THE NAMA GROUP OF SOUTHERN NAMIBIA

The End Game of the First Large, Complex Organisms on Earth, the Ediacarans [IGCP493/587]

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The first contact between humans and Ediacarans?
San structures in southern Namibia.

IGCP 587

THE NAMA GROUP OF SOUTHERN NAMIBIA

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OVERVIEW

Introduction

Simon Darroch, Guy Narbonne, Patricia Vickers-Rich

The Ediacaran-Cambrian boundary (~541 Ma) marks a key point in one of the most dramatic geobiological revolutions in Earth History, including the disappearance of the enigmatic Ediacara biota, the beginning of a sustained period of biological innovation that included the advent of skeletons and complex behavioural systems (the 'Cambrian explosion'), massive perturbations to global geochemical cycles, a shift in the character of shallow-water sedimentation, and a permanent step-change in the complexity of Earth-Life systems. This transition is spectacularly well preserved and exposed in the Nama Group of southern Namibia, which comprises a thick Proterozoic to Cambrian-aged succession of shallow-marine carbonate and siliciclastic sediments, exposed over tens to hundreds of kilometers. These sediments also preserve numerous volcanic ash horizons, which have allowed the construction of a robust chronostratigraphic framework in which to study this interval.

This field trip will visit many of the iconic localities in southern Namibia, which have yielded important insights into the nature of the Ediacaran-Cambrian transition. It will also touch on the human history, from ancient to present, that played a part in these discoveries – including that of the San and Nama peoples, the geologists and traders, the German and British soldiers, and the present population of this region *[even a postage stamp was issued in Namibia to highlight the ediacarans, Fig. 1]*. It will be a quick survey, and one hopes that participants can return in the future and delve into more detail of this brilliant part of southwest Africa.

Fig. 1. Postal stamps issued in Namibia showcasing the Ediacaran biota so well known from the Nama Group.

Regional Stratigraphy and Geochronology

Simon Darroch, Guy Narbonne, Patricia Vickers-Rich

The Nama Group sedimentary sequence records the filling of a foreland basin related to convergence along the Damara and Gariep deformational belts (Figs. 2-5). These sediments were deposited into three sub-basins: the Witvlei sub-basin in the northeast, the Zaris sub-basin in the northwest, and the Witputs sub-basin in the south (Germs, 1983). The Zaris and Witputs sub-basins are separated by an ENE-trending paleotopographic high – the Osis Arch – that represents the peripheral bulge of the Nama foreland basin (Germs, 1983; Grotzinger and Miller, 2008). Along sub-basin axes the Nama Group is up to 3 km thick, but thins to 1 km over the Osis Arch (Grotzinger and Miller, 2008).

The regional lithostratigraphy sequence stratigraphy and chemostratigraphy of the Nama Group have been established through extensive work by a large number of previous workers (*e.g.* Germs, 1972; 1983; Saylor *et al*., 1995, 1998; Kaufman *et al*., 1991; Wood *et al*., 2015), including the position of the Ediacaran-Cambrian boundary (Wood *et al*., 2002; Wilson *et al*., 2012), thus providing a robust temporal and stratigraphic framework.

The Nama Group is divided into the Kuibis, Schwarzrand and Fish River subgroups (Table 1), and each of these can be further subdivivided into formations and members [discussed in the contributions to Day 2 and 3 in this guidebook].

The Kuibis Subgroup consists of up to 200 m of mature siliciclastics and carbonates representing cratonic and early foreland basin deposits. In the northwest Zaris sub-basin, the Kuibis Subgroup is divided into the Dabis and Zaris formations - the latter preserves spectacular outcrops of platform carbonates containing microbial-metazoan reefs, which are overlain by shales following progressive drowning of the platform (Grotzinger *et al*., 2005). An ash bed in the Hoogland Member (Kuibis Subgroup) has yielded a U-Pb zircon age of approximately 547 Ma (548.8 +/- 1 Ma; Saylor *et al*., 1998; recalculated to 547.32 Ma by Schmitz 2012 and Narbonne *et al*., 2012), providing an approximate age for the top of the Kuibis Subgroup. The Kuibis Subgroup is world renowned for its content of Ediacaran soft-bodied megafossils (*e.g*. *Pteridinium, Ernietta, Rangea, Beltanelliformis (Nemiana)*) and Ediacaran shelly fossils (*Cloudina, Namacalathus*) [that will be seen at Farm Aar on Day 2 of this field trip] (Fig. 6).

The overlying Schwarzrand Subgroup consists of 1200 metres of fine-grained, distal flysch and carbonates deposited in shallow-marine environments during development of the foreland basin. Impressions of soft-bodied megafossils occur sporadically throughout this succession, with abundant specimens of *Pteridinium* and *Swartpuntia* and fewer specimens of other taxa (e.g. *Ernietta, Aspidella* and possible *Bradgatia*) present near the top of the Urusis Formation on Farm Swartpunt [Day 3 in this field guide]. The Ediacaran shelly fossils *Cloudina* and *Namacalathus* are also common at some levels in the Schwazrand Subgroup. The Schwarzrand Subgroup in the Zaris sub-basin has been subdivided into the Nudaus, Urusis and Nomtsas formations. U-Pb zircon dates from within the Urusis Formation (Spitskop [Spitzkopf] Member) yield ages of 545.1 +/- 1 Ma and 543.3 +/- 1 Ma respectively (Grotzinger *et al*., 1995; the later recalculated to 540.61 +/- 0.67 Ma by Schmitz 2012 and Narbonne *et al.*, 2012). In both sub-basins, the Nomtsas Formation is separated from the Urusis Formation by an erosive unconformity containing complex valley-filling deposits (Table 1; Wilson *et al.*, 2012). Nomtsas strata preserved around Swartkloofberg Farm contain an ash bed dated to 539.4 +/- 1 Ma (Grotzinger *et al*., 1995; recalculated to 538.18 +/- 1.11 Ma by Schmitz, 2012 and Narbonne *et al*., 2012), confirming an earliest Cambrian age. These dates imply that Ediacaran body fossils and trace fossils described by Grotzinger *et al*. (1995), Narbonne *et al*. (1997), Jensen and Runnegar (2015) and Darroch *et al*., (2015) were alive in the last ~1 million years before the Ediacaran-Cambrian boundary and that the boundary itself is regionally marked by the unconformity between the Urusis and Nomtsas formations within the Schwarzrand Subgroup.

The Nomtsas Formation capping the Schwarzrand Subgroup and the overlying Fish River Subgroup are composed of shallow marine and non-marine, mainly fine-grained molasse that represents the final preserved fill of the foreland basin. Well preserved specimens of the complexly branching trace fossil *Treptichnus pedum* occur locally (Grotzinger *et al*., 1995; Wilson *et al*., 2012), but Ediacara-type megafossils have not been found.

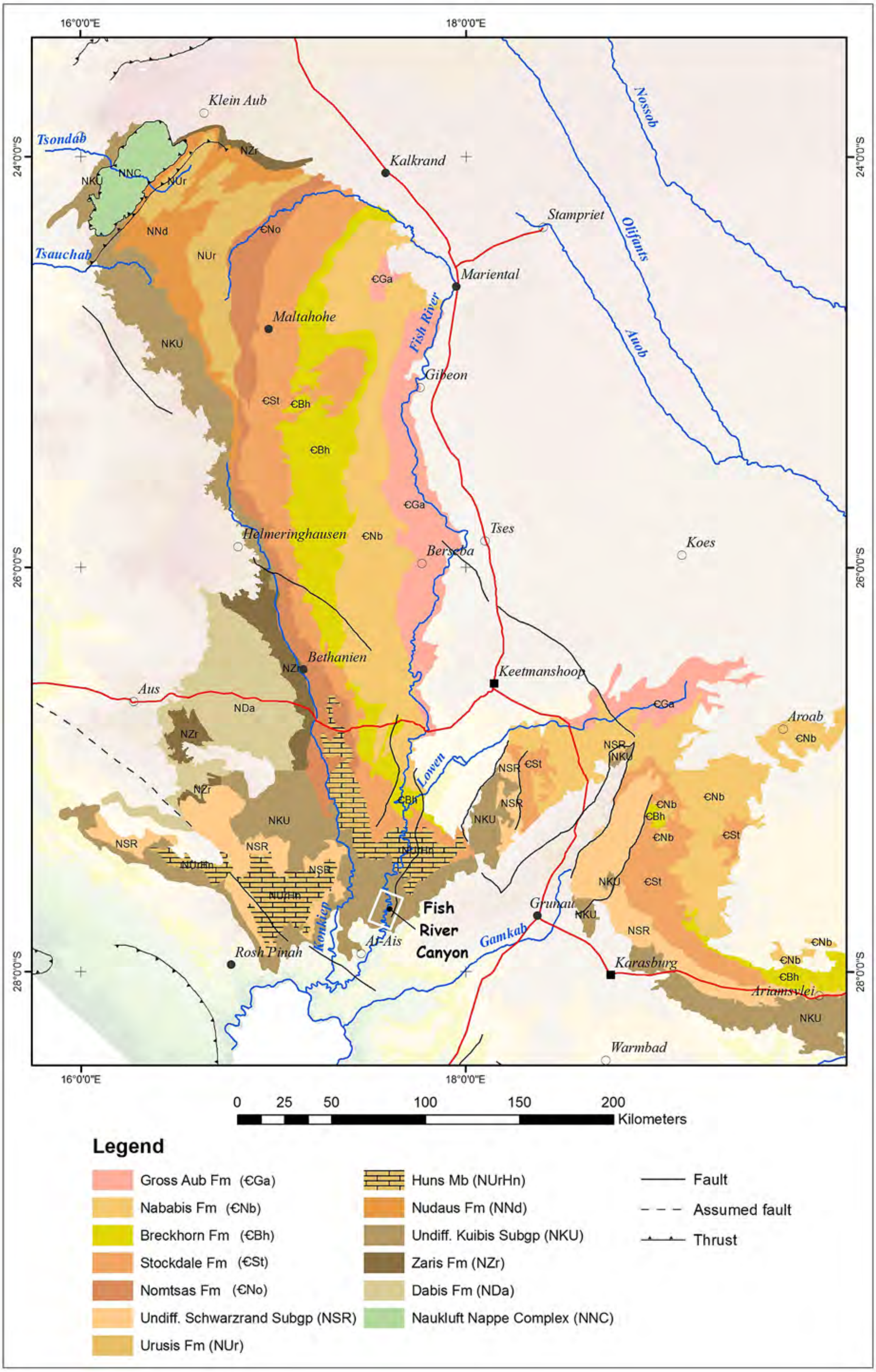


Fig. 2. Distribution of the Nama Group (from Hinder, et al.*, 35th IGC Heritage Volume).*

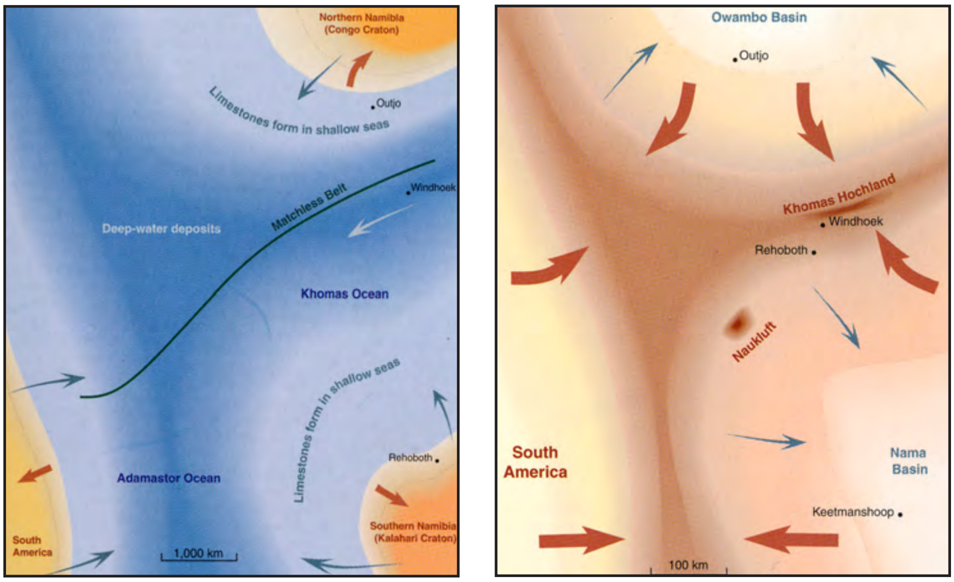


Fig 3. From around 750 to 550 Ma the Adamastor and Khomas oceans formed and then began to close, a dynamic period when the Ediacarans lived and died here leaving their impressions and skeletons behind encased in the Nama Group sediments (from Mendelsohn, et al.*, 2002).*

Fig. 4. The world as it was at the time of the Nama Group deposition around 550-543 Ma (from Fedonkin et al.*, 2007).*

ERA	SUBGROUP	FORMATION	ROCK TYPE	MAIN DEPOSITIONAL ENVIRONMENT
Cambrian	Fish River Subgroup	Gross Aub	cross-bedded sandstone + shale with sandstone	muddy tidal + distal fluvial
		Nababis	cross-bedded sandstone + shale with sandstone	braided fluvial + shallow marine
		Stockdale	cross-bedded sandstone + pebbly sandstone	braided fluvial
	Schwarzrand Subgroup	Nomtsas	cross-bedded sandstone, pebbly sandstone + shale with sandstone	braided fluvial + muddy tidal
			Unconformity	
Terminal Proterozoic		Urusis	shale with sandstone	shallow marine + distal fluvial
		Nudaus	shale + sandstone	sandy tidal to deeper water
	Kuibis Subgroup	Zaris	carbonates, shale with sandstone, calcarenites with reefs	Shelf lagoon, barriers, fore and patch reefs
		Dabis	sandstone, sandstone with shale + carbonates	Braided fluvial to shallow marine

Table 1. Stratigraphy of the Nama Group (after Miller, 2008).

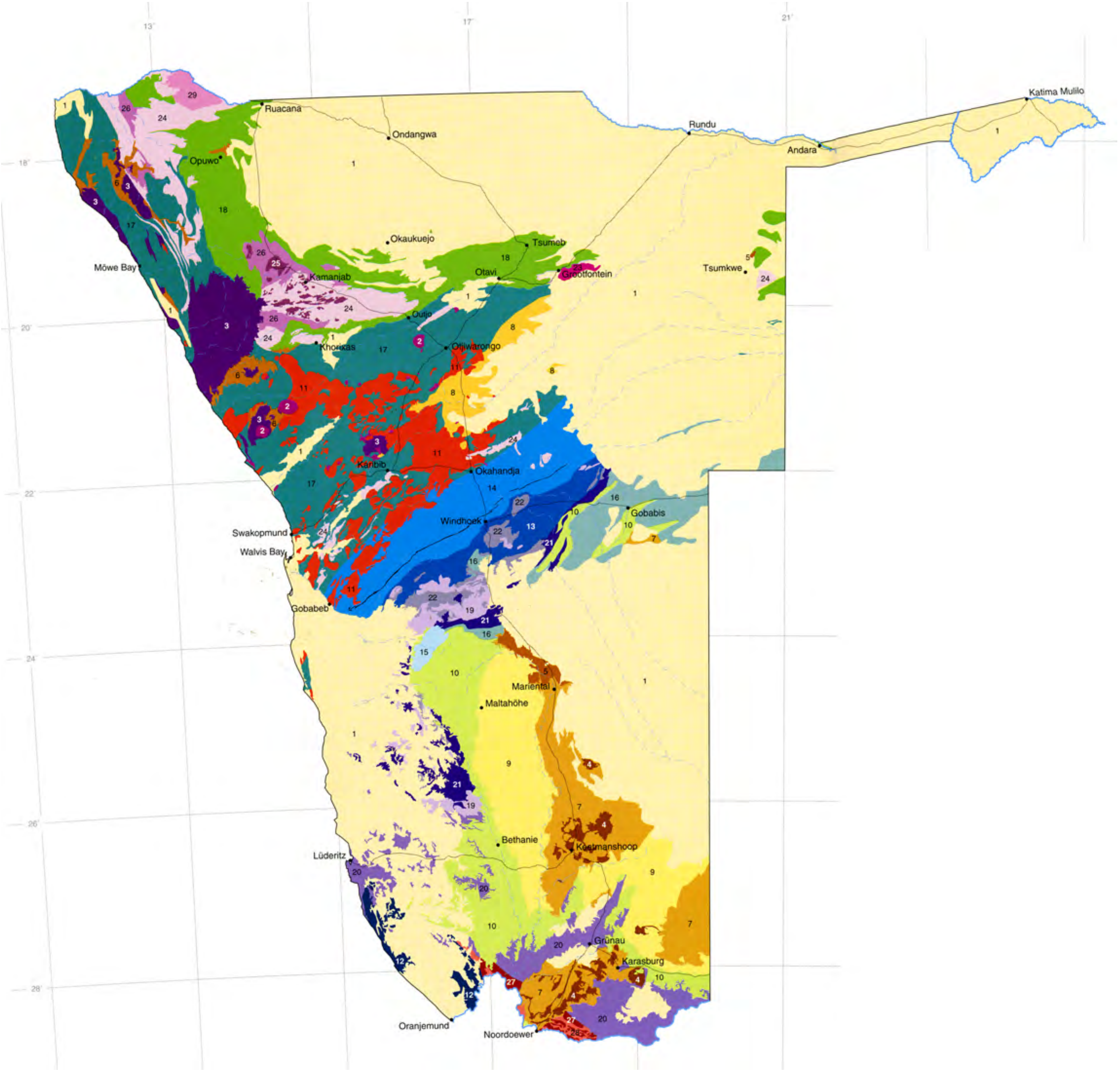


Fig. 5. Geologic map of Namibia. (From Mendelsohn et at.*, 2002).*

AGE	MAJOR GEOLOGICAL DIVISIONS (age in millions of years)		GROUP (ROCK TYPE)
0	**Kalahari Group** (70–present)	1	Kalahari and Namib Sands (S)
70			
130	**Damaraland Igneous Province** (137–132)	2	Igneous Intrusions (Ls Ss)
		3	Etendeka Group (Ss)
180			
	Karoo Supergroup (300–180)	4	Dykes and sills (V)
		5	Kalkrand Basalts (B)
300		6	Huab Basin (Ss Sh)
		7	Main Karoo Basin (Ss Sh)
400		8	Waterberg Basin (Ss C)
500			
	Nama Group (600–543)	9	Fish River Subgroup (Ss)
550		10	Kuibis and Schwarzrand Subgroup (Ss C)
650	**Damara Granite Intrusions** (650–470)	11	Damara Granites (G)
	Damara Supergroup and Gariep Complex (850–600)	12	Gariep Complex (Cx)
		13	Hakos Group (Ss)
850		14	Khomas Group (Sch)
		15	Naukluft Mountains (Ls Sh)
		16	Witvlei Group (Ls Ss)
		17	Swakop Group (Sch)
		18	Otavi Group (Ls)
		∼	Matchless Belt (A)
1,200	**Namaqua Metamorphic Complex and related rocks** (1,400–1,050)	19	Gamsberg and associated granites (G)
		20	Namaqua Metamorphic Complex (Cx)
		21	Sinclair Group and equivalents (Cx)
1,400			
	Oldest rocks (2,600–1,650)	22	Rehoboth Group and associated rocks (Cx)
		23	Grootfontein Metamorphic Complex (Cx)
		24	Epupa, Huab and Abbabis Metamorphic Complexes (Cx)
		25	Fransfontein Granite Suite (G)
		26	Khoabendus Group and Okapuka Formation (R Ss)
1,800		27	Vioolsdrift Granite Suite (G)
		28	Haib Group (Gn)
		29	Kunene Complex (Cx)

Rock types: A = amphibolite; B = basalt; C = conglomerates; Cx = complex;
G = granites; Gn = gneisses; Ls = limestone; R = rhyolites; S = sands;
Sch = schists; Sh = shales; Ss = sandstones; V = volcanic

(From Mendelsohn et at., *2002).*

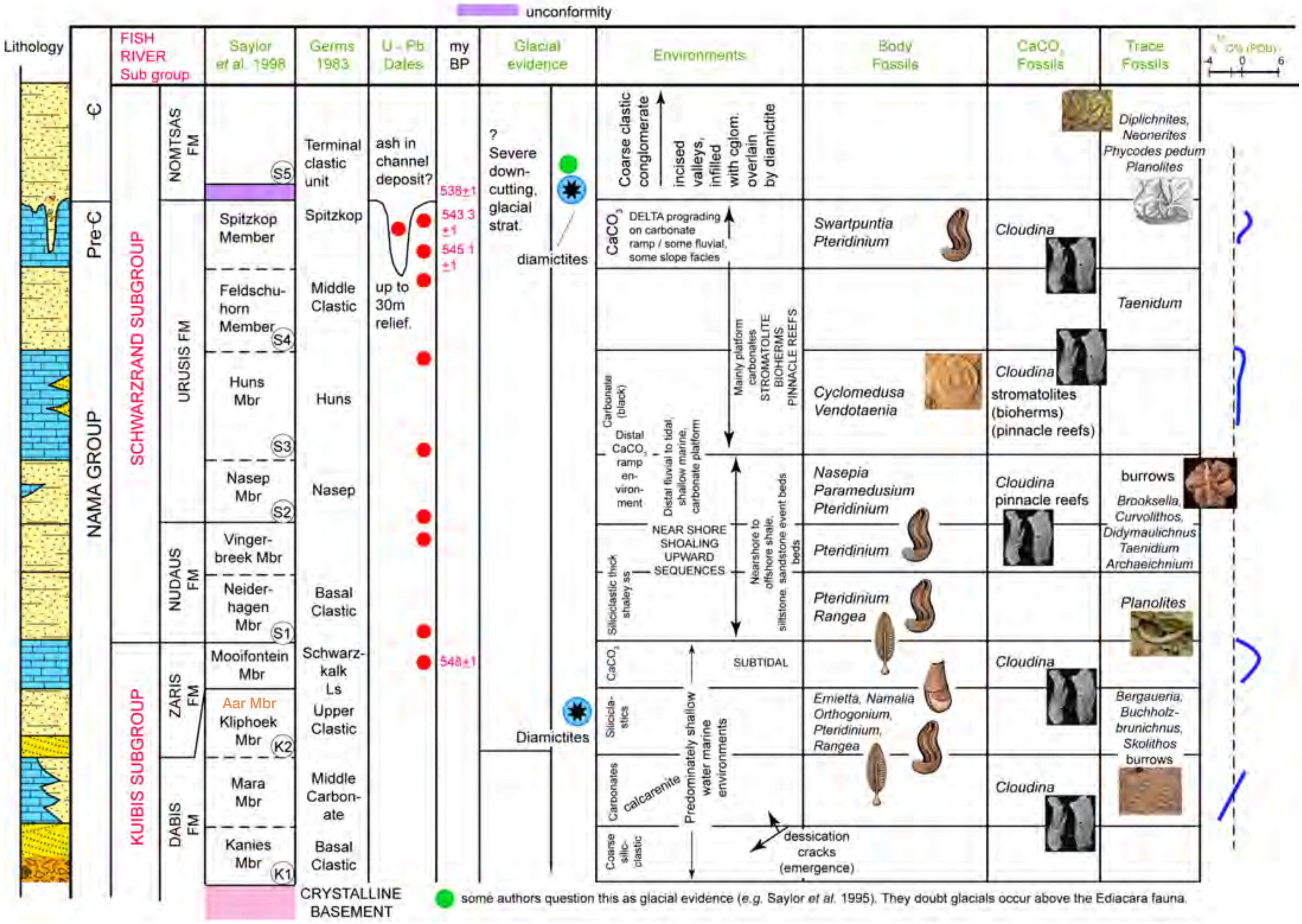


Fig. 6. The Nama Group (modified from Fedonkin et al.*, 2007).*

Paleontology – The 'Ediacara Biota' and Early Metazoan Biosphere

Simon Darroch

The fossil-bearing horizons in the Nama Group offer a rare glimpse of the terminal Ediacaran biosphere, and so are profoundly important for understanding the events that led up to the 'Cambrian explosion'. However, many (if not most) interpretations of these fossils throughout the last ~100 years of study have been controversial, and so the question as to which of them can be recognized as being plausible forerunners to modern animal groups is complex. Crucially, the Ediacaran parts of the Nama Group preserve both soft-bodied 'Ediacara biota' (which are commonly argued to be non-metazoan) as well early examples of burrowing and calcifying organisms, which almost certainly represent metazoans and thus is an interval where these two very different branches of eukaryotic life overlapped in space and time. To simplify things, below are brief summaries of the current understanding of both the enigmatic 'Ediacara biota', as well as the early metazoans that are preserved in southern Namibia.

