outstanding records described by some of the members of the Terminal Proterozoic Period Working Group/Subcommission, but both were regarded as too remote for field trips and consequently neither was nominated as a potential GSSP. Formal meetings of the WG/Subcommission were also held at the IGC in Kyoto (1992) and Beijing (1996). During part of this period, additional investigations and funding were made possible by IGCP Project 320: Neoproterozoic Events and Resources (led by Nick Christie-Blick, M.A. Fedonkin, and M.A. Semikhatov). A special issue of *Precambrian Research* edited by Andrew Knoll and Malcolm Walter in 1995 summarized stratigraphic understanding of important successions and techniques, and additional stratigraphic information and reports on all the field excursions have been distributed in seventeen circulars (newsletters) to the more than 150 voting and corresponding members of the Working Group/Subcommission worldwide. A second issue of *Precambrian Research*, edited by Malcolm Walter in 2000, provided further information on the Neoproterozoic stratigraphy of Australia, including the Flinders Ranges. The list of voting members currently comprises 20 scientists living in 10 different countries on five continents.

After a decade of discussion and field excursions to the principal sites worldwide, a series of increasingly focused ballots were conducted in accordance with ICS regulations. Voter response was excellent, with a participation rate in excess of 90% of voting members for each of the three ballots and a 100% return rate for the 3$^{rd}$ (final) ballot. This speaks highly of the interest and dedication of the voting members, and of the scale of the mandate expressed in the three ballots. Results of the three ballots are reproduced in Appendix 1 and are summarized below.

***Ballot 1*** (December 2000) assessed whether the GSSP of the terminal Proterozoic period should be placed at the base of the Varanger (Marinoan) glacial deposits, at the cap carbonate atop these deposits, at a biostratigraphic level (the first appearance of diverse Ediacaran macrofossils), or at some other level. Level 2, **"the base of, or a horizon within the cap carbonate interval immediately above Varanger (or, Marinoan) glacial beds"**, was selected by 80% of the voting members (89% of ballots cast on the question). This is a clear majority under ICS regulations.

Following this, all voting and corresponding members of the Subcommission were invited to submit formal proposals for the location of a GSSP. Four proposals were received: two for sections in the Flinders Ranges in Australia, one for the Yangtze Gorges in China, and one for Lesser Himalaya in India, and all four were published in the 15th TPS Circular. All of these sites had been examined in official visits by the WG/Subcommission, and their attributes had been discussed in previous TPP Circulars.

***Ballot 2*** (March 2003) revealed at least modest support for all of these options, but the greatest support was for the **"Enorama Creek Section, Flinders Ranges, South Australia"**, which garnered 63% of votes cast. This is a valid majority under ICS regulations, and this led directly to a 3rd Ballot on this one locality and on the name for the new system and period.

***Ballot 3*** (September 2003) asked members to vote "yes" or "no" on the acceptability of the base of the Nuccaleena Formation in the Enorama Creek section as the GSSP for the Terminal Proterozoic Period and, in a separate question, to vote on their preference among the four names that had been proposed for the Terminal Proterozoic Period. The proposal to fix the position of the GSSP for the Terminal Proterozoic Period **"at the base of the Nuccaleena Formation cap carbonate, immediately above the Elatina diamictite in the Enorama Creek section, Flinders Ranges, South Australia"** received 89% of votes cast, a clear majority under ICS regulations. The name **"Ediacaran"** received 79% of votes cast, also a clear majority under ICS regulations. Voting Members who voted against or abstained on the votes for the GSSP proposal or the name were requested to submit a discussion of the reasons for their views, and the two responses received are reproduced in their entirety in Appendix 2.

***Other Candidates and Reasons for Rejection***

For more than 50 years, the "Vendian System" has been used to categorize the terminal Neoproterozoic of the East European Platform and elsewhere (Sokolov, 1952, 1984, 1997). These strata are largely undeformed and unmetamorphosed, contain world-renowned assemblages of the Ediacara biota, and have yielded some high-precision U-Pb dates. Despite repeated requests, no proposals were submitted for a "Vendian" GSSP on the East European Platform. It is difficult to identify a globally correlatable level in this succession that might define a GSSP consistent with the boundary concept approved by a strong majority in Ballot 1. Throughout the East European Platform (e.g. White Sea, Ukraine, and boreholes in the Moscow sineclise) and the Urals, the terminal Neoproterozoic succession consists primarily of siliciclastic rocks with few or no carbonates, and relatively little is known about the chemostratigraphy of these successions. The base of the Vendian, formally defined at the base of the "Laplandian Tillites," (e.g., Sokolov, 1998) is recognizable in surface exposures in Finnmark but in adjacent areas of the East European Platform occurs only in grabens preserved in the subsurface, and is therefore not characterized to the level of surface outcrops of Neoproterozoic glacial deposits elsewhere. Moreover, the concept of placing the terminal Proterozoic GSSP at "the base of the Varanger (or, Marinoan) glaciogenic succession" was overwhelmingly rejected by the voting members in the 1st Ballot (Appendix 1) on the grounds that it is extremely difficult to define when a global glaciation began based solely on physical aspects in an isolated section, that the level of first appearance of glacial deposits is wildly diachronous, that there is little biostratigraphic control on the age of onset of glaciation, and that a boundary defined at the base of the last of the Neoproterozoic global glaciations would be less significant in terms of Earth evolution than one that marks their end. Glacial deposits are not present beneath the fossiliferous outcrops of Ukraine, which nonconformably overlie crystalline basement covered with varying thicknesses of arkosic sediments and regolith, and are also not exposed in the White Sea area.

Proposals for locating the GSSP in south China and in the Lesser Himalaya, India, were considered carefully. Both regions are attractive for the wide distribution of terminal Proterozoic rocks, including the Marinoan glacial level and overlying cap carbonate, and in each example passing upward into a carbonate platform many hundreds of meters thick (Jiang et al., 2003a, 2003b). In both regions, a varied biota has been described from Ediacaran strata and the Proterozoic-Cambrian boundary is securely located. Carbon isotopic data have been acquired, and at high resolution through the cap level, which is locally well preserved in south China. Ediacaran megafossils, however, are rare in the Chinese sections, and there are serious questions about putative Ediacaran megafossils reported from India.

The proposed GSSP locations, in the vicinity of Yichang in China, and Dehradun, India, are relatively accessible by air and rail. The main shortcomings of these sections relate to the overall quality and continuity of exposure, particularly at the cap level. The rocks in the Lesser Himalaya are considerably more deformed than their counterparts in the Flinders Ranges. In neither area does the level of systematic geological mapping and availability of mapping match that in Australia. Marinoan glacial deposits beneath the level of the GSSP (the Nantuo Formation in China and the Blaini Formation in India) are not well documented, or recently studied.

The final candidate, the base of the Wearing Dolomite in the Flinders Ranges of Australia, is at an isotopic excursion below the first occurrence of Ediacara-type fossils in the section. This boundary is at a considerably higher stratigraphic level than was agreed to in the 1st Ballot (see Appendix 1). The relatively few occurrences of the Ediacara biota worldwide do not at present provide sufficient constraints to use the first appearance of Ediacaran fossils in a local section as a reliable biostratigraphic indicator, and the proposed boundary is difficult to categorize or correlate using other criteria.

## Conclusions

In conclusion, the ICS Subcommission on the Terminal Proterozoic Period recommends acceptance of the proposed initial GSSP for the newly defined Ediacaran Period, extending the geochronological time scale downward into the Proterozoic Eon. The proposed period encompasses a distinctive interval of Earth history that is bounded both above and below by equally distinctive intervals. Both chemostratigraphic and biostratigraphic data indicate that the subdivision of the period into two or more epochs is feasible, and this should be a primary objective of continuing work by the subcommission.