The 'Ediacara biota' – Ediacaran-aged rocks worldwide preserve a suite of fossils belonging to complex eukaryotes termed the 'Ediacara biota', whose phylogenetic affinities are controversial. Whereas some Ediacaran body fossils are now thought to represent stem-group metazoans (i.e. 'animals'), the vast majority of the Ediacara biota from Namibia belong to higher-order groupings termed the Erniettomorpha and Rangeomorpha (Fig. 7). These taxa share few (if any) characteristics in common with metazoans, and are thus currently best interpreted as complex eukaryotes with no modern representatives and uncertain relationships with extant animal phyla. The organisms commonly found in the Nama Group exhibit a variety of growth forms and life habits, including benthic 'recliners', upright multi-foliate fronds and loose 'bags' that likely lived at least partially buried in the sediment (Ivantsov *et al.*, 2015). Field trip participants will be able to see exquisitely preserved examples of these enigmatic fossils from iconic localities where they still attract worldwide scientific interest.

Metazoan trace fossils – Whereas body fossils represent the physical remains of organisms, trace fossils are a record of biological activity (for example, borings, burrows, footprints and feeding marks), and as such record the early evolution of organismal behaviors (*e.g*. Jensen *et al*., 2005; Carbone and Narbonne, 2014). With rare exceptions (*e.g.* Ivantsov, 2011), the Ediacara biota leave little in the way of trace fossils, as most represent sessile benthic organisms employing a passive feeding strategy. The vast majority of Nama Group trace fossils are, therefore, attributable to Metazoa, and those that are attributed to Ediacara biota are easily distinguished (*e.g.* Ivantsov, 2011). Because of the profound effects these behaviors had on the physical and chemical attributes of depositional environments (both in terms of destroying ecological niches occupied by Ediacara biota, and creating new ecospace for the emerging Cambrian fauna), these organisms are recognized as powerful ecosystem engineers. This fundamental difference between Ediacaran and Cambrian life strategies has long been recognized as a distinct boundary in the global stratigraphic record (Knoll *et al.*, 2004) and has been termed variously the 'agronomic revolution' and the 'Cambrian substrate revolution' (Seilacher, 1999). Recent work has recognized a large diversity of trace fossils in latest Ediacaran parts of the Nama Group, but the earliest accounts were compiled by Germs (1972) and Crimes and Germs (1982), who recognized a wide diversity of ichnotaxa representative of bilaterian metazoans.

Metazoan body fossils – In addition to trace fossils, southern Namibia is arguably the best place in the world to examine some of the oldest examples of metazoan biomineralization. The reef tracts preserved throughout the Nama Group play host to incredible numbers of *Cloudina* and *Namacalathus* skeletons, which are a significant rock-forming component of many of the carbonate units. Other taxa (such as the enigmatic *Namapoikia*) are rarer, but are no less important in terms of what they represent. The interpretations of these organisms are still debated, but they almost certainly represent metazoans, and recent work (*e.g*. Penny *et al*., 2014; Wood *et al*., 2014, 2015) is making important strides towards unravelling their paleobiology and phylogenetic affinities. Hou *et al*. (2003) discovered that a significant portion of *Cloudina* assemblages contain individuals bearing predatory drillholes, providing the earliest examples of macroscopic predation in Earth history, and the beginning of ecological escalation which would eventually culminate in the Cambrian explosion.

Neoproterozoic "Ghosts"– The Ediacaran Fossils of the Nama Group

Patricia Vickers-Rich, Guy Narbonne, Peter Trusler, Leslie Kriesfeld

Namibia has been a key region for understanding Ediacaran paleontology since early days of the 20th century, when geologists such as Paul Range and German soldiers manning isolated outposts in the Aus region of southern Namibia first reported these fossils. The history of Ediacaran research in Namibia was described by Vickers-Rich and Komarower (2007) and Fedonkin *et al*. (2007). The following description is condensed and updated from these reviews.

Fig. 7. Rangea schneiderhoehni *frond.*

The first formal name for an Ediacaran fossil from Namibia was given by Gürich in 1930, when he proposed *Rangea schneiderhoehni* (Fig. 7-8) for an enigmatic, cm-scale frond that had been collected from the Dabis Formation. *Rangea* Gürich 1930 represents the first complex Ediacaran fossil named anywhere in the world, predating Sprigg's (1947) description of *Dickinsonia* from Ediacara in Australia by nearly two decades and Ford's (1958) description of *Charnia* from Charnwood Forest in England by nearly three. This was not a simple disc that could be described and then forgotten (Billings, 1872; Gehling *et al*., 2000) – it was a frond covered with constructional features so complex that Gürich assumed that *Rangea* must be Cambrian in age.

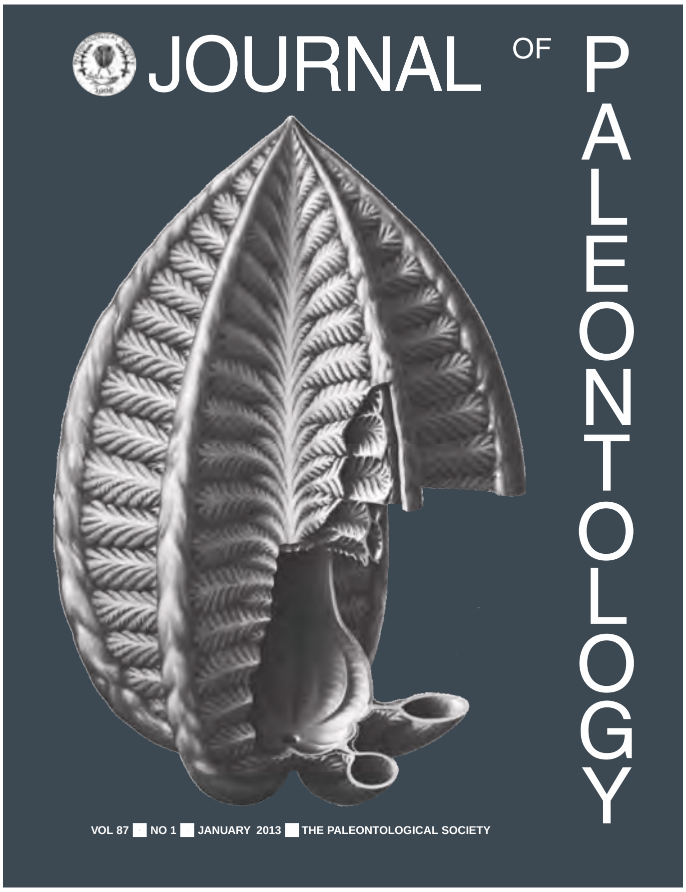


Fig. 8. Reconstruction of Rangea *by Peter Trusler (from Vickers-Rich,* et al.*, 2013).*

Over the 85 years since Gürich's designation, *Rangea* and other core Ediacaran forms have become bellweather taxa for our changing interpretations of the Ediacara biota. *Rangea* was originally regarded as a primitive member of an extant phylum, perhaps a primitive ctenophore (Gürich, 1930, 1933; Dzik, 2002) or cnidarian (Richter, 1955; Jenkins, 1985, 1992). Seilacher (1992), Grazhdankin and Seilacher (2005), and Seilacher and Gishlick (2014) specifically removed it from the animals and regarded it as a core taxon of Seilacher's proposed kingdom 'Vendobionta'. Pflug (1970a,b, 1972) designated it as the type genus of a key Ediacaran division of life, the Rangeomorpha, a view subsequently endorsed and refined by Narbonne (2004), Gehling and Narbonne (2007), Laflamme and Narbonne (2008), Xiao and Laflamme (2009), Erwin *et al*. (2011) and Laflamme *et al*. (2013). Recently, Vickers-Rich *et al*. (2013) described complete, three-dimensional specimens from a gutter-cast on Farm Aar (Day 2) that allow *Rangea* to be reconstructed as a six-vaned multifoliate frond with an expanded basal bulb that acted as a weight-belt on the sediment (Fig. 8).

Another group that is nearly unique to the Nama Group are the erniettomorphs – *Ernietta, Pteridinium*, and *Swartpuntia*. *Pteridinium simplex* (Fig. 9) was first described by Gürich (1933), and its body consists of a double-layered palisade of tubes, an architecture quite distinct from the fractal morphology of *Rangea* and other rangeomorphs. Thus far, all specimens of *Pteridinium* have been found in transported masses, and their lifestyle is controversial. Traditional views (*e.g*. Jenkins, 1985) regarded them as fronds extending into the water column, but this was disputed by Seilacher (1989, 1992) and Grazhdankin and Seilacher (2005), who regarded *Pteridinium* as mainly or completely infaunal (Fig. 10). Subsequent studies by Elliott *et al*. (2011) and Meyer *et al*. (2014a, b) refuted much of the evidence provided for an infaunal lifestyle, but the question of lifestyle still remains unresolved.

Fig. 9. Pteridinium *preserved in submarine avalanche sediments, Aarhauser, Farm Aar, Nama Group.*

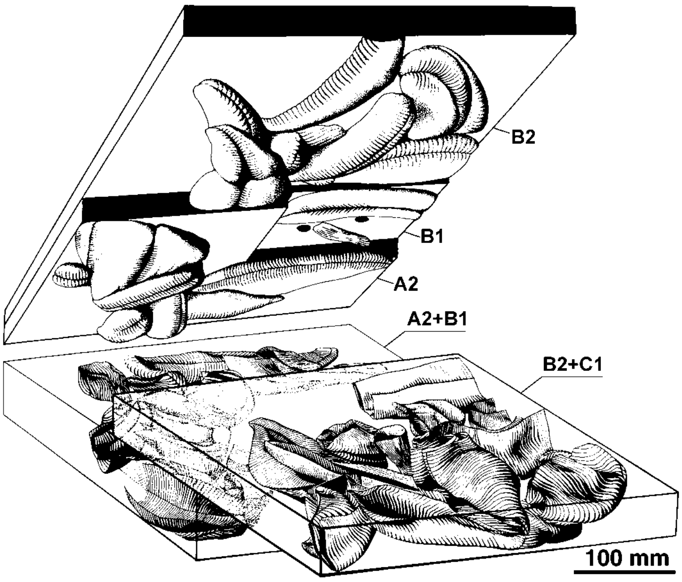


Fig. 10. Infaunal interpretation by Grazhdankin and Seilacher (2005) Aarhauser, Pteridinium.

Ernietta Pflug 1966, is a bag-shaped fossil that is also constructed of the double-layered palisade of parallel tubes diagnostic of the Erniettomorpha. It is known from literally hundreds of specimens (Fig. 11), most of them from float and all of them until recently incomplete, preserving only the basal part of the fossil. Recent discovery, however, of complete, three-dimensionally preserved *Ernietta* fossils in a gutter-cast from Farm Aar (Day 2) now permits recognition of the full structure of *Ernietta* as comprising a basal bag-shaped anchor that was permanently buried in the sediment and that extended upward into the water column with two facing frondose structures at its distal opening (see Day 2 of field trip for illustration of the most complete specimens, Fig 12) (Ivantsov *et al*., 2015). San (Bushman) artists carved images of these strange structures, and they were certainly not far off the now documented complete morphology! (Fig. 13)

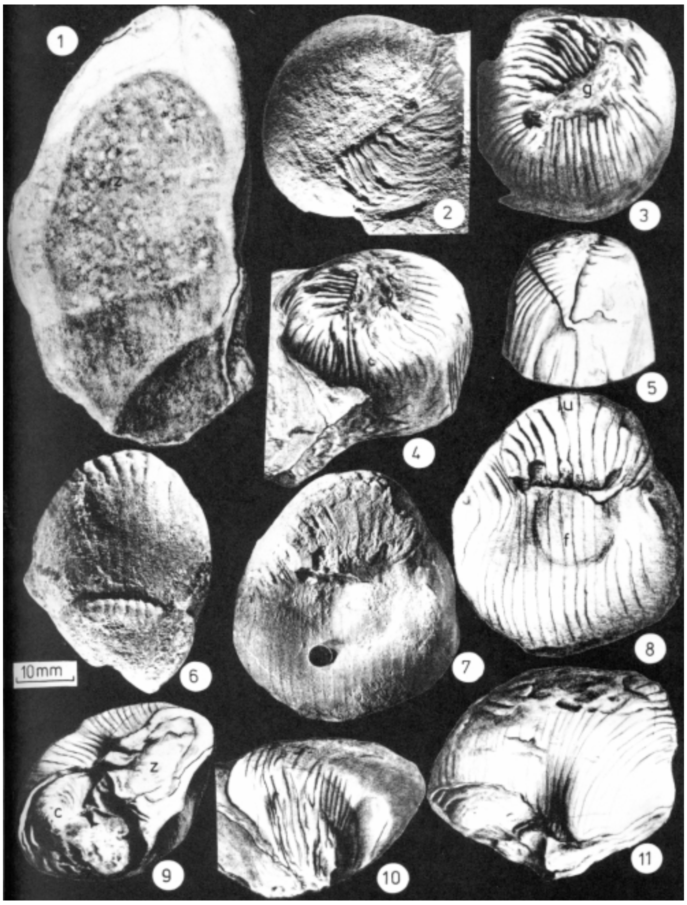
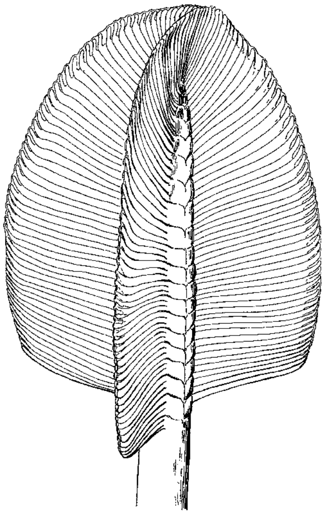


Fig. 11. A collection of Ernietta *(from Pflug, 1972).*

Fig. 12. Ernietta *(scale upside down to emphisize how interpretations of up and down with regard to this metazoan have changed in light of recent discoveries.*

Fig. 13. San carvings on Farm Aar, interestingly resembling the detail of Ernietta *morphology.*

Swartpuntia Narbonne *et al*. (1997) is a multifoliate, frondose erniettomorph that reached over a decimeter in height (Figs.14-15). It is abundant at the top of Swartpunt (Day 3), where geochronological and geochemical data imply it lived during the last one million years of the Ediacaran Period, alongside such forms as *Pteridinium* (Fig. 16).



Figs. 14-15. Swartpuntia*, holotype (l);* Swartpuntia*, reconstruction.*

Fig. 16. Pteridinium carolinense *from Swartpunt*

Another common taxon comprises cm-scale, circular discs that invariably occur in profusion, completely covering bedding planes with adjoining specimens, all of them exactly the same size and presumably the result of a single spatfall. These fossils were originally named *Hagenetta aarensis* Hahn and Pflug, 1988 and were interpreted as bivalve shells, but Ivantsov *et al.* (2015) concluded that the name *Beltanelliformis* has priority over the other common names (*e.g. Nemiana*) that have previously been used for this taxon.

Beltanelliformis (Nemiana) is abundant in shallow-water Ediacaran assemblages worldwide, and is most commonly interpreted as a spherical 'polyp' of unknown affinities (Narbonne and Hofmann, 1987) or as a Nostoc-like ball of bacteria (Ivantsov *et al*., 2015) (Fig. 17).

Fig. 17. Beltanelliformis (Nemiana) *from Farm Aar.*

Other, rarer Ediacara-type impressions from Namibia include *Protechiurus* Glaessner, 1979 (Fig. 18) and *Ausia* Hahn and Pflug, 1985 (Fig. 19), most of these taxa based on one or a few specimens, and consequently of uncertain affinities. Carbonaceous tubular compression fossils such as *Vendotaenia* (Fig. 20) are locally common (Cohen *et al.*, 2009).

Fig. 18. Protechiurus

Fig. 19. Ausia*, suggested by some to be a tunicate.*

Fig. 20. Vendotaenids from southern Namibia.

A major contribution of Namibia to our understanding of Ediacaran paleobiology is the abundant occurrence of the world's first skeletal fossils in carbonate formations throughout the Nama Group, including appearing in constructional roles in the world's first skeletal-microbial reefs (Germs, 1972; Grant, 1990; Grotzinger *et al*., 2000, 2005; Wood *et al*., 2002; Wood, 2015; Penny *et al*., 2014; Zhuravlev *et al*., 2015). *Cloudina* Germs, 1972, the first pre-Cambrian shelly fossil named anywhere in the world, occurs as mm-scale diameter calcified tubes with a distinctive pattern of stacked, funnel-shaped transverse partitions inside the tube (Figs. 21-23). *Cloudina* is generally regarded as a skeletal metazoan of uncertain affinities, and is known from late Ediacaran carbonates worldwide. *Namacalathus* (Grotzinger *et al*., 2000) is another calcified reef-dweller, which, like *Cloudina*, occurs as skeletal packstones between microbial elements in the reefs. It occurs as a cm-scale cup atop a short stem, with a hole in the top of the cup and several holes along its sides (Fig. 24). It represents a calcified metazoan that Zhuravlev *et al*. (2015) regarded as a stem-group lophophorate (Fig. 25).

Fig. 21. Cloudina

Fig. 22. Cloudina

Fig. 23. Cloudina *(Geological Survey of Namibia).*

The vague outlines and impressions in the rocks that fascinated the early geologists and German soldiers appear to have intrigued the indigenous people of the region as well, long before the arrival of the Europeans. The Bushmen skillfully carved images closely resembling Ediacaran fossils, those fossil ghosts, into the limestone surfaces of the Zaris Formation – carefully depicting the unique, offset symmetry that so differs from the anatomy of animals we know today and through the Phanerozoic and well as the entire morphology of *Ernietta*.

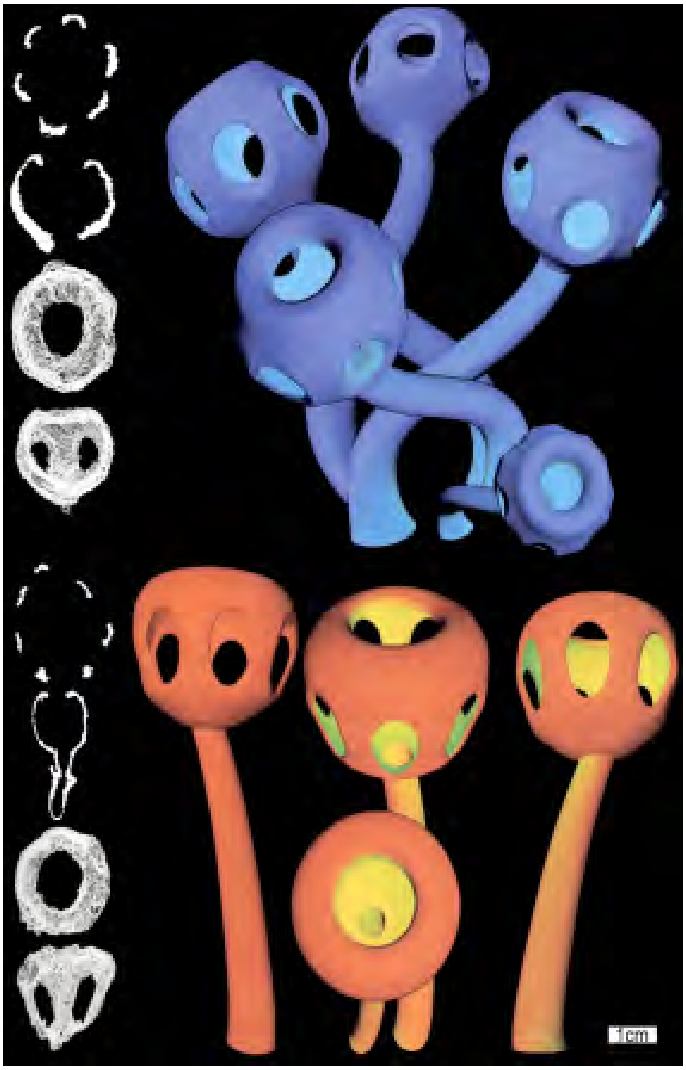


Fig. 24. Namacalathus, *CaCO3 skeletonized Metazoan and reef builder.*

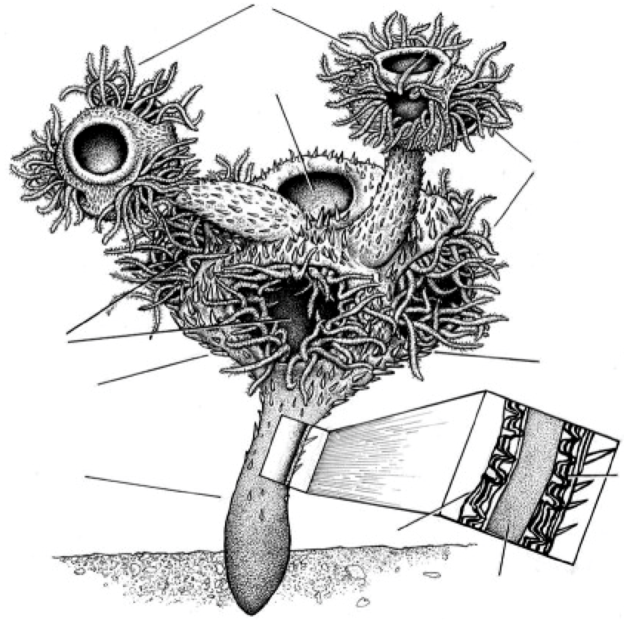


Fig. 25. Zhuravlev et al. *(2015) interpretation of soft anatomy of* Namacalathus.

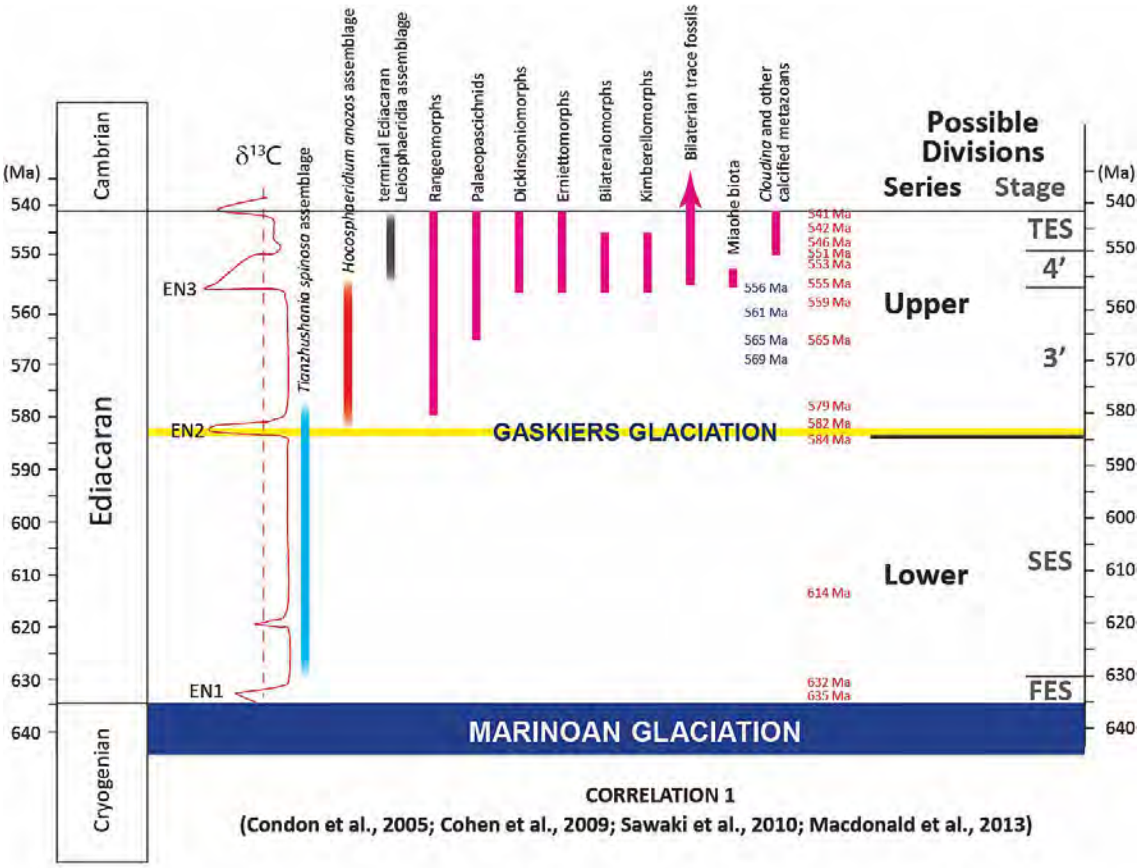
An intriguing question posed by paleontologists is what happened to the last of these first complex and large eucaryotes that developed on Earth? Recent discoveries and ongoing work continue to inform about the environmental conditions faced by the last of the Ediacarans around 541 million years ago. In future, such knowledge will assist hopefully in our understanding of what happened to the Ediacarans and the dynamics of the dramatic biotic change at the beginning of the Cambrian..... and perhaps give some guidance on planning the future of humanity! http://insider.si.edu/2015/09/did-mystery-worms-cause-worlds-first-mass-extinction/

Definition and recognition of a terminal ediacaran stage in Namibia

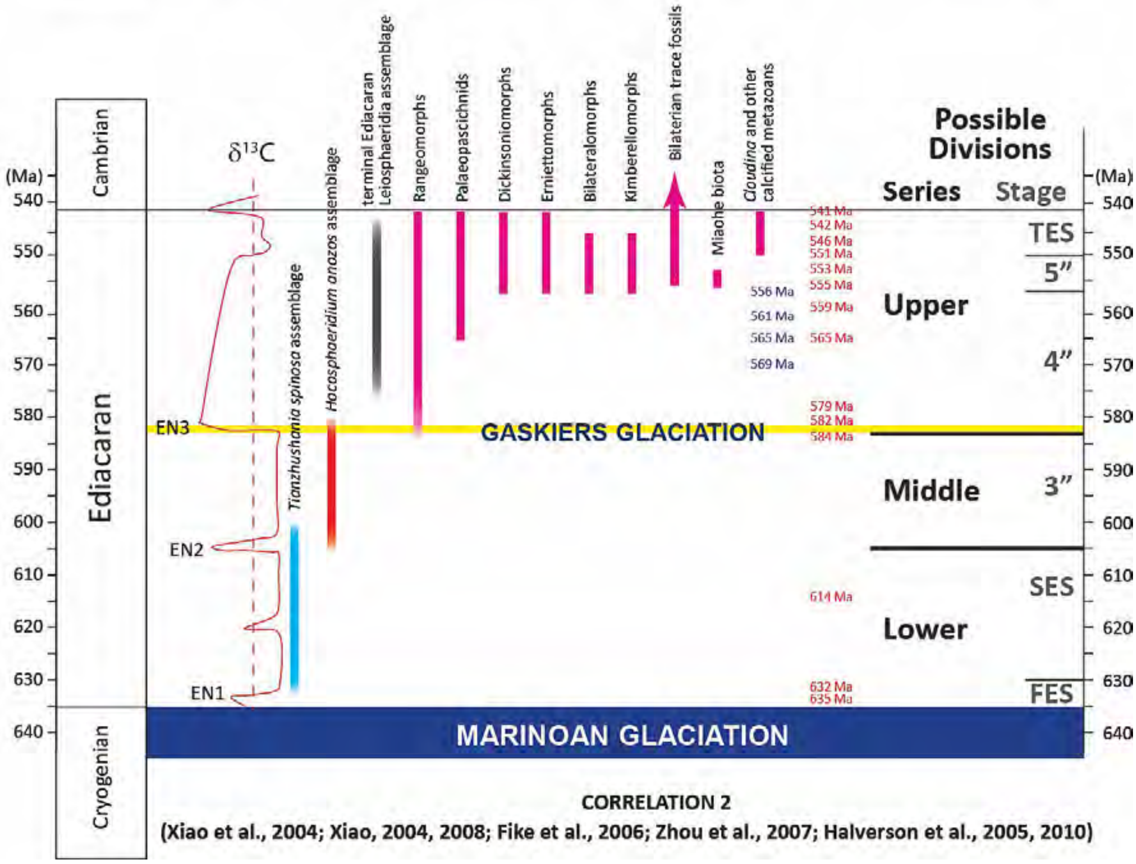
Guy Narbonne

The Ediacaran System was ratified by ICS and IUGS in 2004, with its basal boundary defined by a GSSP at the base of the distinctive cap carbonate that overlies the Marinoan (Cryogenian) diamictite of the Elatina Formation at the Enorama Creek section in South Australia (Knoll *et al*., 2004). Its base has subsequently been dated at approximately 635 Ma on three different continents (Condon *et al*., 2005; Calver *et al*., 2013; Rooney *et al*., 2015); its top is at the base of the Cambrian, which is currently estimated at 541 Ma based on radiometric dates from Oman and Namibia (Schmitz, 2012; Narbonne *et al*., 2012; Peng *et al*., 2012).

Since the establishment of the Ediacaran System, emphasis has shifted to formal subdivision of the Ediacaran into series and stages. The Ediacaran Period can informally be subdivided into a lower part (ca. 635-580 Ma) characterized by complex Doushantuo/Pertataka-type microfossils, including possible animal embryos, and an upper part (ca. 580-541 Ma) that contains abundant soft-bodied fossils of the Ediacara biota (Knoll and Walter, 1992; Narbonne *et al*., 2012; Xiao *et al*., 2016). The lower part of the Ediacaran is divisible into several stages that can be grouped into either one or two series (see complementary proposals in Narbonne *et al*., 2012; Xiao *et al*., 2016). The upper part of the Ediacaran is similar to Sokolov's (1952) original concept of the Vendian 'Series' and can be subdivided into several distinct stages. Options for these subdivisions are presented in Figure 26. The uncertainty in global correlation between the siliciclastic and carbonate realm in the middle part of the Ediacaran has no influence on correlations in the upper Ediacaran, where abundant Ediacara-type fossil impressions, trace fossils, and skeletal fossils, such as *Cloudina*, can be used in conjunction with well-constrained isotopic chemostratigraphy, numerous radiometric dates and proximity to the overlying Cambrian to significantly constrain global correlation (Fig. 26).



CORRELATION 1
(Condon et al., 2005; Cohen et al., 2009; Sawaki et al., 2010; Macdonald et al., 2013)



CORRELATION 2
(Xiao et al., 2004; Xiao, 2004, 2008; Fike et al., 2006; Zhou et al., 2007; Halverson et al., 2005, 2010)

Fig. 26. Options for subdivisions of the Ediacaran.

In 2014, the Ediacaran Subcommission established Terminal Ediacaran Stage Working Group (TES-WG) to recommend formal establishment of a globally correlatable stage characterized by *Cloudina* and other skeletal Ediacaran fossils at the top of the Ediacaran System. This field trip will investigate the criteria that might be used to recognize and define this stage, their expression in the Ediacaran strata of Namibia and the potential of various sites and stratigraphic levels in Namibia to be used in formal subdivision of the Ediacaran System. A fuller account of these criteria and supporting literature citations can be found in Xiao *et al.* (2016).

The abundant appearance of the oldest skeletal animals in Earth history approximately 550 million years ago represents a significant evolutionary event that can be used to recognize and potentially define a terminal Ediacaran stage. Ediacaran shelly fossils were first described and named in Namibia, where they commonly occur in rock-forming abundances in carbonate formations throughout the succession. Three genera of Ediacaran shelly fossils (*Cloudina, Namacalathus* and *Sinotubulites*) are abundant in terminal Ediacaran strata worldwide (Namibia in Africa; Oman in the Middle East; South China and Siberia in Asia; the western Cordillera of Canada, USA, and Mexico in North America; Spain in Europe; and Brazil and Uruguay in South America) but disappear abruptly at the Ediacaran-Cambrian boundary, enhancing their utility as index fossils for a terminal Ediacaran stage.

In contrast with the diverse assemblages of Ediacaran soft-bodied megafossils present in the older Avalon and White Sea biotas, terminal Ediacaran megafossil impressions consist mainly of a low diversity of long-ranging taxa such as *Pteridinium* and *Rangea*. *Swartpuntia* and *Ernietta* are known with certainty only from the terminal Ediacaran of Namibia and the southwest USA, but questionable reports from older and younger strata need to be investigated. Horizontal trace fossils are moderately abundant in most terminal Ediacaran successions worldwide, and the oldest treptichnid burrows make their first debut in terminal Ediacaran strata. In contrast to the diverse assemblages of ornamented acritarchs that permit zonation of older Ediacaran strata (Fig.26), terminal Ediacaran strata are typified by low diversity assemblages of smooth leiospheres.

Chemostratigraphy and radiometric dating will also be critical in defining the terminal Ediacaran stage. With a single possible exception from the Mara Member of Namibia that requires confirmation, Ediacaran shelly fossils such as *Cloudina* consistently postdate an apparently global Ediacaran C-isotope excursion that may represent the deepest C-isotope excursion in Earth history. The minimum age of the termination of this excursion, variably termed the Shuram anomaly in Oman, EN3 in China, and the Wonoka anomaly in Australia, is constrained by radiometric dates of 551 Ma from an ash bed immediately above the excursion in China and 547 Ma from an ash bed approximately 200 m above the excursion in Namibia (Fig. 26). This excursion is potentially a significant global marker in Ediacaran stratigraphy, but geological relationships between the EN3 excursion in China and the 551 Ma ash above it that constrains its minimum age may be complex (compare Condon *et al*., 2005; Kaufman, 2005; An *et al*., 2015). The age of the onset of the Shuram-Wonoka-EN3 isotope isotope excursions are unknown, and the mechanism for their formation is controversial. Further studies to elucidate these questions are in progress (Xiao *et al*., 2016).

The best boundary level for a terminal Ediacaran stage would be one that integrates multiple stratigraphic criteria to ensure multiple means of recognition and correlation of the stage. The abrupt end of a major chemical oceanographic event (Shuram/Wonoka/EN3) followed almost immediately by the abundant appearance of the world's oldest skeletal fossils (*e.g*. *Cloudina*) represents a significant boundary that can be correlated using multiple criteria, and this biological/chemical marker is associated with radiometric dates that constrain its termination to >550 Ma on two continents. Distinctive taxa of Ediacara-type fossil impressions and trace fossils occur in Ediacaran strata above this proposed basal boundary in Namibia and in China, enhancing recognition of this stage in siliciclastic deposits. If selected, this boundary would produce a Terminal Ediacaran Stage that was 10-20 million years long, which is similar in length to some Phanerozoic stages. Other potential markers for a terminal Ediacaran stage higher in the succession should also be considered.

The Kuibis and Schwarzrand subgroups of Namibia consist of alternating siliciclastic and carbonate formations, which represent a nearly ideal combination for recognition of the key stratigraphic markers that are useful in Ediacaran chronostratigraphy. The siliciclastic formations host world-renown assemblages of Ediacaran soft-bodied megafossils and trace fossils, whereas the intervening carbonate formations host abundant Ediacaran shelly fossils and contain a world-class record of chemical oceanographic changes in C, Sr, and redox indicators. The succession is punctuated by numerous volcanic ash beds that have yielded high precision U-Pb dates that constrain both terminal Ediacaran stratigraphy and the base of the overlying Cambrian. All of these features will be examined during this field excursion, and there will be a chance for abundant dialogue and discussion during this trip and during the IGC in Cape Town!

FIELD CONFERENCE DAY 1 – WINDHOEK TO AUS

Patricia Vickers-Rich, Guy Narbonne, Bernd Roemer

Day 1 of the Nama field trip will begin in Windhoek, and the route taken will be along the B1 (Fig. 27) through Rehoboth, Kalkrand to Mariental, at which point the C19 will take you to Maltahöhe and then the C14 south to Helmeringhausen (where it is hoped you can stop briefly for a coffee and a beautiful Apple Strudel or Cake!). From there the trip will continue on the C13 to Aus where you will find accommodation at one of two hotels, the Bahnhof or Klein Aus Vista.

Along this route, reference to the included generalized geologic map along with excerpts from Gabi Schneider's *The Roadside Geology of Namibia* will be good companions for understanding and enjoying your rather longish ride.

Fig. 27. The road between Rehboth and Mariental on the B1.

For this part of the trip the good source of geological information is the summary geological map enclosed with your field guide. In Windhoek the rocks are part of the Damara Supergroup (Khomas Group), a metamorphic complex of schists of 850-600 Ma in age. Moving south towards Rehoboth you will pass through some even older rocks, the Rehoboth Group, which ranges in age dating back to 1650 Ma or older. Near Rehoboth the road skirts the Namaqua Metamorhic Complex (the Gamsberg and associated granites) and to the west and further south the Sinclair Group and equivalents, both part of the Namaqua Metamorphics.

Your travels will then take you through some spectacular country, especially once onto the C19, where you will finally get off the flats (Figs. 28-29). The Fish River has its beginnings in this region, and its drainage is subtle, but at the end of your trip you will see it further downstream where it becomes absolutely spectacular in its incisive behaviour!

Fig. 28. Now things get more interesting – the C19 just east of Maltahöhe. Along the C19 the drive has been across the Fish River Subgroup of the Nama, and as one descends into Malhahöhe one moves downsection into the Schwarzrand and Kuibis subgroups of the Nama, which will dominate the cliffs from here south to Aus.

Figure 29. Outcrop showcasing large scale hummocky cros-stratification to be seen along the route south from Maltahöhe in the Fish River Subgroup (photo by C. Greentree).

Fig. 30. Aus region with granites and associated rocks of the Namaqua Metamorphics.

Interesting Icons Around Aus (Figs 30-43)

Fig. 31. The Bahnhof in early days.

Fig. 32. Aus and the granites.

Fig. 33. Monument to Kaiser Wilhelm.

Fig. 34. Old Catholic Hospital.

Fig. 35. Snake fountain, from which Aus got its name.

Fig. 36. German Army gun emplacement, Aus.

It is most unfortunate that there is no time to really get a bit more on the history of Aus, from distant times when the San, Nama and many others left their traces with art and tools, or the arrival of a variety of Europeans who sailed and sank ships off the coast to the west, oxwagons leaving their marks as the merchants plied their trade across the vast arid lands, til the times of the German and British/South African colonization. There are also reminders of the impact of WWI and II, reflected by many

Fig. 37. German Army gun emplacement, Aus.

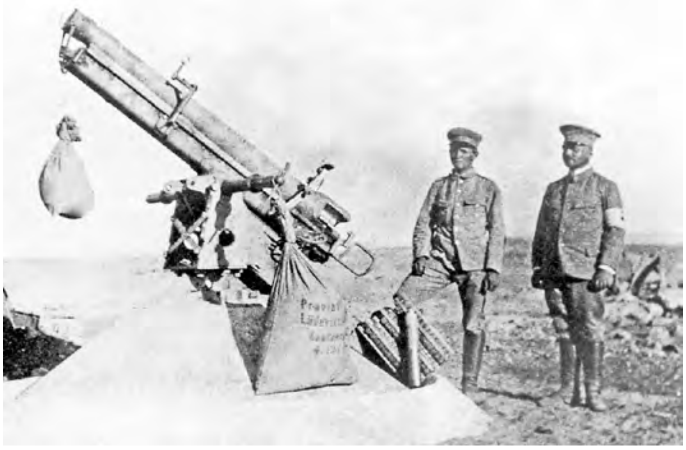


Fig. 38. Schutztruppe in and around Aus, early 1900's.

Fig. 39. Ready for attack, during WWI, South African forces, Aus.

Fig. 40. Old German School atop Aus granites

Figs. 41-43. German Prisoner of War Camp in Aus (See Bruwer, Prisoner of War Camp AUS 1915-1919). Leftovers in POW camp (far right).

icons around Aus,far from the wars, one outstanding being the manner in which the POW camp was managed by Major Nelson – in a humane and sometimes humerous manner, with the main loss of life due to the Spanish Flu. The Aus region is full of history and certainly worth of another visit (see Goldbeck, M. et al.*, 2011, 2012; Vaupel, 2011; McGregor and Goldbeck, 2014).*

FIELD CONFERENCE DAY 2 – FARM AAR

Patricia Vickers-Rich, Guy Narbonne, Michael Hall, Andrey Ivantsov, K.H. Hoffmann, David Elliott, Peter Trusler, Mikhail Fedonkin, Les Kriesfeld, Alan Jay Kaufman, Jeff Smith

One stunning area in southern Namibia is Farm Aar, owned and managed by Barbara Boehm-Erni (Fig. 44). It is criss-crossed by the Aar River, which has cut deep canyons into Ediacaran sedimentary rocks older than 547 Ma that overlie granites dated at 1.7 to 2.0 billion years old. Farm Aar spreads across 210 square kilometres and includes a most varied landscape.