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## APPENDIX 1 – RESULTS OF THE BALLOTS

### IUGS SUBCOMMISION ON A TERMINAL PROTEROZOIC PERIOD
### First Ballot, December 2000

I **vote in favor of placing the initial GSSP of the terminal Proterozoic Period at a stratigraphic horizon characterized by:**

**__1__ the base of the Varanger (or, Marinoan) glaciogenic succession**
Brian Harland

**_16__ the base of, or a horizon within the cap carbonate interval immediately above Varanger (or, Marinoan) glacial beds (80% of voting members / 89% of votes cast)**
Nick Christie-Blick, Andrew Knoll, Malcolm Walter, Guy Narbonne, Hans Hofmann, Wolfgang Preiss, Anna Siedlecka, Janine Bertrand-Sarfati, Gerard Germs, Sun Weiguo, Martin Brasier, John Shergold, Ian Fairchild, Xing Yusheng, Gopendra Kumar, Laurence Robb

**__1__ the first appearance of diverse Ediacaran macrofossil assemblages. (1)**
Richard Jenkins

**__0__ Abstentions**

**__2__ Declined to vote**
Mikhail Semikhatov, Mikhail Fedonkin

**Vote scrutineer: Guy Narbonne, Secretary, IUGS Subcommission on the Terminal Proterozoic System**

## IUGS SUBCOMMISION ON A TERMINAL PROTEROZOIC PERIOD
## Second Ballot, March 2003

I vote to place the initial GSSP of the Terminal Proterozoic Period at the designated point in the following section:

__4__ **Tianjiayuanzi Section, eastern Yangtze Gorges region, Hubei, China**
Xing, Sun, Fedonkin, Semikhatov

__1__ **Maldeota Section, Mussoorie Syncline, Krol Belt, Lesser Himalaya, India**
Kumar

__12__ **Enorama Creek Section, Flinders Ranges, South Australia (60% of voting members, 63% of votes cast)**
Christie-Blick, Fairchild, Hofmann, Narbonne, Knoll, Walter, Preiss, Shergold, Robb, Harland, Germs, Brasier

__1__ **Wearing Dolomite Section, Flinders Ranges, South Australia**
Jenkins

__1__ **Abstentions**
Sarfati

__1__ **Did not vote**
Siedlecka

**Vote scrutineer: Guy Narbonne, Secretary, IUGS Subcommission on the Terminal Proterozoic System**

# I.U.G.S. SUBCOMMISSION ON THE TERMINAL PROTEROZOIC PERIOD
# Third Ballot, September 2003

**Question 1: The initial GSSP of the new, terminal Proterozoic period shall be placed at the base of the Nuccaleena Formation cap carbonate, immediately above the Elatina diamictite in the Enorama Creek section, Flinders Ranges, South Australia.**

**_16_ I approve (80% of voting members / 89% of votes cast)**
Janine Bertrand-Sarfati (France), Martin Brasier (UK), Nick Christie-Blick (USA), Ian Fairchild (UK), Gerard Germs (South Africa), Brian Harland (UK), Hans Hofmann (Canada), Richard Jenkins (Australia), Andy Knoll (USA), Gopendra Kumar (India), Guy Narbonne (Canada), Wolfgang Preiss (Australia), Laurence Robb (South Africa), John Shergold (Australia and France), Anna Siedlecka (Norway), Malcolm Walter (Australia)

**__2___ I disapprove**
Mikhail Fedonkin (Russia), Mikhail Semikhatov (Russia)

**__2__ Abstentions**
Sun Weiguo (China), Xing Yusheng (China)

**__0___ Did not vote**

**Question 2: The terminal Proterozoic Period shall be named the**:

**__15___ Ediacaran Period (75% of voting members / 79% of votes cast)**
Janine Bertrand-Sarfati (France), Martin Brasier (UK),Nick Christie-Blick (USA), Ian Fairchild (UK), Gerhard Germs (South Africa), Brian Harland (UK), Hans Hofmann (Canada), Richard Jenkins (Australia), Andy Knoll (USA), Gopendra Kumar (India), Guy Narbonne (Canada), Laurence Robb (South Africa), John Shergold (Australia and France), Anna Siedlecka (Norway), Malcolm Walter (Australia)