Widespread table mountains, sheltered valleys and canyons lie beneath expansive clear blue skies. Elevation of the territory is just over 1500 meters above sea level, and because of this topographic height, climate on Aar is not as hot as in many of the other deserts of Namibia - mild in summer but sometimes quite cool in winter.

Fig. 44. Termite mounds in valley along the dirt track leading to Farm Aar.

Fig. 45. PTERIDINIUM – *NAMIBIA (P. Trusler). Farm Aar landscape from “*Pteridinium *Hill” near Windy Peak. Inset: Weathered Quartzite, Dabis Formation, Nama Group (Ediacaran). With* Pteridinium *specimens, ‘Living Stones’,* Lithops *and Lark-like Buntings,* Emeriza impetuani*.*

Farm Aar – Geologic Setting

Studies carried out by participants in UNESCO IGCP493/589 from 2003 to present have concentrated on one of the four areas into which Saylor *et al*. (1995) subdivided the southern Nama Basin, in particular in the region to the east of Aus, on Farm Aar, an area that has been studied paleontologically since the beginning of Ediacaran research and field work in the 1930s. These strata are richly fossiliferous, with Ediacaran shelly fossils (mainly *Cloudina*) present in the carbonates and iconic representatives of the Ediacara-type soft-bodied megafossils *Pteridinium, Rangea*, and *Ernietta* in the siliciclastics (Figs. 45-46). Farm Aar stands out as the most significant single site in all of Africa for these ancient organisms, and it has been designated and preserved as a National Heritage Site and National Geopark by the Namibian Government.

Nama Group strata on Farm Aar are represented by the lower part of the Kuibis Group, an early foreland basin succession comprising mainly shallow-water fine siliciclastics and carbonates. Saylor *et al*. (1995) recognized four sequences (K1 to K4) in the Kuibis Subgroup, two of which are relevant to this field trip, their K1 and K2. ***Sequence K1*** comprises the lower part of Dabis Formation, which nonconformably overlies crystalline basement. K1 consists of a basal unit of coarse, tabular-bedded sandstones (Kanies Member)) overlain by fine-grained, irregularly laminated dolostone and limestone (Zenana and Mara members). Sequence K1 is extremely thin on Farm Aar, but is considerably thicker at Pockenbank to the south [where we will see it on the morning of Day 3].

Sequence K2 comprises the Kliphoek and Aar (Hall *et al*., 2013) members of the the Dabis Formation and the overlying Mooifontein Limestone of the Zaris Formation. Saylor *et al*. (1995, 1998), Grotzinger and Miller (2008), Vickers-Rich *et al*. (2013) and Hall *et al*. (2013) described

Fig. 46. Reconstruction of the Nama Ediacarans by Christine Marais (from Schneider and Marais, 2004. Passage Through Time. The Fossils of Namibia).

the environmental succession of the Kliphoek, Aar and Mooifontein members, and the following descriptions of each of those members are from these papers.

The ***Kliphoek Sandstone*** consists of lowstand deposits consisting of mainly thick-bedded, coarse-grained quartzarenites with abundant meter-scale trough cross-bedding. Deposition may have occurred in a sandy braided fluvial or high energy nearshore or deltaic setting. The upper 70 cm of the continuous sandstone within the lower part of the Kliphoek Member consists mainly of fine-grained quartzarenite with syneresis cracks and/or sandstone injection structures, current and combined-flow-ripplemarks and hummocky cross-stratification.

The overlying ***Aar Member*** represents sediment accumulation during the transition from a braided, sandy, fluvial environment (Kliphoek Sandstone) to a fully marine, clear water environment, which eventually facilitated carbonate deposition (Mooifontein Member). The Aar Member consists of transgressive gray-green shale and siltstone with sporadic interbeds of very fine - to fine - grained, centimeter-scale sandstone event beds that are laterally discontinuous over decameter scales. Sandstone event beds are erosionally based. The lower part of each event bed consists of parallel-laminated sandstone reflecting upper-flow regime plane beds, which is overtopped by sandstone exhibiting hummocky cross-stratification, wave ripples, or combined-flow ripples. Centimeter-scale rip-up clasts of shale and/or microbialite also occur commonly in the upper half of these event beds. These features are diagnostic of storm beds modified by wave processes during the waning flow stage, and imply deposition slightly below fairweather wave-base on a muddy ramp (Myrow, 1992; Myrow and Southard, 1996; Plint, 2010).

Shallow-water limestones with hummocky and swaley cross-stratification, intraclastic textures, and microbial textures first appear abundantly near the top of the Aar Member. Laminated carbonates, locally containing cross-bedded ooids and the shelly fossil *Cloudina*, dominate the overlying ***Mooifontein Member*** and imply shallow-water deposition during highstand conditions to the top of the K2 sequence. The Mooifontein Member is part of an extensive carbonate platform that thickens northward toward the Damara Belt (Germs, 1983) and reaches a maximum thickness of 500 m along the Zebra River in the northern Nama sub-basin (Day 5 of this trip).

Detailed Studies on Farm Aar, 2004 – Present (UNESCO IGCP493/587)

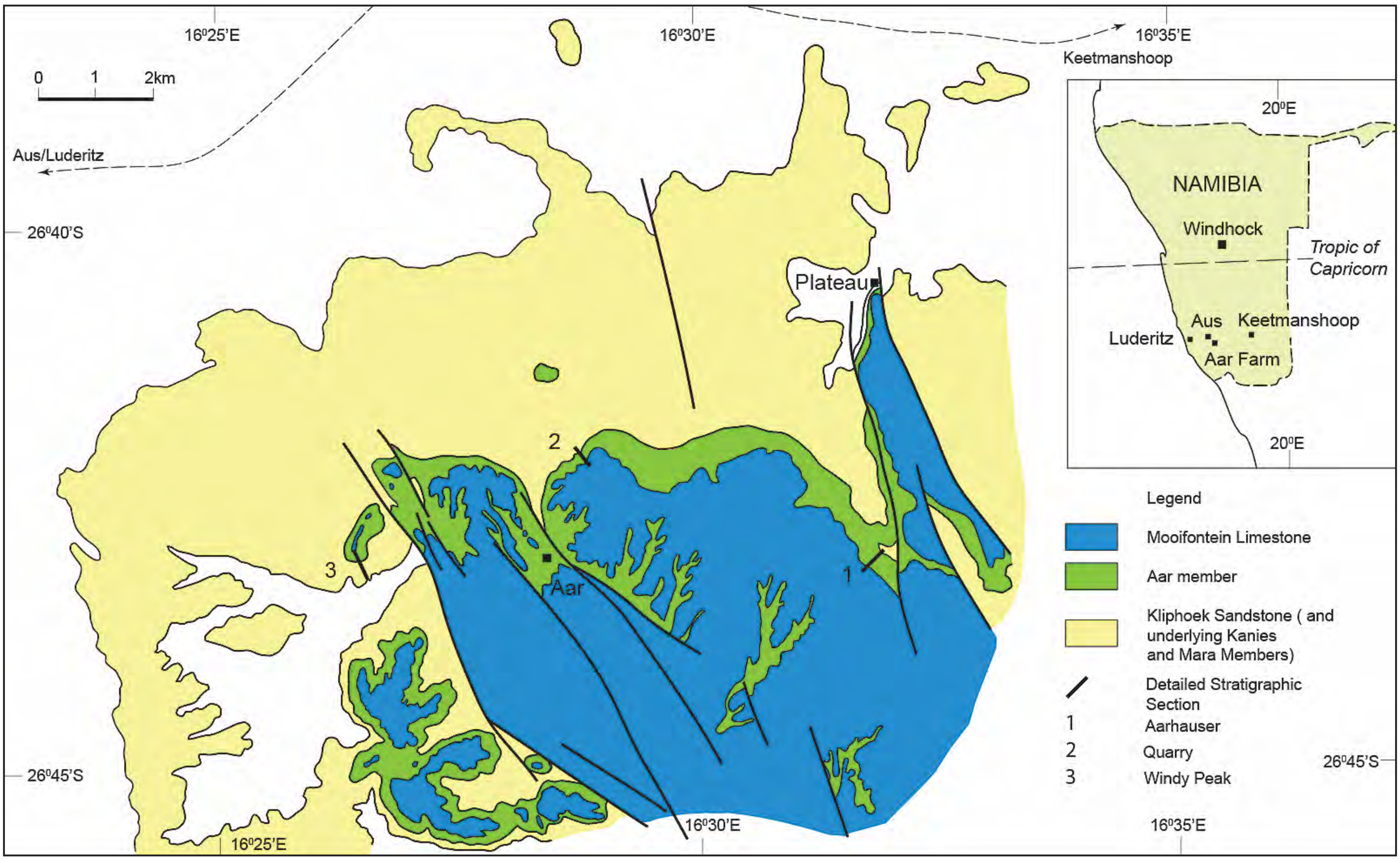


Fig. 47. Map of three localities of geological significance to be visited on Farm Aar.

Locality 1, Farm Aar: Aarhauser

The best known site, both human-history-wise and paleontologically, is the Aarhauser Site on the NE part of Aar (1, Fig. 47). It has long been known, first as a tool-making site of the Bushman (San), who left quartzite cores and tools (Fig. 48), second as an encampment site for some of the isolated Schutztruppe soldiers (thus the name "Aar Houses") in the early part of the 20th century (Fig. 49) and then later as a source for building materials used in such structures as the homestead on Plateau. Paleontologically it hosts a number of the Nama taxa, including abundant *Pteridinium* (Figs. 50-51) and *Ernietta*, as well as rare specimens of *Rangea* (Figs. 52-53).

Fig. 48. The Aarhauser sandstones were a source of Bushman (San) cores and resulting tools such as these, common on the eastern side of the Aarhauser site.

Fig. 49. One of the Schutztruppe huts which gives the name to this site.

Fig. 50. Slab with Pteridinium *at Aarhauser.*

Fig. 51. Pteridinium *at Aarhauser in Aar Mbr.*

Figs. 52-53. Rangea *specimen (l) exposed at Waterfall site at Aarhauser(r).*

Two members of the Dabis Formation are exposed at the Aarhauser locality, the Kliphoek Member and the Aar Member, and these will be explored in some detail. Desiccation cracks and other evidence of exposure is apparently absent from both the Kliphoek and the Aar members at this locality. The Kliphoek Sandstone is best exposed in the waterfall section, and consists of mainly thick-bedded, coarse-grained quartzose sandstones showing unimodal cross-bedding directions (Fig. 53). A single specimen of *Rangea* is preserved at the top of this succession (Fig. 52). Overlying strata in the uppermost part of the Kliphoek Sandstone are thinner-bedded and finer-grained quartz sandstones. The overlying Aar Member includes sandstones and shales interspersed with a number of the limestone units that typify the dynamic environments of the time, which eventually led to the transgression resulting in the dark limestones of the overtopping Mooifontein forming the top of the plateau [see, included literature for this field excursion]. Within the Aar Member at Aarhauser there are a number of enigmatic structures, such as the bag-like impressions that may indeed be to external covering of *Pteridinium* (Fig. 54), and some of the better known ediacaran taxa preserved in ironstone (see Fig. 55). Stromatolites are also evident in the sequence here (Fig. 56).

Figs. 54 a, b. In the upper part of the Aar Mbr bag-like structures occur that may have been the outer surface of Pteridinium *(r). David Elliott and Guy Narbonne exploring the level in which these impressions are preserved (l).*

Fig. 55. Ironstone preservation of ediacarans is rare but gives the possibiity of preservation of internal structures.

Fig. 56. Stromatolitic structures in the Aar Member at Aarhauser.

This stop showcases one of the most famous Ediacaran fossil occurrences anywhere in the world, a huge and nearly monospecific accumulation of the erniettomorph fossil *Pteridinium*. This abundance of *Pteridinium* at Aarhauser was figured by Andy Knoll and Sean Caroll on the cover of Science (June 25, 1999), and it was a key site for debates about the nature and affinities of *Pteridinium* by Grazhdankin and Seilacher (2002), Elliott *et al*. (2011), Meyer *et al*. (2014a,b) and Seilacher and Gishlick (2014). Specimens are twisted and bent, and although several elongate specimens are preserved in this bed, it is not clear if any specimen preserves either the proximal or the distal end of *Pteridinium*. Grazhdankin and Seilacher (2002) interpreted these fossils as the *in situ* remains of Ediacaran organisms that lived permanently buried within the sediment, and this formed the basis for their well-publicized model for “Underground Vendobionta” (see Fig. 10).

Some of the evidence for this conclusion, specifically fossils apparently growing through each other (Grazhdankin and Seilacher, 2002, text-fig. 5), was challenged by Meyer *et al*. (2014b), who concluded that subsequent CT-scans Fig. 57) demonstrated that all such interpreted occurrences reflected twisted rather than intergrown specimens. Hall *et al*. (2013) concluded that the massive sands that host these fossils were produced by downslope avalanches, which had picked up, transported and finally entombed these Ediacaran organisms in their present jumbled positions. This trip will provide an opportunity for participants to examine the wide array of paleontological and sedimentological features in this famous fossil occurrence. We anticipate a lively discussion on the outcrop and later in the evening!

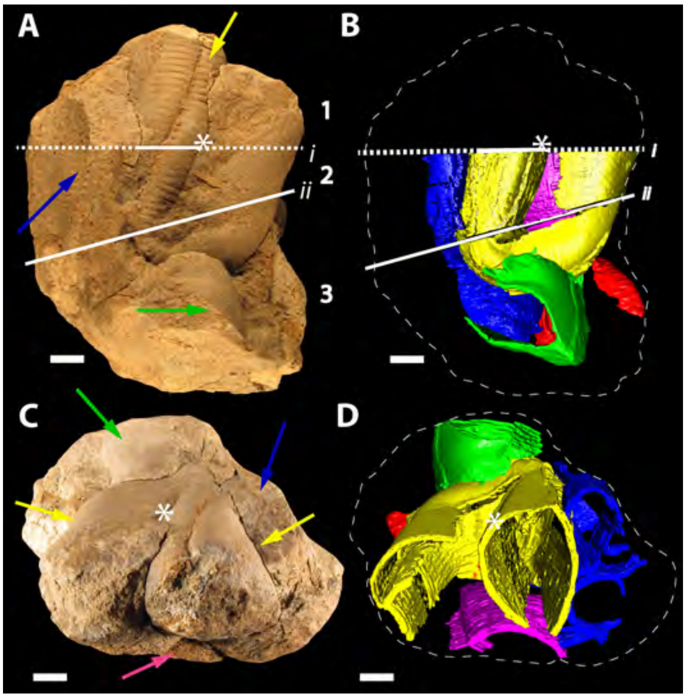


Fig. 57. Light photography and 3D reconstruction of Pteridinium simplex *(from Meyer* et al.*, 2014).*

Locality 2 Farm Aar: Road Quarry 2.3

This stop (Fig. 60) illustrates the contact between the Kliphoek Sanstone and the overlying Aar Member, and showcases a remarkable occurrence of complete, three-dimensional specimens of *Rangea* preserved 35-40 cm above this contact. *Rangea* was the first complex Ediacaran fossil named and defined anywhere (Gürich, 1930), and it has become both an iconic image of the Ediacara biota that has been figured in nearly every Ediacaran diorama - the type genus for the Rangeomorpha, a major clade in Ediacaran life. Prior to 2004, a total of less than 25 specimens of *Rangea* had been described worldwide, none of them collected from outcrop by a paleontologist.

Discovery of more than 100 *in situ* specimens in gutter casts from the basal Aar Member at Stop 2 and 3 (Vickers Rich *et al*., 2013) significantly enhanced the global dataset and also provided the first 3-dimensionally preserved specimens for this taxon. Details of this stop can be found in Hall *et al.* (2013) and Vickers-Rich *et al*. (2013), and the following descriptions are summarized from these two papers.

Fig. 58. Road Quarry 2.3.

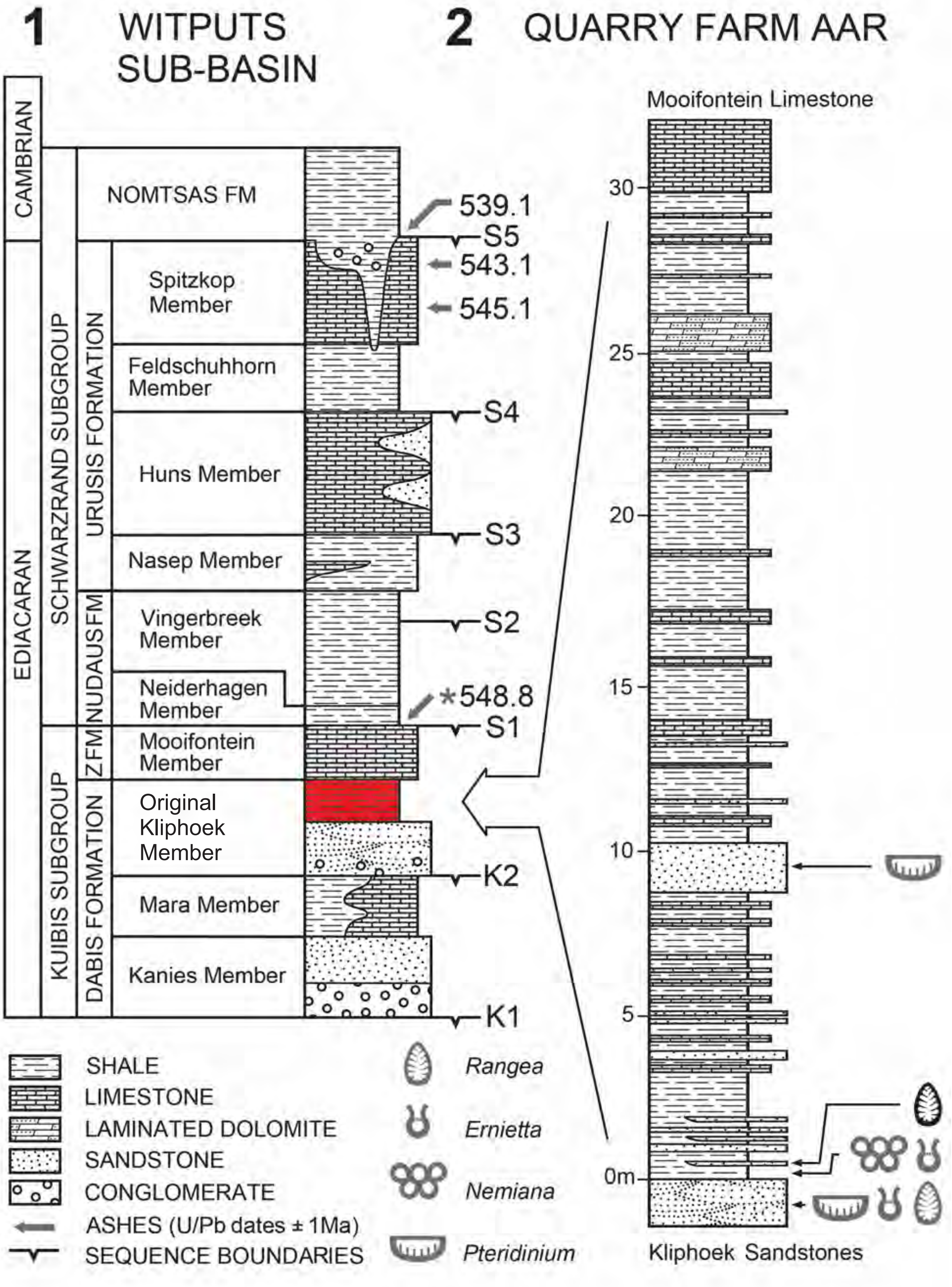


Fig. 59. Road Quarry 2.3, Loc. 2, the type section of the Aar Member of the Dabis Formation. Strat column on left shows the newly named Aar Member, which is the upper part of the 'old' Kliphoek Member, now restricted to the bottom half of the original Kliphoek Member. It also records the revised dates discussed in this report (Narbonne et al.*, 2012; Schmitz, 2012). Strat column on right reflects the understanding of this sequence.*

Uppermost strata of the Kliphoek Sandstone (Kliphoek Member) consist mainly of fine-grained quartzarenite with syneresis cracks and/or sandstone injection structures, current and combined-flow-ripplemarks and hummocky cross-stratification. The basal part of the overlying Aar Member consists of recessive-weathering mudstones interbedded with very fine - to fine-grained, centimeter-scale, erosionally based, sandstone event beds that are laterally discontinuous over decimeter scales. The lower part of each event bed consists of parallel-laminated sandstone reflecting upper-flow regime plane beds, which is overtopped by sandstone exhibiting hummocky cross-stratification, wave ripples, or combined-flow ripples. These features are typical of storm beds modified by wave processes during the waning flow stage, and imply deposition slightly below fairweather wave-base on a muddy ramp (Myrow, 1992; Myrow and Southard, 1996; Plint, 2010). Shallow-water limestones with hummocky and swaley cross-stratification, intraclastic textures, and microbial textures first appear approximately 3.5 m above the base of the Aar Member and increase in importance upward through the Aar.

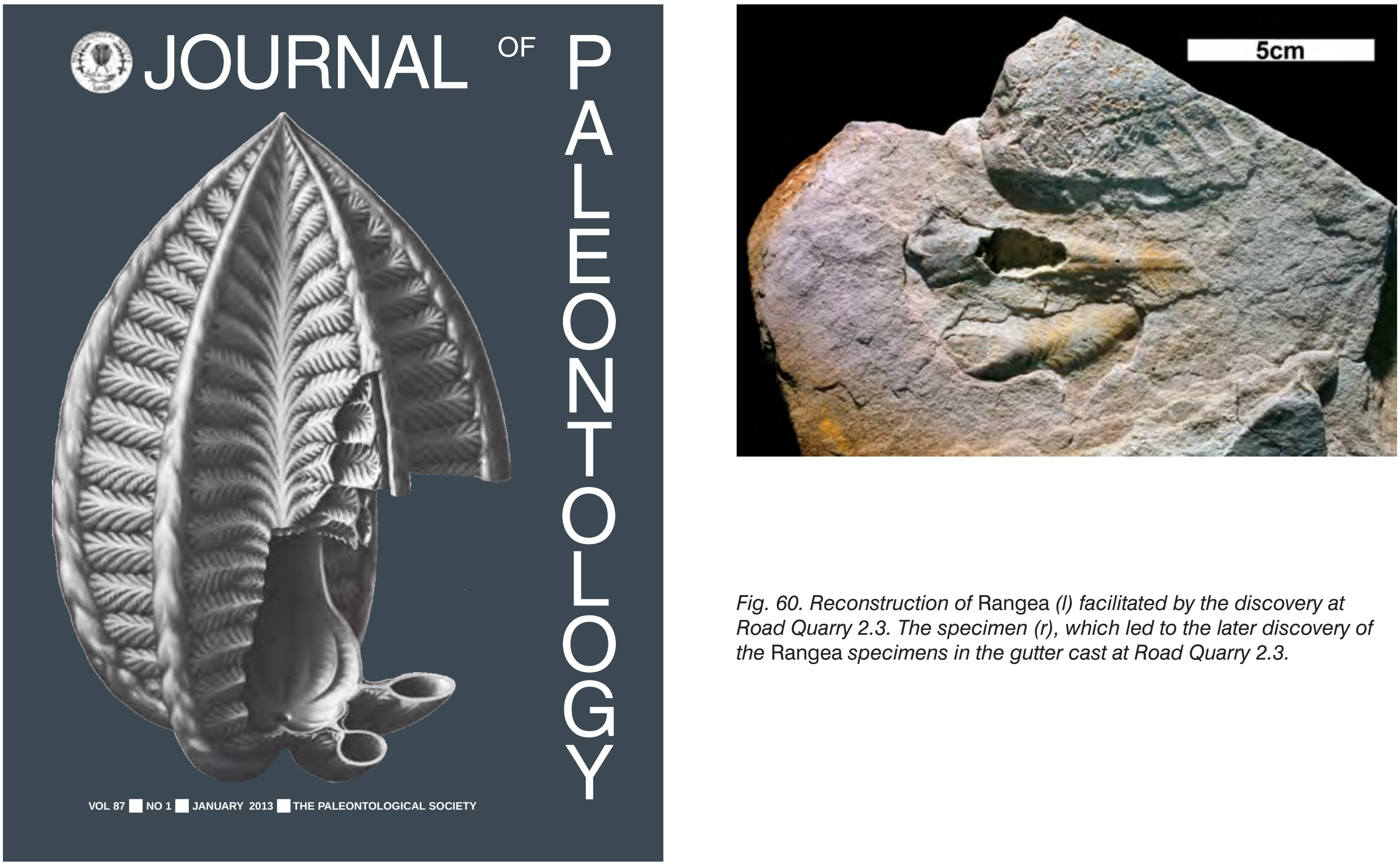


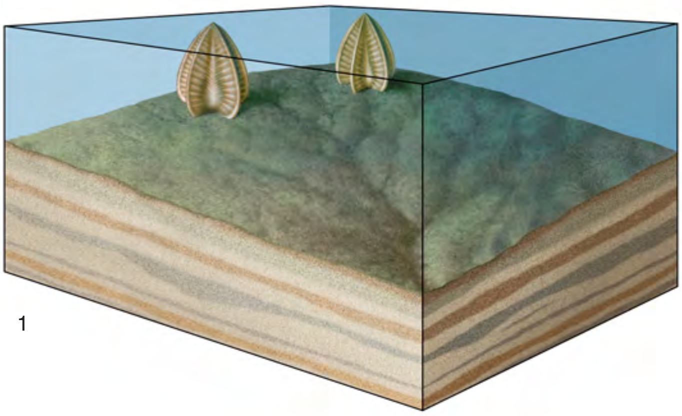
Fig. 60. Reconstruction of Rangea *(l) facilitated by the discovery at Road Quarry 2.3. The specimen (r), which led to the later discovery of the* Rangea *specimens in the gutter cast at Road Quarry 2.3.*

The newly-discovered *Rangea* fossils occur in two gutter casts one at Stop 2 and one at Stop 3, that are located approximately 35-40 cm above the base of the Aar Member. Both gutter casts were completely excavated, and the fossils have been reposited in the National Earth Science Museum (NESM,) Geological Survey of Namibia, Ministry of Mines and Energy collections in Windhoek. The gutter cast at Stop 2 was 38-55 cm wide with a preserved length of 1.2 meters. It had gentle to near-vertical walls and a flat-bottom that was adorned with tool marks and other evidence of erosion. It was 10 cm deep, with a bipartite fill that consisted of unfossiliferous, finely laminated, fine-grained quartz sandstone confined to the gutter cast and abruptly overlain by very fine-grained quartz sandstone with low angle hummocks and swales filling the gutter cast and occasionally steps beyond the erosional margins of the underlying channel. Fossils are known only from the upper part of the gutter-cast-fill, and invariably are oriented horizontally but with no preferred orientation within this horizontal plane. None are in their original life position, and all specimens appear to have been transported in the flow that filled the gutters.

The fine structural details of the *Rangea* specimens are preserved in the mineral jarosite, a complex hydrous sulfate of potassium and iron with a chemical formula of KFe3+3(OH)6(SO4)2, which appears as a yellow mineral coating the *Rangea* fossils. It seems likely that the original coating mineral was pyrite, with later oxidation to jarosite by acidic groundwater, the addition of potassium probably coming from the subarkosic sandstones in which the fossils are preserved. These jarosite coatings are key to the three-dimensional preservation of these specimens and to the techniques that were used to elucidate it (Vickers-Rich *et al*., 2013).

The internal structures of *Rangea* (Fig. 60) consist of a basal, hexaradial axial bulb that passes into an axial stalk, which extends to the distal end of the specimen. This axial structure is the foundation for six vanes arranged radially around the axis, with each vane consisting of a bilaminar sheet composed of a repetitive pattern of elements exhibiting at least three orders of the self-similar (rangeomorph) branching. The basal part of the axial bulb is typically partly filled with sediment, with the dorsal end of the stalk typically preserved as an empty, cylindrical cone. This base probably served as a 'weight belt' to keep the organism in an upright position sitting on the sediment surface in life, with later transport to form the fossil accumulations in the gutter cast (Figs. 61-62).

Further information and additional illustrations can be found in the paper by Vickers-Rich *et al*. (2013) [see included literature for this field excursion].



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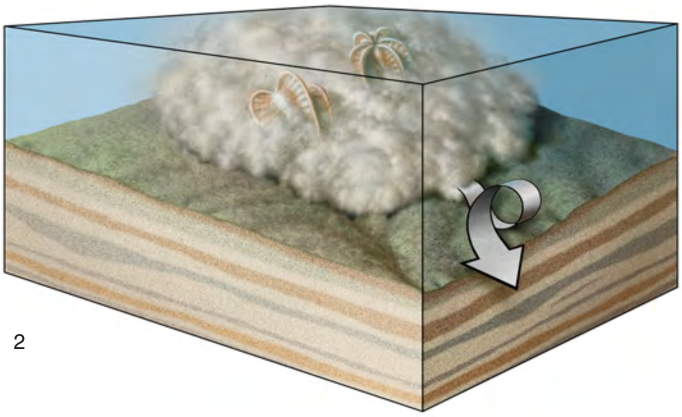

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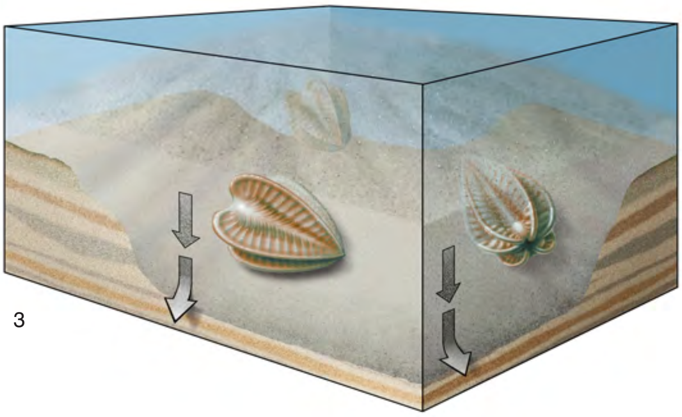

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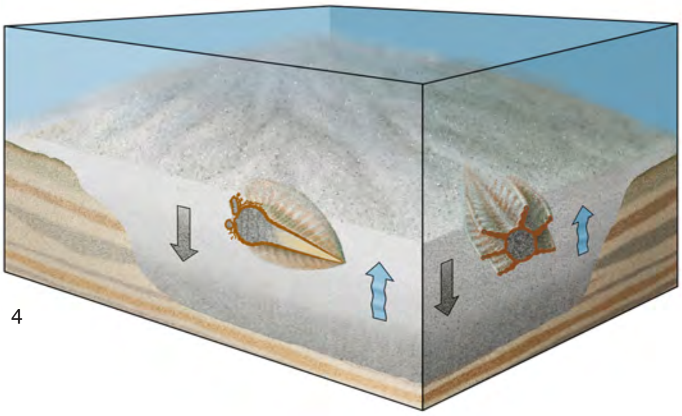

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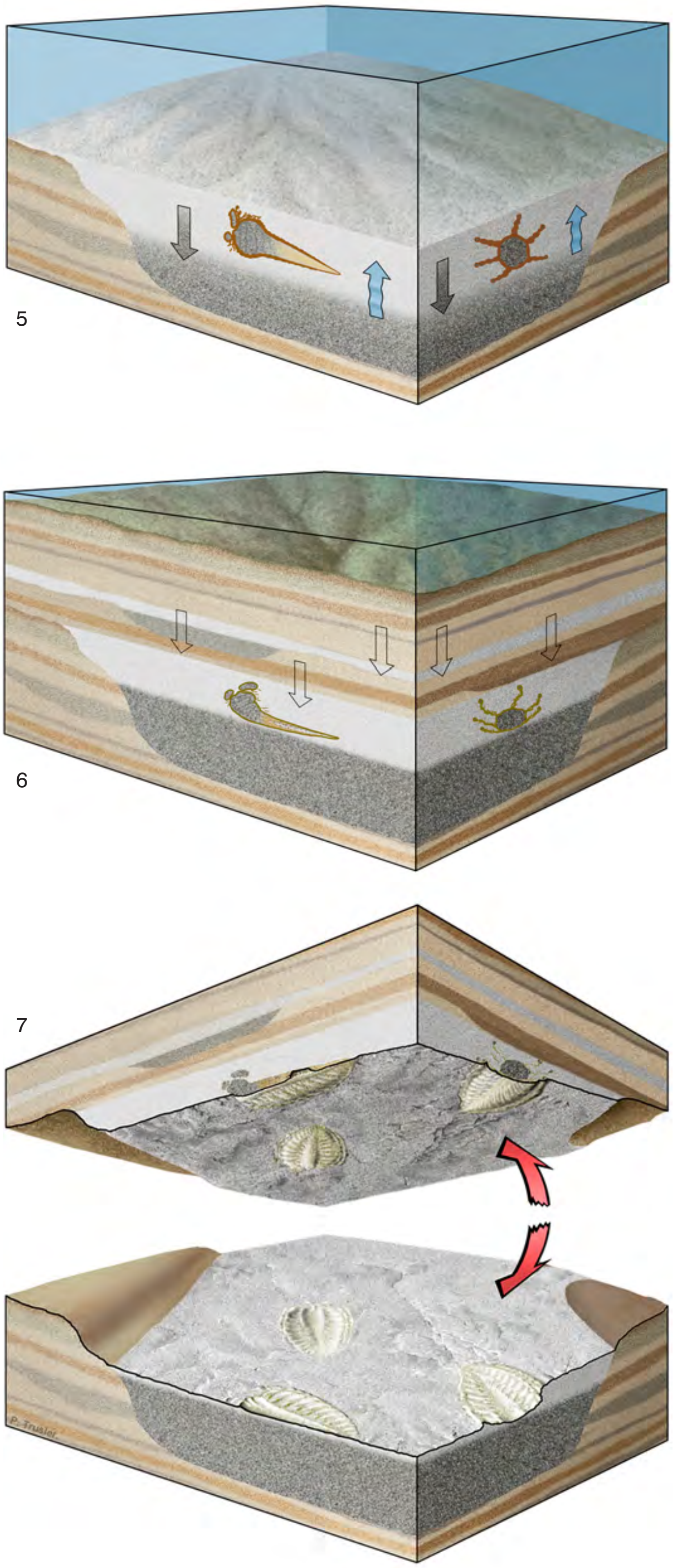


Fig. 61. Scenario depicting how the Rangea *material was preserved in the gutter sediments cropping out at Road Quarry 2.3. (P. Trusler in Vickers-Rich* et al.*, 2013).*

Fig. 62. Sedimentary features immediately overlying the Rangea *gutter cast at stop 2 (Road Quarry 2.3) shales, thin-bedded sandstone event beds and hummocky cross-stratified sandstones.*

Fig. 63. Some of the clay layers in the shale sequence above the Rangea*-bearing sediments host dark structures of enigmatic origin, perhaps some of these algae (see Leonov* et al.*, 2010).*

Locality 3, Farm Aar: *Ernietta* Hill, Teapot, Windy Peak Area

One of the most complete sections of the Nama Group on Farm Aar occurs in the Windy Peak area of the farm, to the west of the Homestead (Figs. 64-65). Here the contact between the basal granites and the Nama Group can be viewed in the valley that runs south and east of Windy Peak. This basement gives concordia ages of 1985+/-10 Ma and 1985+/- 12 Ma. (Linneman and Hofman, pers. com.; Hall *et al.*, 2013).

Fig. 64. Windy Peak showing basal Kanies, Mara, Kliphoek, Aar and members of the Dabis Formation and overtopped by the Mooifontein Limestone of the Zaris Formation. This is the most complete section that will be examined on this field trip and clearly records the change from fluvial conglomerates at the the base through a dynamic sequence that terminates with the truly marine conditions leading to deposition of the dark grey limestones overtopping this sequence.

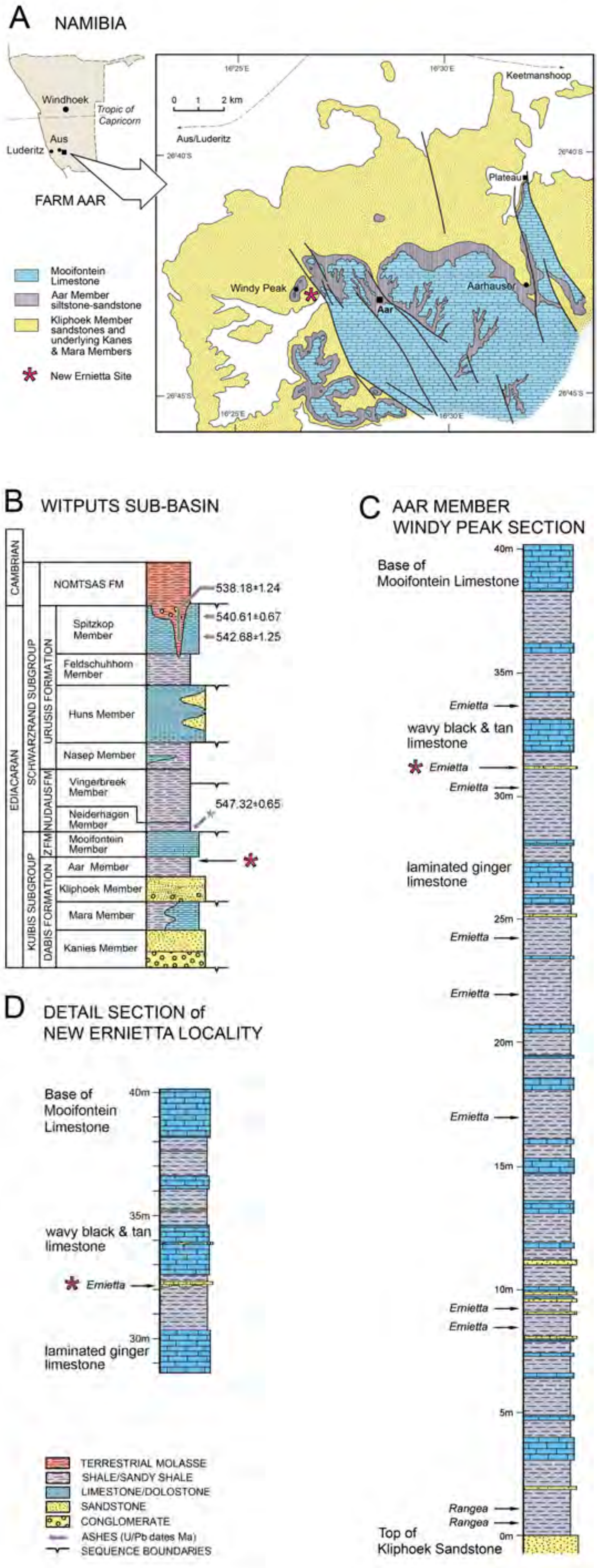


Fig. 65. Stratigraphy of the Windy Peak area.

Detail for this part of the field trip can be found in Hall *et al*. (2013) and Ivantsov *et al*. (2015) [see included literature for this field excursion]. This area has produced important material leading to a much better understanding of the morphology of Ediacaran taxa from Namibia. Specimens of the globally distributed discoid fossil *Beltanelliformis* (Nemiana) (Fig. 66-68) are common, and strata slightly to the west of Windy Peaks contain excellent specimens of *Pteridinium* (Fig.69) as well as gutter cast containing spectacular specimens of *Rangea* preserved in the three dimensions (Fig.70).

The key discoveries, however, are those of the genus *Ernietta*, which until recently was known largely from float specimens and thus lacked geological context and completeness. *Ernietta* was named by Pflug (1966) for sand-filled, sac-shaped fossils having walls constructed from vertically arranged tubes that form a palisade-like structure. It is an iconic Ediacaran taxon that, like *Rangea*, appears in all major Ediacaran dioramas and forms the type genus for one of the two major clades of Ediacaran life (in this case, the Erniettomorpha).

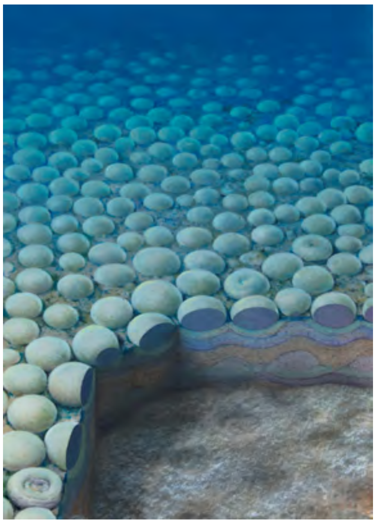


Fig. 66. Beltanelliformis (Nemiana) *reconstruction (P. Trusler).*

Fig. 67. Beltanelliformis (Nemiana) *(*Ernietta *Hill).*

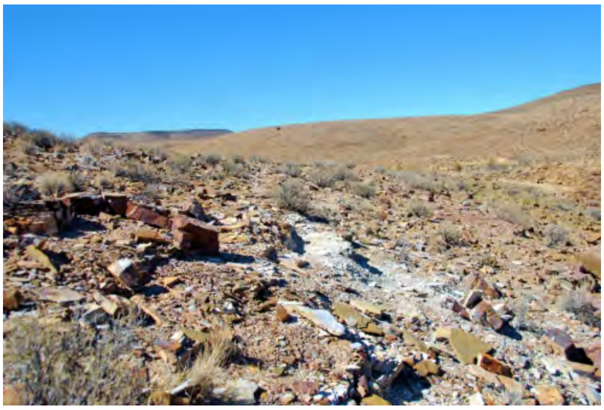


Fig. 68. Quarry on the flank of Ernietta *Hill where* Beltanelliformis (Nemiana) *was found in concentrations.*

Fig. 69. Pteridinium *(l) from the top of the Kliphoek Member, west of* Ernietta *Hill, Windy Peak area and associated baggy structures that may be the external covering of either* Pteridinium *or in some cases* Ernietta*.*

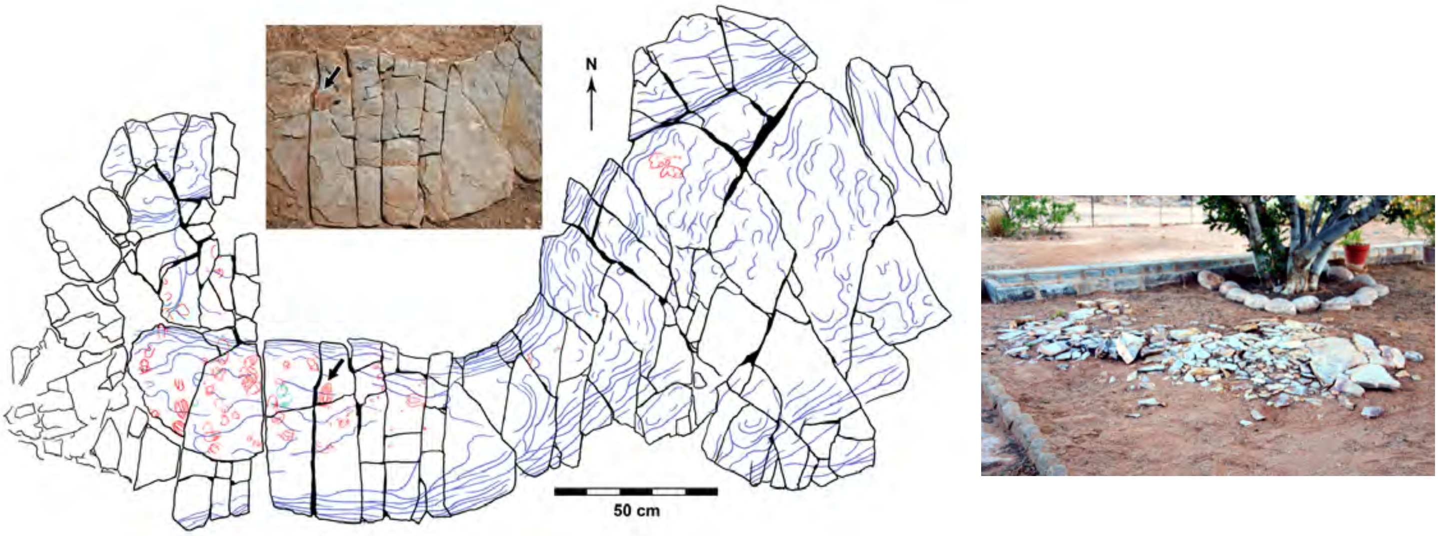


Fig. 70 a, b. Small channel discovered and recovered from the Aar Member near Ernietta *Hill. This gutter cast was transported to the front yard of Farm Aar homestead (r) where it can be viewed on this field conference. This particular channel contained mainly* Rangea*, red outlines on the channel noting position and orientation of fossil material in channel, blue indicative of channel flow directions.*

Fig 71. Teapot locality (l and r) near Ernietta *Hill where* Ernietta *was first found in place.*

A large collection of *Ernietta* bases preserved on a deflation surface were discovered in 2004 at the appropriately named *Ernietta* Hill and were subsequently been described by Elliott *et al*. (2016, in press) (Figs. 71-72).