**__0___ Ediacarian Period**

**__2__ Sinian Period**
Sun Weiguo (China), Xing Yusheng (China)

**__2__ Vendian Period**
Mikhail Fedonkin (Russia), Mikhail Semikhatov (Russia)

**__1__ Abstentions**
Wolfgang Preiss (Australia)

**__0___ Did not vote**

**Vote scrutineer: Guy Narbonne, Secretary, IUGS Subcommission on the Terminal Proterozoic System**

# APPENDIX 2
# COMMENTS ON THE 3RD BALLOT DECISION

All voting members who voted against or abstained on the votes for the GSSP proposal or the name in the 3rd Ballot were invited to submit a discussion of the reasons for their views. Two responses were received, and are reproduced in their entirety here.

**COMMENTS BY B. S. SOKOLOV, M. A. SEMIKHATOV, AND M. A. FEDONKIN**

Congratulations with the final votes and the result of the Subcomission activity. We respect both the IGCP procedure and the opinions of the voting members of our Subcomission concerning the GSSP of the lower boundary of the Terminal Proterozoic System and the name of the latter. At the same time we understand that majority of the votes reflects in a great extent the personal composition of the Subcomission, national (geographic) representation of the voting members, their educational background, professional experience, and the result may have little in common with the basic principle of the scientific tradition and rationality.

Let us express our thoughts on what's on and where to go in the nearest future.

First, we have to admit our disappointment with the decision to recommend the Ediacaran as a name for the TPS. This decision ignores both the priority of the name Vendian and a long tradition to use this term in the international geological literature; our colleagues mentioned both aspects in the previous circular. The Vendian Period and Geological System, like no other candidate for the TPS, was theoretically substantiated and formally defined in a number of the papers since the first publications on the Vendian by B.S.Sokolov in 1950 as well as in the later comprehensive articles and monographs which have been published both in Russian and in English. Major contribution has been done by the specialists of the Russian geological school who have collected enormous material from both siliciclastic and carbonate paleobasins of the late Proterozoic age over the vast territory of the former USSR and globally. In addition to the regional geological and paleobiological data, stratigraphic subdivisions at the stage rank were substantiated within the Vendian. Recent achievements in the study of the stratigraphic distribution of the microfossils, megascopic algae, metazoan body and trace fossils in the sections of the East-European platform and Siberia (as well as Ukraine) open the way towards more detailed biostratigraphic division of the TPS. Will all that experience be claimed in the further activity of the Subcomission?

The name Ediacaran is somehow associated with the Ediacara Fauna, which is a rather taphonomic term similar to the Burgess Shale Fauna. The major problem is that the metazoan fossils occur in a very small topmost part of the type section of the Ediacaran while the most portion of the TPS section below has very poor paleontological characteristics or it is being non-fossiliferous.

Choice of the Ediacaran in fact means that valuable geological and paleobiological data collected and synthesized for the substantiation of the Vendian as a TPS will be ignored in a great extent because these data and approaches can not be of use in the paleontologically poor section of the Ediacaran in its type area. By the way, let us to remind that the age of the Ediacara member itself was not clear at the beginning and it has been proved to be Precambrian by B.S. Sokolov after identification of the Ediacara-type fauna in the Precambrian (Vendian) successions in Russia.