An even more significant find is the discovery of the first-known specimens of *Ernietta* anywhere in the world that are in outcrop, complete and preserved in three-dimensions (Ivantsov *et al*., 2015) (Fig. 73). Despite the many scores of specimens illustrated by Pflug (1966, 1972), Jenkins *et al*. (1981), Vickers-Rich and Komarower (2007), Seilacher and Gishlick (2014) and Elliott *et al.* (2016, in press), all known specimens were from float and were incomplete, consisting only of the basal part of the organism or basal and part of the more dorsal section.

This led to considerable variation in the three-dimensional reconstructions of *Ernietta* and in interpretations of its lifestyle, which ranged from fully endobenthic (Crimes and Fedonkin, 1996) to semiendobenthic (Jenkins., 1981, 1985, 1992; Seilacher, 1992; Seilacher *et al*., 2003; Seilacher and Gishlick, 2014) to epibenthic (Jenkins *et al*., 1981; Jenkins, 1985, 1992; Dzik, 1999).

Fig. 72. Ernietta *in cross-section showing two layers of tubular structure (scale 1 cm.).*

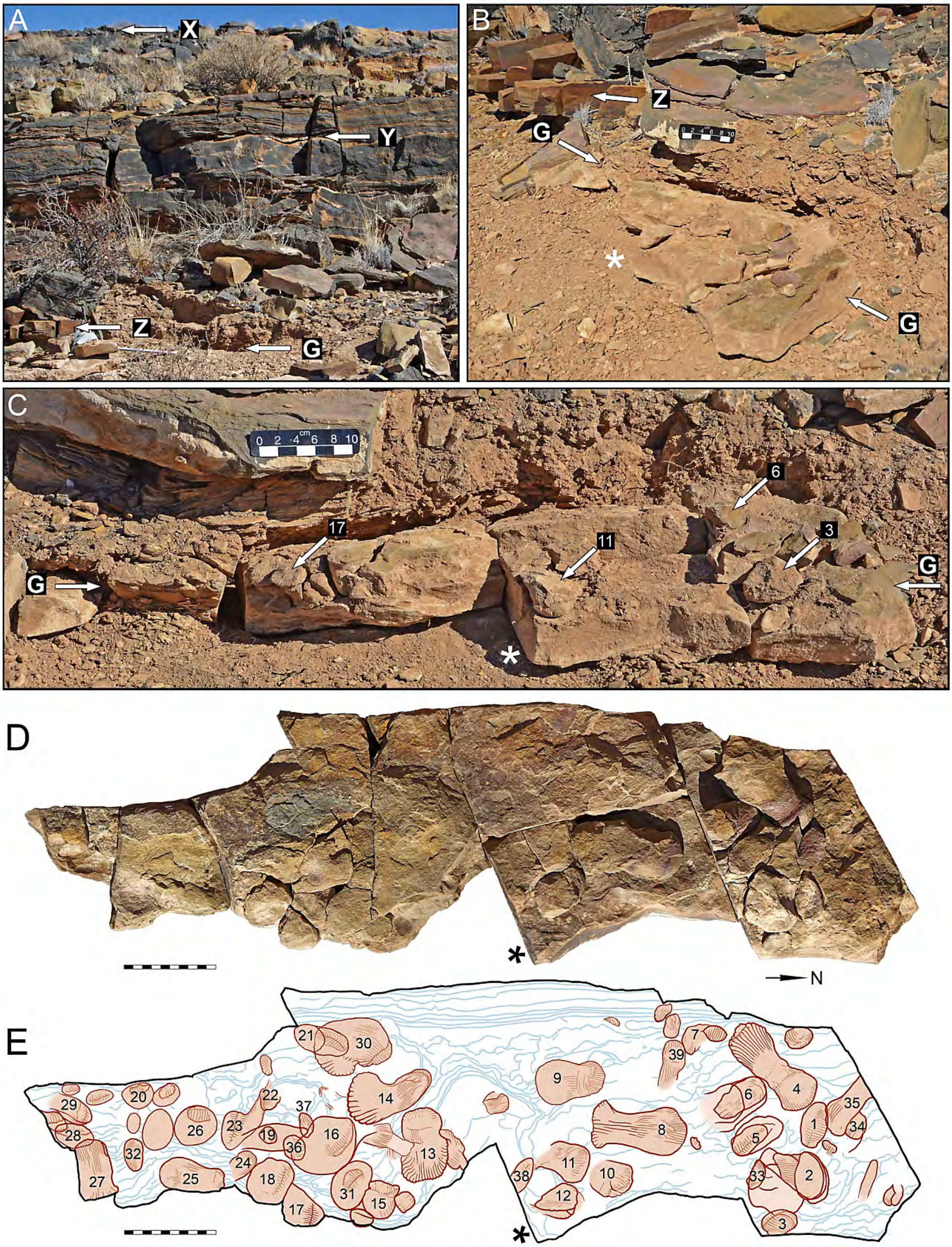


*Fig. 73. Fossiliferous gutter cast NESM-F722, Farm Aar in south-western Namibia. Symbols G = gutter cast; X = base of Mooifontein Member; Y = wavy black and tan limestone; Z = sandstone layer immediately above gutter cast; *common point for reference in B–E, Scale bar (A, B) represents 10 cm. Gutter cast and all specimens reposited in the National Earth Science Museum (NESM) collection in Windhoek under the numbers listed on the image (D, E, e.g. NESM-F722-8). Scale bar subdivisions 1 cm. A, location of the fossiliferous gutter cast in section. B, C, photographs of the partially excavated gutter cast* in situ. *D, reassembled gutter cast in top view. E, outline of the gutter cast (as though transparent) showing the horizontal distribution of* Ernietta *fossils excavated from within the deposit and registered against the flow pattern (light grey lines) as cast by the lower sediment unit (from* Ivantsov *et* al.*, 2015).*

In 2014, more than 100 specimens of *Ernietta* were found in a small gutter-cast located near the top of the Aar Member (Fig.73A-E). As summarized from Ivantsov *et al*. (2016) specimens within the mass-flow deposits in the gutter cast ranged through a continuous series from short, vertically oriented specimens indistinguishable from the type specimens of *Ernietta*, longer, obliquely oriented specimens (Fig. 73 D-E), to a few fully horizontal (procline) specimens that reveal the complete, three-dimensional shape of *Ernietta* (Fig. 73-74). These specimens collectively show that most all of the classic specimens of *Ernietta* represent only a basal, sand-filled anchor that in complete specimens passes distally into a trunk that is crowned by two facing fans which extended into the overlying water column (Figs. 74-76). In contrast to these differences in shape in different parts of the complete *Ernietta* organism, the architecture of *Ernietta* everywhere consists of a longitudinal palisade of morphologically similar tubes. These tubes could be modified to fill all of the functional needs of *Ernietta* – ranging from sand-filled tubes that helped to anchor the buried base of the organism in the seafloor, to the support function fulfilled by fluid-filled tubes in the mid-trunk region, to the tubes in its distal fan that may have performed feeding and/or respiratory functions.

Fig. 74. Complete specimen of Ernietta *found near* Ernietta *Hill, showing the base and the dorsal fan. These were the first complete specimens known of this taxon and found in small channel deposited as part of the Aar Member, Dabis Formation.*

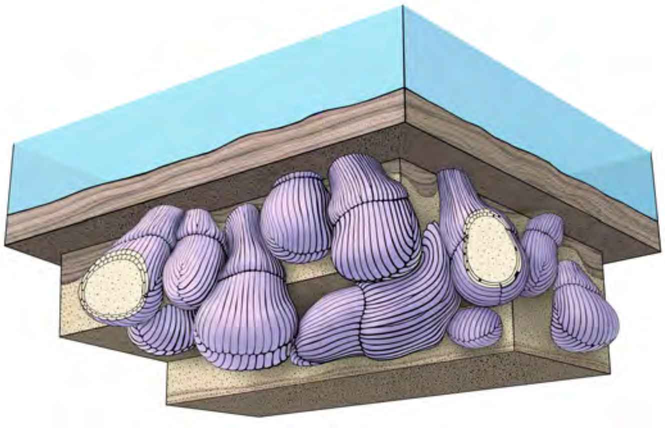


Fig. 75. Reconstruction of the possible lifestyle of Ernietta*.*
(P. Trusler, from Ivantsov et al.*, 2015)*

Fig. 76. P. Trusler's reconstruction of a complete Ernietta
(from Ivantsov et al.*, 2015).*

Most Ediacaran specimens in Namibia occur in graded, hummocky or swaley cross-stratified event beds of sandstone (Bouougri *et al*. 2011), and this represents the norm for Nama-style preservation (Narbonne 2005). The occurrence of complete, three-dimensional specimens of *Rangea* and of *Ernietta*, preserved in gutter casts at the bottom and top of the Aar member (respectively), provide a new search image for exceptional preservation of Ediacaran fossil impressions in Namibia and elsewhere.

Farm Aar – National Heritage Site And Geopark – Human History And Natural Treasures

Patricia Vickers-Rich, Bernd Roemer, Barbara Boehm-Erni and the Erni Family

Fig. 77. Barbara Boehm-Erni with friends on Farm Aar.

Fig. 78. Oryx on Farm Aar.

Fig. 79. Oryx rock art on Farm Aar.

Fig. 80. Springbok on Aar.

Farm Aar, owned by Barbara Boehm-Erni (Fig. 77), boasts many treasures, modern and ancient, and has been declared both a Geopark and a National Heritage Site by the National Heritage Council of Namibia. It is a haven for wildlife - the magnificently horned oryx, kudus, ostriches, springhares, baboons, small wildcats, a great variety of birds (including the noisy bustards), lizards (the big-eyed gecko and even frogs at the waterholes), snakes, scorpions and an array of insects (Figs. 78-87, 90, Plate 1) as well as an abundance of unique vegetation (Figs. 89-91). It is a place with significant historical and scientific assets.

Aar has been a working farm for more than 100 years, and some of the original and architecturally stunning farm buildings are constructed of the very quartzite rocks that are so telling of the Earth's most ancient of history here. The activities of humans, both modern and ancient, are apparent in the way the land has been managed and utilized. Rock engravings and ochre paintings in sandstone overhangs bespeak of an ancient past. And even older are the remains of the first complex and large eucaryotes to appear on Earth, the Ediacarans, first recognized by geologists mainly searching for water and German soldiers stationed in this area during the early part of the 20th century. Geologists Dr Paul Range and Hans Schneiderhöhn were aware of these strange fossils, and they began collections in 1908, then informed Dr George Gürich, who then ran a field trip when he attend the 15th International Geological Congress in Pretoria in 1929. Similar fossils were discovered later in Australia (Sprigg, 1947; Glaessner, 1959) and England (Ford, 1952). Only then were the importance of these finds in Namibia truly realized – complex and large forms that were older than the Cambrian – they were a solution to Darwin’s dilemma of where complex life came from! And importantly, the Nama Ediacarans were really the last of their lot before forms clearly related to living animals appeared in abundance in the early part of the Cambrian some 541 million years ago.

Fig. 81. 'Big bird' Ostrich, Aar.

Fig. 82-83. Scorpions come in small and large sizes on Aar and Plateau farms.

Fig. 84-85. Camouflage: Left to right, spider and lizard.

Fig. 86. Camouflage: Sand Grouse.

Fig. 87. Klipspringer in the rocks on road to Aar Farmhouse.

Fig. 88. Lithops, *well adapted to the aridity.*

Fig. 89. Ornithogalum
(Bird's Milk Plant).

Fig. 90. Social Weaver nests on dirt road from Aar to main highway.

Fig. 91. Aloe

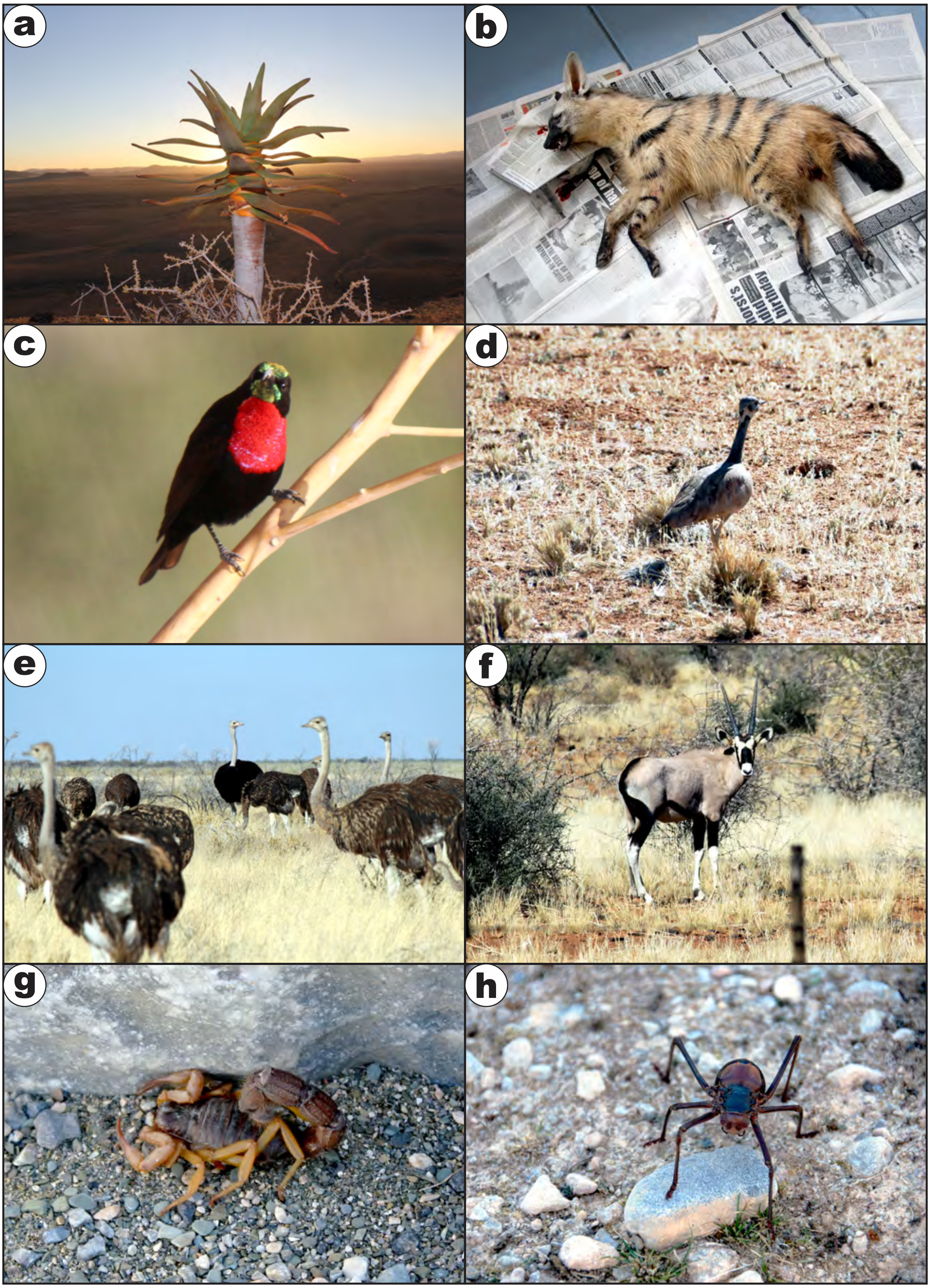


Plate 1. Native fauna and flora on Farm Aar. a, Quiver Tree, Aloe dichotoma *(young); b, Aardwolf,* Proteles cristata *(road victim); c, Scarlet-chested Sunbird,* Chalcomitra senegalensis *(male);d, Ruppell's Korhaan,* Eupodotis rueppellii *(male); e, Ostrich,* Struthio camelus *(males, females and immatures); f, Oryx (Gemsbok),* Oryx gazelle*; g, scorpion; h, Armoured Bush-Cricket,* Acanthopllus discoidalis*.*

Farm Aar and Surrounds, Human History

The canyons, deep notches in the landscape, have sheltered humanity for tens of thousands of years on Farm Aar. Early human history on Aar is documented by petroglyphs carved into the Mooifontein limestones, which serve as cap on the plateaus. The Bushmen have also left their colourful ochre paintings on the ceilings and walls of some overhangs. This ancient art includes animals and birds that still live in the area – the magnificent oryx and ostrich – but also depicted are people and animals long gone from this place - zebras, giraffes, rhinos, elephants and dancing Bushmen. There are even paintings of animals from far away today and in the past - the image of a whale – perhaps seen by a traveller to the region from the Skeleton Coast more than 120 km to the west. This paleoart can be appreciated at many sites around Farm Aar, especially in the low angled afternoon light. And, in addition to their art, ancient peoples also left their artefacts - stone tools and the tool factory floors of worked quartzites, cherts and quartz. There is even a large ‘singing stone’, which when struck resounds as echoes along the sinuous canyon walls. The petroglyphs and paintings have been the subject of scientific research resulting in several publications (Wendt, 1974, 1978; Breunig, 2014) for decades, and in many senses are still not well understood. (Figs. 92-101, Plate 2).

Also abundant around the farm, especially along the cliff edges formed by the dark Mooifontein Limestone, in addition to the stone artefacts, are some crude iron arrow tips and potsherds along with Ostrich shell beads. Clearly this is a jumble, and dates that have been determined on charcoal associated with two sites, KN-I-630 from Aar A and B, are very young, only at most a hundred or so years. Other dates determined by associates of Wolfgang Wendt (Freundlich *et al*., 1980) in such places at Apollo 11 Cave to the SE range from 18,000 to greater than 49,500 years, and Pockenbank to the south of Aar from 6900 to more than 39,000 years. The area is complex, and more dating and exploration is in order for the many sites on Aar. At this point the dates noted by Breunig (2014) for rock art and paintings on Aar range between 6000-8000 years.

Cave Art On Aar (Figs. 92-98)

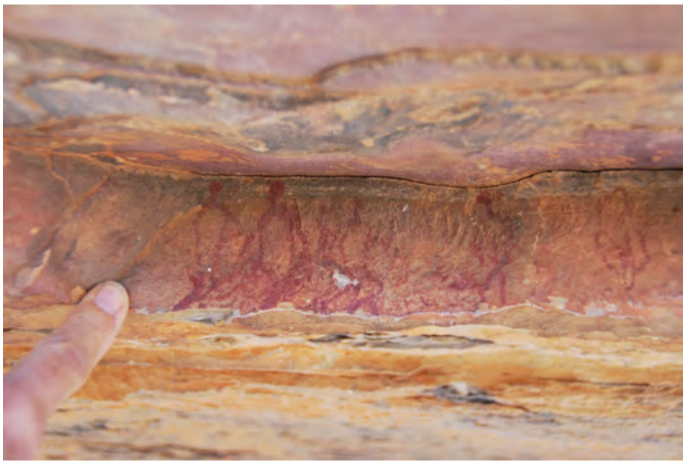
A variety of cave art that occurs in several overhangs across Aar, some of which is estimated to date at from 6000-8000 years (Breunig, 2014) as noted above.

Fig. 92. Snake Cave roof, Farm Aar.

Fig. 93. Snake Cave on Farm Aar.

Fig 94. Cave Art on Aar, Ostrich, near homestead.

Fig 95-96. Cave Art on Aar, from left to right – Whale (or some have suggested shark) and Rhinos.



Figs. 97-98. Cave Art in overhang near Farm Aar Homestead – from left to right dancing people and Shaman, an image of mystery.

Petroglyphs on Aar (Figs. 99-101, Plate 2)

Figs. 99-101. Left to right – waterhole near the site of rock art on Aar, running Rhino and running human figure.

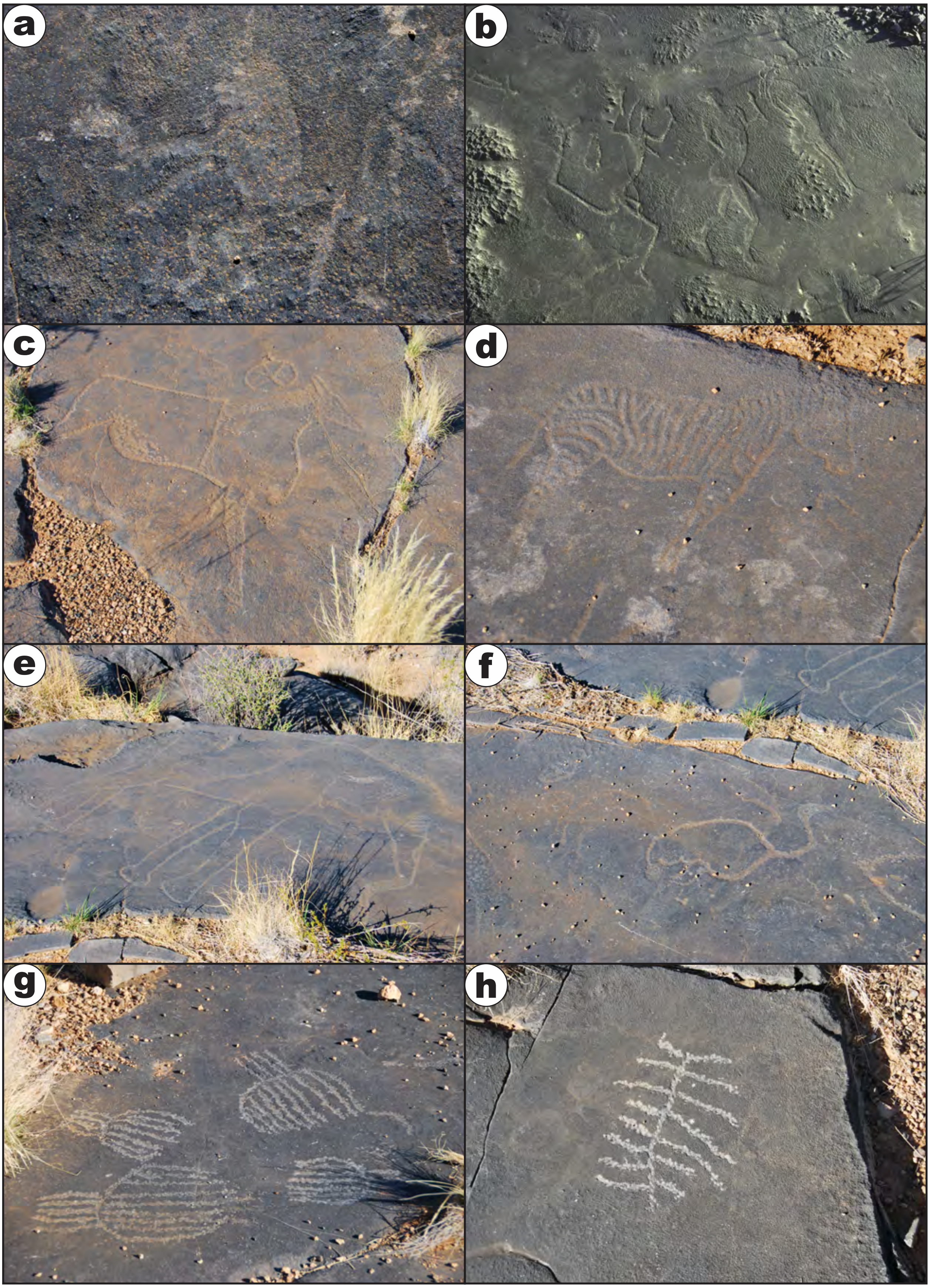


Plate 2. Rock art is abundant on Farm Aar. One outstanding site is "Arche Noah" described by Wendt (1978). Here the art records many animals that no longer occur in this area – rhinos, giraffes, elephants – and human behaviour in many of the carvings and also depicted are what appear to be some of the Ediacarans, the fossils of which evidently the Nama and San observed in the sandstones of the Nama group and then carefully depicted in their rock art. [See refs Breuing (2014), Wendt (1974, 1978)]. a, baboon; b, human figures; c, Eland; d, zebra; e, elephant; f, Ostrich; g, Ernietta *image; h,* Pteridinium *image.*

A Time of the Ox Wagons on Aar (Figs. 102-106)

Fig. 102. Ox Wagons en route in the Aus region.

Fig. 103. Split shoe common for oxen.

Fig. 104. Scratch marks left by hooves.

Fig. 105. Ox Wagon trail on Aar near waterhole. (see Conradt, 2006; Goldbeck, M. et al.*, 2011)*

Fig. 106. When the train line was finished to Aus in 1906, it was really the beginning of the end of the Ox Wagon trade.

Stone Buildings on Aar – Merchants and Soldiers (Figs. 107-114)

Fig. 107.Schutztruppe huts at Aarhauser.

Fig. 108. Site of German telegraph station from a time when troops were in the Aus region on Farm Aar before and at the beginning of WWI.

Figs. 109-111. Stone buildings and rubbish give some idea of the Europeans, soldiers, merchants and farmers who have inhabited Aar for more than a century.

Figs. 112-114. Rubbish and carvings left by occupants of many of the stone buildings on Farm Aar, likely both German and South African soldiers, and Ox Wagon merchants along with postal staff [and maybe even some of the geologists who were mapping and searching for water in this area in the late19th and early 20th centuries!]. These inscriptions and leftovers lie alongside the tools and carvings of the San and Nama people, reflecting a long and complex past for this area of southern Namibia (Conradt, 2006; Goldbeck et al*., 2011; Vaupel, 2011; McGregor and Goldbeck, 2014).*

The Farm from Beginning to Now (Figs. 115-123)

Patricia Vickers-Rich, Barbara Boehm-Erni and the Erni Family, Gunter von Schumann

The oldest farm records related to the current Farm Aar date back to around 1903 when Barbara Boehm-Erni's grandfather (Franz Sales Erni) set out originally to leave Switzerland and travel to New York – however, a friend of his convinced him to sail south to Africa. He had a 'soul of unrest' and was eager for adventure. He first went to South Africa but later moved on to German Southwest Africa. Barbara's grandmother, Kathie Schwinn from Berlin, arrived in 1904 on one of the Lady's ships coming to Africa – the two eventually met and married and had children. Later they went separate ways when Franz travelled to Tanzania to visit one of their daughters. In the meantime, Kathie teamed up with August Lubowski, and in time they became associated with the Bahnhof Hotel, which was the progeny of the original hotel, the Hotel Germania (burned down in 1925!, the first to be built in Aus with the coming of the railway). Well before his association with the hotel, August Lubowski was farming on properties such as Aar and Kubub (where there was a Post Office for a number of years in the early 1900's) (Fig. 116). Lubowski was also well known in the area as a businessman.

The railroad construction to Aus was finally completed in 1906 (Fig. 106), although connection to Seeheim and Keetmanshoop was not finalized for almost another year.

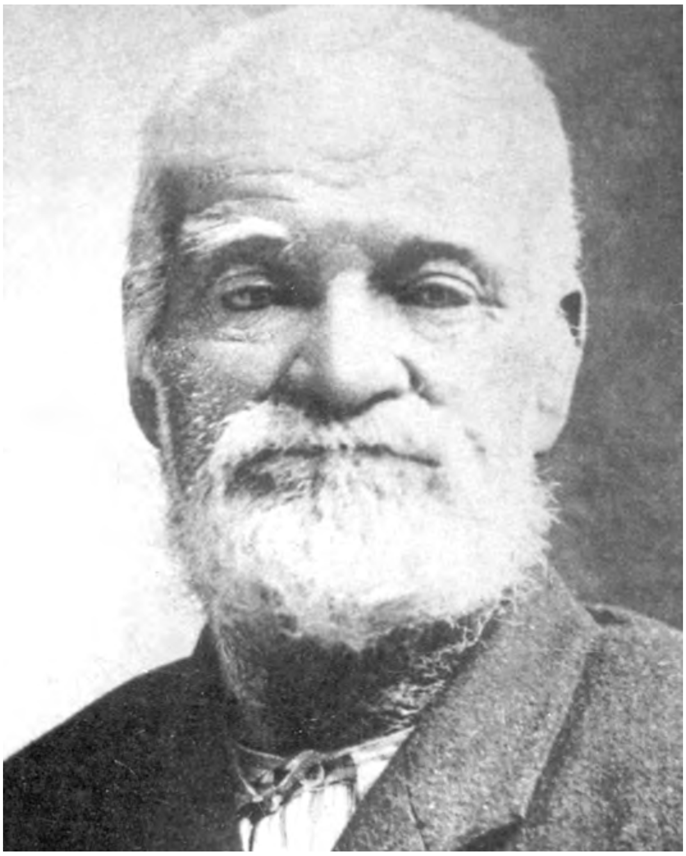


Fig. 115. David Radford

Fig. 116. Kubub Post Office and an Ox Wagon rest point.

The first records of anyone actually managing what is now Aar, was David Radford (Vogt and Vogt, 2009) (Fig. 115), who took out a lease on Kalkfontein, which at that time included Aar – this in 1905 (Vogt and Vogt, 2009). Lubowski had come to Lüderitz as early as the 1800's, as a trader in guano and seals, so was a longtime resident. At about the same time John Coleman, who was situated on Farm Arodal, was managing Post Office at Kubub. Water, of course, was a resource so needed in this area, and fortunately Farm Aar had a reliable supply – so it was a property in demand, and many people held the lease on it over the years. Paul Range was one of the geologists in the area at this time leading a group searching and recording the water resources. In 1908 he reported fossils in the debri of the shelters in the Aus region, shelters that had been constructed by the German Schutztruppe (Range, 1906, 1907; Schneiderhöhn, 1920).

Water at this time, and even more so before the coming of the railway, was not only needed for farming but also used to care for hundreds of oxen pulling the wagons across the deserts from places like Keetmanshoop to the coast at Lüderitz. On Farm Aar there is ample evidence of the trails that these Ox Wagons took, regularly halting at waterholes (Fig. 99), such as one not far from the Aar Homestead. The hoof scratches (Fig. 117), abandoned double shoes and structures that were likely mercantile way-stations dot the landscape of Aar. Once thought to be exclusively military structures, it seems that many were simply water-stops and supply stations for the lucrative oxcart trade up until the railway was completed.

Although there was legal contention, Radford noted that because of the lack of water, he cancelled the lease on Aar in 1910, as there was no water, even on land that usually had supply.

After much legal turmoil, Aar was leased to Karl Eyth, 6 months at a time, and he used the water not only to graze stock but to care for the horses of the Schutztruppe.

Then in 1914 came the War, and occupation of German Southwest Africa began with South African troops landing in Lüderitz and eventually overtaking the Schutztruppe. The bases of gun emplacements in Aus as well as the rock inscription noting the presence of a telegraph station on Farm Aar (Fig. 108) are reminders of this history (Fig. 118). Between telegraph installations in southern Namibia, mirror communication made it possible for the Schutztruppe on Aar to communicate directly with Windhoek (McGregor and Goldbeck, 2014). Another likely reminder of this time period is one of the carvings on Aar Farm rocks – that of P. J. S. Nel, an Afrikaner name. Interestingly, 3 Afrikaner soldiers with similar names perished near Jakalswater inland from Swakopmund in 1914 (Stejskal, 2014), and one wonders what happened to P. J. S. Nel (Fig. 114)?

Once the South Africans and the British had quelled the German Schutztruppe, a Prisoner of War camp was set up in Aus, the remains of which are still to be seen there (Bruwer, 1985) (Figs. 41-43). This camp remained in action from 1915 to 1919 and at times had more than 1500 – both German and South African – living there. It was a well run and compassionate camp, in large part due to the leadership of Major Nelson – the Germans built reasonable housing, had an orchestra, a band, a theatre group....! Most of the deaths in the camp, including that of Major Nelson's wife Breeza, who was a camp nurse, were due to the Spanish Flu.

Again, Aar was leased to William Steenkamp in 1925, and the property took on the shape of the current Aar 16 – at that time 18,333 hectares. 1926-1927 were bad years for the farm, with more than 1000 sheep lost to Gallam sickness – a gall bladder and liver disease. Steenkamp kept the lease, 6 months at a time, until the late 1920's when he at first re-leased to Agust Lubowski, and many improvements were made to the farm. At this time the funding put into improvements were deducted from the lease fees. Between 1925 and 1929 such improvements as a new reservoir, outstations, stone walls, a house with 5 rooms, a cottage, a wagon house and windmill were all added to the land (Fig. 119-120). These structures suffered some with major rains in 1934. The core of the current farm house likely dates back to this time, and it has subsequently had many additions.

Fig. 117. Hoof scratch marks left by the passing oxcart teams.

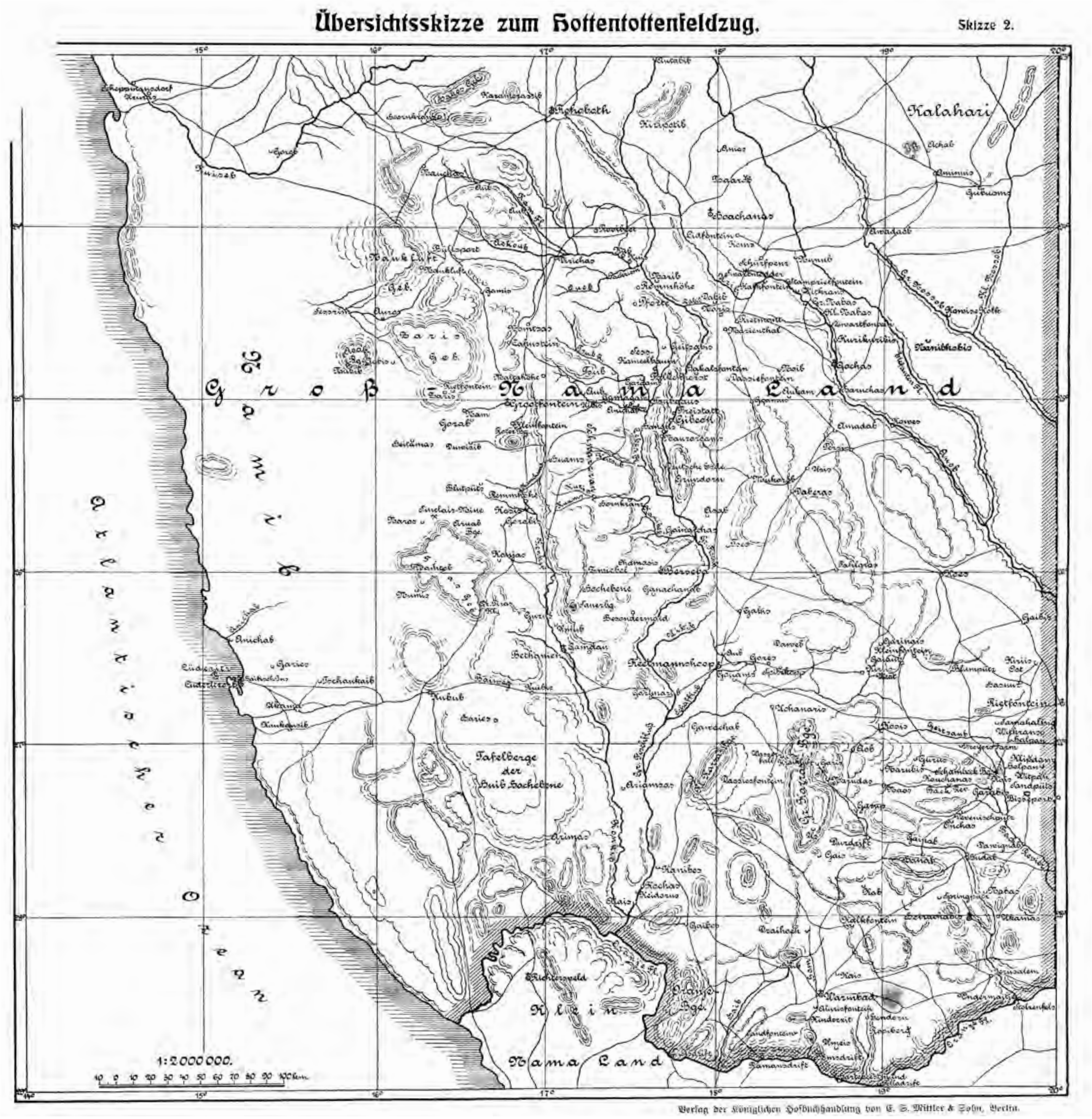


Fig. 118. German Southwest Africa, before World War I.

Fig. 119-120. Early construction of windmill near Windy Peak and times when there was more water than really needed!

Then came the Depression and WWII, but farming began in earnest after each war and between the wars. In 1947-1948 Wilfried Erni, Barbara-Boehm Erni's uncle and brother to her father Helmuth, inherited Farms Aar and Plateau from Lubowski. Helmuth then purchased Farm Aar from Wilfried. The family had been visited by Hans Pflug when he came to Namibia to study the Ediacarans, which, of course, resulted in the many publications concerning these enigmatic organisms. Wilfried's father had discovered some of these fossils when he was building his house on Farm Plateau in the 1960's, these recovered at Aarhauser. Helmut, Barbara's Father, was a pilot for Swissair, but had managed the Farm Aar from 1962, finally retiring from the airline in 1973 and spent the rest of his life on Aar. Barbara visited him many times from Switzerland during her youth and fell in love with Namibia – and so herself settled here with her husband Bruno Boehm.

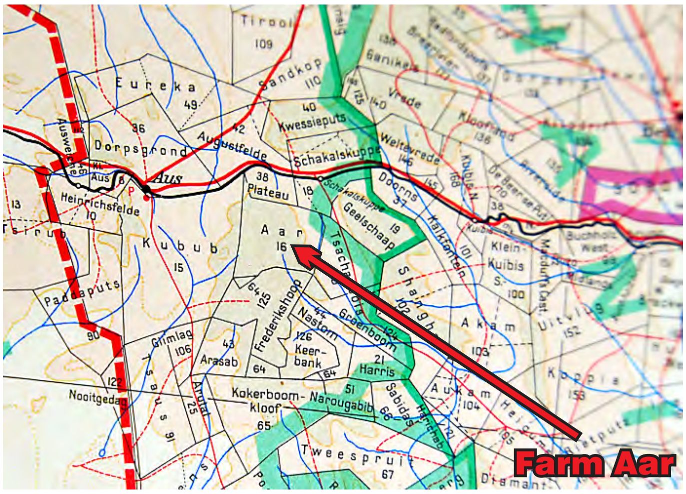


Fig. 121. Property boundaries in the Aar area.

Farming in this region is not easy. For a time karakal skins from newly born sheep were a fad, and wool and meat were too. Most of the sheep are now gone, and limited herds of cattle are still using the land. On many properties in the region, wild game are a source of both pleasure and limited hunting. Drought, and thus rarity of water, both continue to be the challenge for all the farms in this region (Fig. 121), as they have been for a very long time during the Late Pleistocene – factors dealt with by the San, the Nama, the oxcart drivers, the soldiers and traders and the current population that have and still manage the land.

Farm Aar offers not only a place to be treasured by the general populace, but many possibilities for specialists and students of the natural sciences to carry out research in a wide range of disciplines - ecology, botany, zoology, paleontology, geology, astronomy (Figs. 122-123). Some university courses in these disciplines are being planned to engage with this rich environment.

Currently the farm has two comfortable living spaces with facilities and an ideal place for the laboratory research and seminars as well as delightful ecotourist visits.

Fig. 122.The original farmhouse, modified (2015).

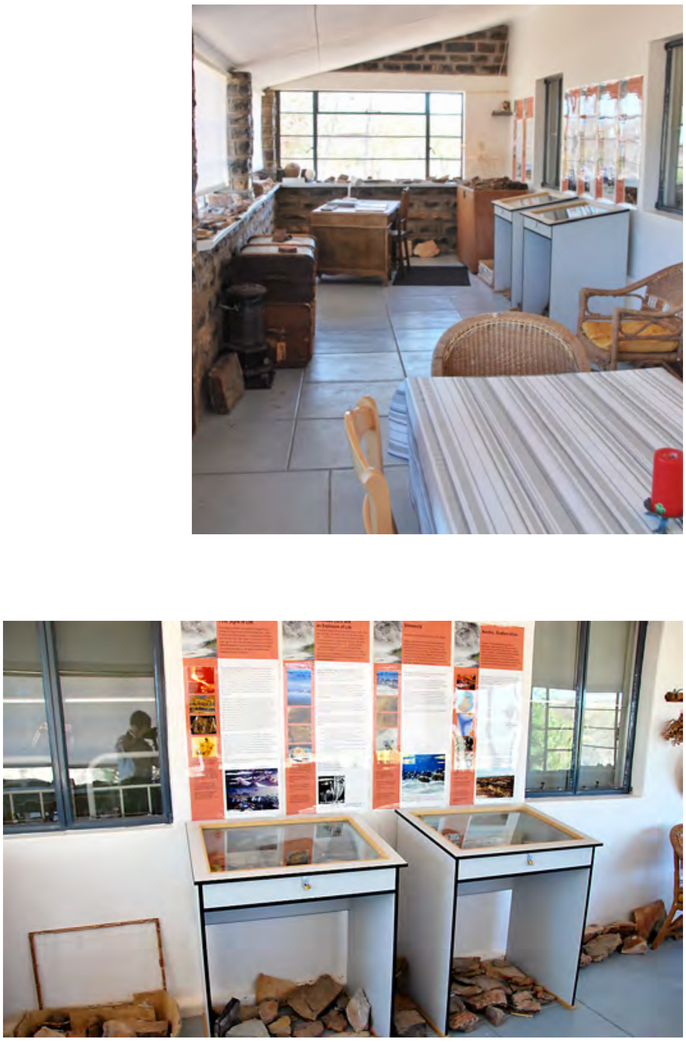


Fig. 123 a, b. "The Lab" (above) and display cases of the small eco-museum in the farmhouse (below) (a project sponsored by UNESCO projects 493/587 and the National Geographic Society).