One can say that the Vendian has a slightly different time range compared to the Ediacaran but this is a weak argument (and no reason!) to discriminate the Vendian. Choice of the global standard of the Precambrian/Cambrian boundary on the NFL has changed the stratigraphic range of the Cambrian but this was not a reason to reconsider the name of the Cambrian. By the way, we see much in common between the two cases – choice of the GSSP for the lower boundary of the Cambrian on the Newfoundland and GSSP of the TPS lower boundary in South Australia. Choice of the Global standard of the lower boundary of the Cambrian on the Newfoundland was a Pyrric victory of those who voted for it – precision of the stratigraphic correlation with the trace fossils is much lower that with the body fossils (SSF, microfossils). This choice does not correspond to the Montreal IGC recommendation of the biological principle in the boundary substantiation. It was bold but wrong decision, which causes severe harm to classical and reliable biostratigraphy of the Cambrian, the fact admitted in many recent papers internationally. The only stratigraphic boundary substantiated paleoichnologically turned out to be the weakest one. It looks like the case repeats with the GSSP for the TPS lower boundary but in the worse form in spite of stratigraphic importance of the boundary itself.

There is no reliable instrument at the moment to prove that the cap dolomites are synchronous. Difficulty increases when one try to distinguish the older Sturtian tillite from the Marino tillite or distinguish separate tillites of the Marino (Varanger) glaciation. Cap dolomites may be unrelated to the activity of biota at all, and there is no instrument suggested for the correlation of the cap dolomite to the sections with no cap dolomite preserved. So, in case with the GSSP of the Lower boundary of the Cambrian on the Newfoundland we see the change of the principle of the boundary substantiation (no one boundary was established paleoichnologically before). In case of the TPS, the Subcomission rejects the biostratigraphical principle recommended by the International Stratigraphic Code. The situation cause doubt: do we have a valid base to accept Ediacaran as a Geological System if the substantiation of its both upper and lower boundaries do not correspond to the International Code and scientific tradition which has proved its effectiveness?

In the connection with what is said above the activity of the Subcomission on the typification of the TPS boundaries can't be considered as completed. We strongly suggest continuing the discussion of the TPS concept and its stratigraphic boundaries. And before the job is done, one can expect that the Vendian will be used as the name for the Terminal Proterozoic System and geological Period in Russia and other countries as it is actively used now.

One could appreciate high speed of the decisions of the Subcomission on the Terminal Proterozoic System in the contrast to the Subcomissions on the Phanerozoic geological systems (and periods), which spend decades of the field and lab research to establish the major stratigraphic boundaries and approve their correlation potential. Indeed, the substantiation of the Silurian-Devonian boundary required over 12 years of the international field excursions, joint study of the fossil collections and other geological data, which were carried out in different countries. This work of the Subcomission on the Silurian-Devonian boundary has got the recognition by the International Congress in Montreal as the first outstanding experience in this sort of activity.

Subcomission on the TPS has established the volume of the TPS, its GSSP and the name surprisingly fast. The speed of the major decision made by our Subcomission could be explained by the sharp distinction between enormous amount of data accumulated during over a hundred years of the Phanerozoic stratigraphy and relatively poor and uncertain data on the TPS. Lesser amount of data requires lesser time for the processing but does not mean that the result is reliable. Fast does not mean good. We cannot accept the results of our Subcomission activity as successful and final.

Future plans and recommendations:
1. Substantiation of any stratigraphic system requires the establishment of its subunits. Stage division and even more detailed biostratigraphic zonation of the Vendian were developed during decades on the East-European Platform and its frame, where the Vendian deposits have uniquely rich paleontological characteristics. This region (in particular, the vast outcrops by the White Sea, Ural Mountains and Dniester River) has to be the object of an international study in order to develop the multidisciplinary approach for the stratigraphic correlation of the Vendian subdivisions. Paleontological and biostratigraphic experience of the Russian and Ukrainian specialists has to be combined with the chemostratigraphic, radiometric and paleomagnetic study.

2. Vendian sedimentary successions and biotas of the carbonate paleobasins have to be the major target of the international study as well. Vast experience in the study of the carbonate platform of the late Precambrian (Yudomian) of Sakha (Yakutia) in Siberia will be a solid base to develop the understanding of the biological history of the warm paleobasins of the Vendian.

3. Instead of one approach to the definition of the lower boundary of the TPS, we would prefer to develop an alternative approaches (for instance, chemostratigraphic vs. biostratigraphic)

And the last, but not the least. We consider the whole period of activity of the Subcomission on the TPS as a step aside from the fundamental achievements of the TPS stratigraphy and analogous experience on the Phanerozoic Systems. The whole situation is marching in step with the choice of the lower boundary GSSP of the Cambrian on the Newfoundland (and not in Siberia), the removal of the Siberian names of the Lower Cambrian stages and the term “Vendian” from International Stratigraphic Chart, with the attempts to reconsider the Permian and Carboniferous stratigraphic nomenclature etc. All these cases tend to ignore the priority and enormous amount of the fieldwork and lab research as well as the classical publications by generations of geologists and paleontologists. Strong influence of the non-paleontologists in the substantiation of the boundaries of the systems brings the stratigraphy into the critical situation.

-B. S. Sokolov, M. A. Semikhatov, and M. A. Fedonkin

**COMMENTS BY WOLFGANG PREISS**

I voted to approve Question 1. However, I abstained from voting on Question 2 on the name of the Terminal Proterozoic System, and feel that needs some explanation.

I feel that the issue of a name has not been paid nearly enough attention during the stratotype selection process. There seems to have been an unwritten assumption that one of the previously widely used names would automatically be selected. I may have missed it, but I don t ever recall seeing formal proposals being put for these names, with supporting arguments, as there was for the stratotype. In my view all of these four names are all parochial and will be seen as some sort of status symbol for the successful proponents for their name.

This issue is not about kudos for the successful and loss of face for the unsuccessful porposals. This is about finding a name that is significant in terms of Earth and Life history. There is no reason for it to be based on a geographic name (unlike lithostratigraphic units). I believe more time is needed to find such a name. In the meantime, my preference is to leave the interim term Terminal Proterozoic in place until a better, non-parochial, term is found.

I have previously argued against the application of any of the derivatives of the South Australian geographic name Ediacara for the System and Period. I still believe that these are inappropriate, and I summarise my reasons below:

1) The term Ediacara has been applied widely to the metazoan assemblage. Since it is not the whole of the Terminal Proterozoic that is characterised by this assemblage, it would be confusing to apply the name to the chronostratigraphic unit.

2) The boundary stratotype is not represented in the Ediacara area; only the upper part of the system is represented there.

3) The term Ediacara has already been used for a lithostratigraphic unit the Ediacara Member of the Rawnsley Quartzite. Again, this represents only a small part of the Terminal Proterozoic. It can only lead to misunderstanding.

4) Perhaps most importantly, the Terminal Proterozoic boundary stratotype has been selected on general historical geological criteria, not just on palaeontology. Thus while the Ediacara assemblage and acritarch assemblages are very important in the younger part of the system, no palaeontological criteria were actually used to select the boundary. Richard s proposal came closer than any of the others to using palaeontological criteria, but even this was blended with a mix of lithostratigraphic and tectonic ideas.

I also believe not enough thought has been given to the relationship of chronometric to chronostratigraphic units. The Terminal Proterozoic System, whatever name is given to it, cannot form part of a system of subdividing the Neoproterozoic, as it is a chronostratigraphic unit, based on a physical rock section.

The units Palaeo-, Meso- and Neoproterozoic are chronometric units defined purely arbitrarily and for convenience. They have nothing to do with stratigraphy but are a numerical subdivision of a time scale. Chronometric and chronostratigraphic units can exist in parallel, but they can never form part of a single time scale. Likewise, it is invalid to place the chronometric subdivisions of the Neoproterozoic into the same time scale as the chronostratigraphic units. Thus it would be quite improper to imply that the Cryogenian goes up to the base of the Terminal Proterozoic in a common time scale. The two are independent of each other.
An analogy would be in human history where we use numerical time scales in centuries, but also talk of historical periods based on recorded events e.g. the Elizabethan Period vs the 16$^{th}$ Century.

-Wolfgang Preiss