FIELD CONFERENCE GUIDE – DAY 3. POCKENBANK

Alan Jay Kaufman, Les Kriesfeld

History of Research and Field Work

The Pockenbank area (27°8’55.99”S, 16°26’46.13”E) is located in the Witpütz Subbasin east of highway C13, ~60 km south of Aus and ~110 km north of Rosh Pinah where diamictite and overlying cap carbonates associated with Cryogenian glaciation have been deformed, folded and faulted during subduction of the Kalahari Craton beneath the South American Rio de la Plata Craton to the west and the Congo Craton to the north. Although faulting is noted in the Pockenbank area, the sedimentary succession is otherwise flat-lying and little deformed. The region is dominated by 160 metre high mesa-like escarpments atop an eroded batholith of the Gariep Group granite (ca. 1.7 to 2.0 Ga) (Fig. 124).

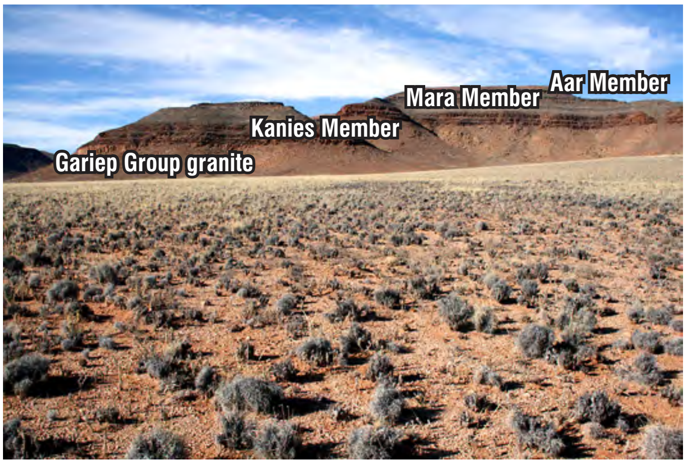


Figure 124: Basal Nama Group strata at Pockenbank include the Kanies, Mara and Aar members of the Dabis Formation (the Mooifontein Member of the Zaris Formation occurs in the next southerly mesa, but is not seen in this image).

The basal sedimentary succession consists of 30 meters of alternating coarse arkosic sandstone and argillite (occasionally mud-cracked) of the fluvial Kanies Member. Oceanic transgression over the eroded top of the Kanies Member resulted in the accumulation of alternating grey shale and mixed fine-grained grey to pink limestone/dolomite facies of the Mara Member (Fig. 125-129). The facies within this 30 meter, shallowing upward interval include: 1) massive and laminated micrites and dolomicrites, 2) vuggy dolomitic microbialites with occasional rip up clasts and roll up structures, and 3) minor grainstones. A notable karstic unconformity separates microbialites and grainstones of the Mara Member at the top of the measured section (Fig. 128).

Figure 125: Pink and grey dolomicrite in the vug-rich interval of the Mara Member.

Within the region, the Mara Member preserves carbon isotope evidence for the enigmatic Shuram Excursion (Wood *et al*., 2015), the most profound negative carbon cycle anomaly in Earth history. This extreme biogeochemical event neatly subdivides the Ediacaran Period and immediately precedes the evolution and diversification of the Ediacara biota. During systematic stratigraphic sampling of this Mara exposure, several distinct horizons within the vuggy dolomite facies were discovered containing centimetre-scale calcite nodules (Fig. 126).

Figure 126: Centimetre-scale quartz-lined calcite nodules in dolomicrites of the Mara Member.

These nodules are rimmed with coarse quartz cements with occasional embedded pyrite grains that impart a reddish-brown stain to the rims upon weathering. These calcite nodules are petrologically indistinguishable from those recently discovered in the Shuram equivalent upper Doushantuo Formation of South China (Kaufman *et al*., 2015; Cui *et al*., in review for EPSL) (Fig. 127) that have been interpreted as authigenic (*i.e*. forming within the sediments soon after their deposition) precipitates.

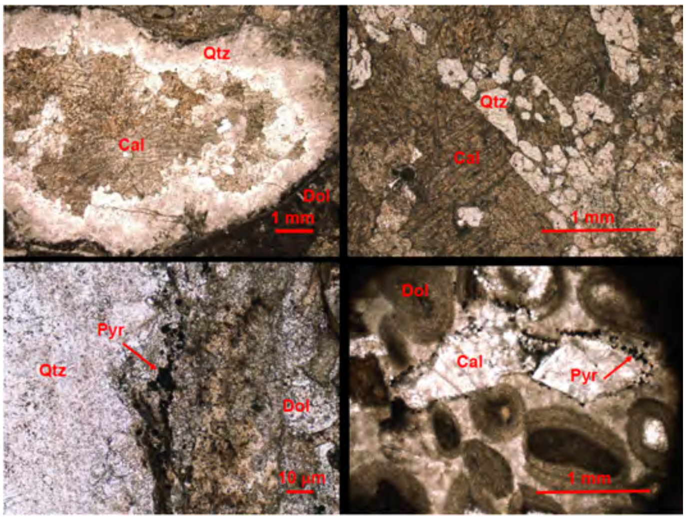


Figure 127: Photomicrographs of calcite nodules and cements in phosphatic carbonates from the middle Ediacaran Doushantuo Formation of South China; (upper left) chert lined coarse calcite nodule; (upper right) euhedral quartz crystal replaced by coarse calcite in nodule; (lower left) pyrite discs at interface between matrix and chert cement in nodule; (lower right) partially dissolved and replaced phosphatic oolites and inter-granular rhombohedral calcite cement lined with round pyrite discs.

The displacive nature of the chert- and pyrite-lined nodules and cements suggests evolving chemical conditions in pore fluids resulting in the dissolution of the pre-existing sediments. This was most-likely due to an initial increase of acidity due to microbial activity. Lower pore water pH promoted the authigenic formation of chert. In the Doushantuo nodules, the grain size of the chert increases towards the center of the sedimentary voids, and in some examples hexagonal quartz crystals with pyramidal terminations were formed. Within these nodules, coarse rhombohedral calcite then filled in the remaining void space, and clearly replaced the pre-existing quartz crystals (Fig. 127). This mineralogical transformation must have followed an increase in pore water alkalinity and pH, again modulated by microbial activity within the sedimentary environment. The coarse nodular calcite, however, is not in optical continuity and appears as coalesced patches. This observation suggests that there are several generations of calcite preserved within the nodules. The linings of the nodules as well as the infilled allochems contain abundant round pyrite grains, ranging from 1-10 mm in diameter, which under the highest power of magnification (500x) appear to be framboidal. Pyrite framboids are spheroidal clusters of cubic or octahedral pyrite microcrystals that in aggregate are typically between 10 and 20 mm in diameter.

Insofar as pyrite framboids are directly associated with microbial sulfate reduction, the discovery of these crystallites in association with chert and calcite cements suggests a direct linkage between this microbial process and authigenesis.

Carbon isotope measurements of the calcite nodules in both South China and Namibia reveal remarkable degrees of ^{13}C depletion. In the upper Doushantuo Formation the nodules have a wide range of **d**^{13}C values down to -37‰, whereas in the Mara Member the nadir of values is nearly -21‰ (Fig. 128). Coupled with petrographic observations, these carbon isotope compositions support the view that the authigenic calcites grew into the sediments associated with the oxidation of methane and other organic molecules within the sulfate-methane transition zone. These observations suggest that the release and anaerobic oxidation of methane (AOM with sulfate) from gas hydrate deposits in the Middle Ediacaran Period may explain the unique Shuram Excursion. Speculatively, this process was driven by the enhanced delivery of sulfate to seawater associated with the oxidation of surface environments and enhanced continental weathering.

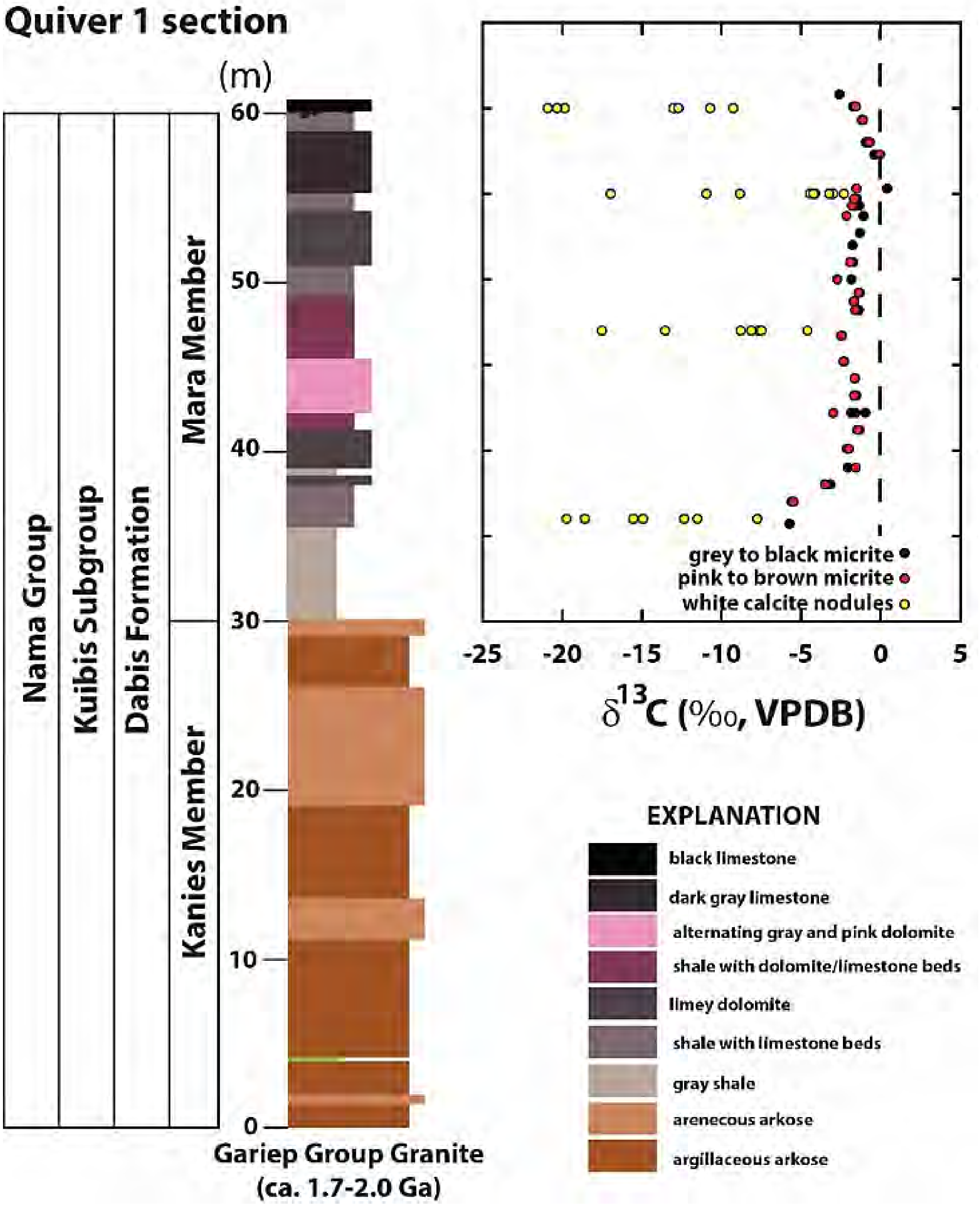


Figure 128: Carbon isotope stratigraphy of the Mara Member at Pockenbank. Apparently only the last phase of the profound negative d*13C anomaly is preserved at the base of the sampled Mara interval in this section. Four levels of calcite nodules were intensively sampled, revealing significant degrees of* ^{13}*C depletion. Coupled with petrographic observations this suggests an authigenic origin from the oxidation of methane and other organic molecules (from Kaufman* et al.*, 2015).*

The time-series trend in carbon isotope compositions show strongly negative values in micrite phases at the base of the Mara Member (ca. -6‰) that rise rapidly to a plateau between -1 and 0‰ up to the karstic unconformity surface (Fig. 128). At this location the Shuram Excursion is not fully expressed. It is plausible that the Pockenbank area was on a paleo-high (relative to other areas that preserve the Shuram in its entirety) and thus did not begin to accumulate carbonates until near the end of the biogeochemical event.

Above the Mara Member there is little expression of the Kliphoek Member sandstone in the Pockenbank area, but is instead dominated by the 40 metre thick shallow marine fossiliferous Aar Member (Figs. 129-130). This unit consists of multiple shale and sandstone beds interspersed with several thin limestones. Although no *Ernietta* have been identified at this locality, multiple very finely detailed float samples of silicified *Nemiana* have been observed. Indicative of an evolving complexity in the Ediacaran life forms, extensive *Pteridinium* beds have been located up-section near the base of the Mooifontein Member (Figs. 131-133). Limestone horizons in this part of the succession become increasingly darker in colour up-section (see Fig. 129), suggesting an increase in organic carbon contents. Carbonates in the Aar Member preserve evidence of basin-ward slumping, while those from the overlying Mooifontein Member form stromatolitic and thrombolitic reefs. *Cloudina* is noted in the uppermost reaches of the Mooifontein in the Pockenbank succession.

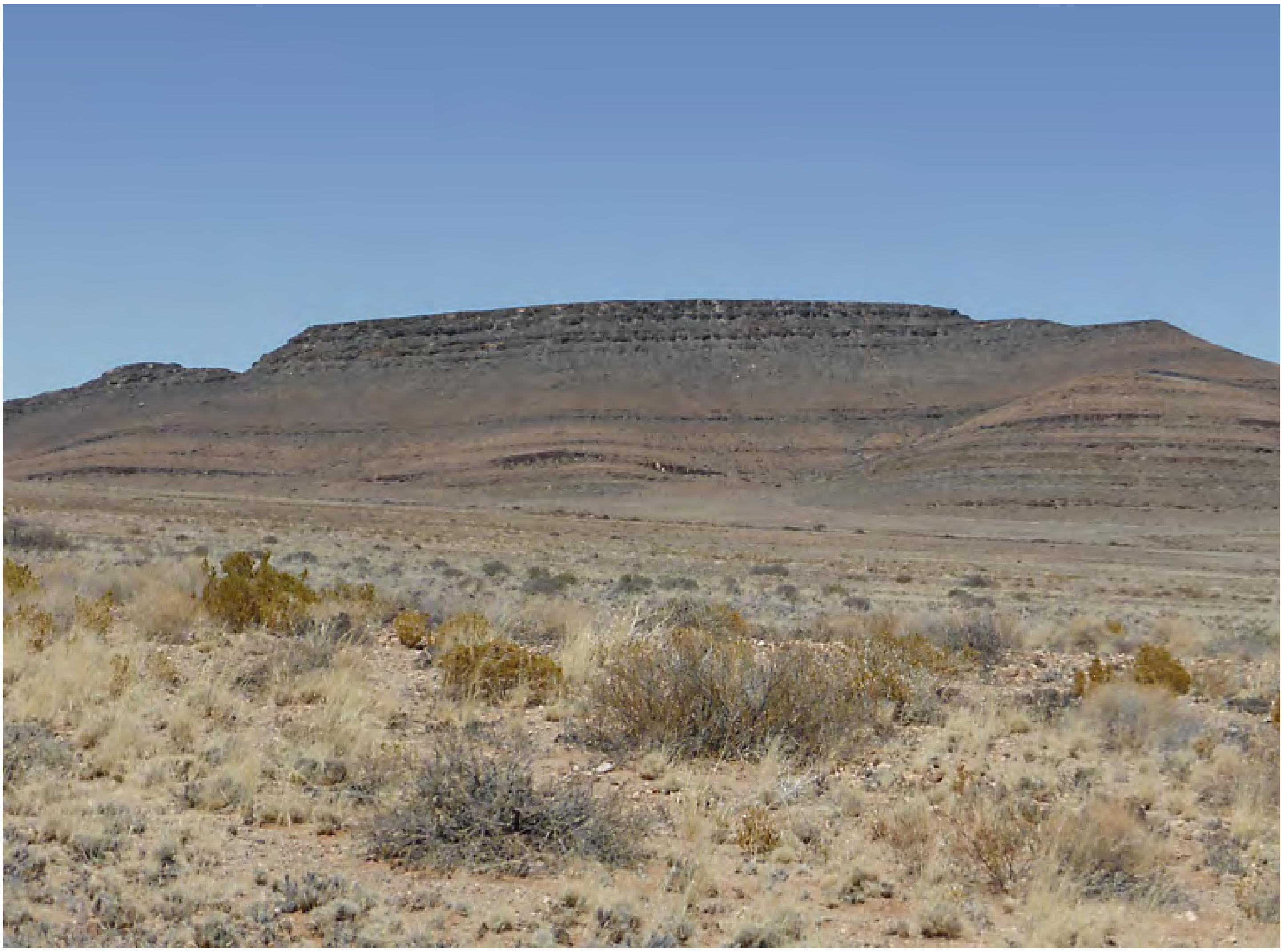
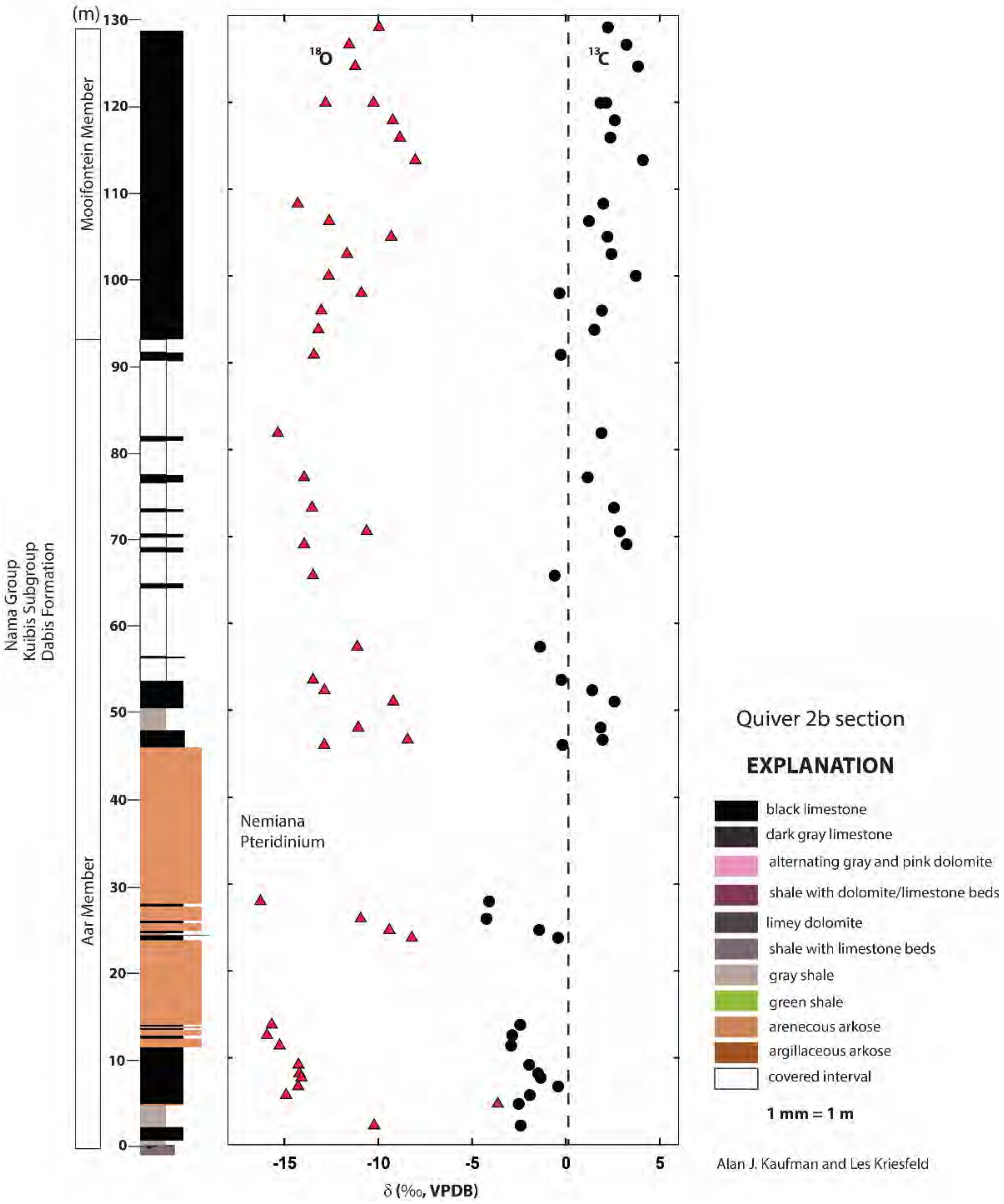


Figure 129: Transition from the Mara through the Aar and into the Mooifontein limestones at Pockenbank. The limestone beds become increasingly organic rich rising up to the top of the exposure.



Alan J. Kaufman and Les Kriesfeld

Figure 130. Carbon and oxygen isotope chemostratigraphy of the Aar and Mooifontein members at Pockenbank. The Kliphoek sandstone in this section is preserved between 12 and 46 m above the unconformity surface.

The carbon isotope stratigraphy of the Aar and Mooifontein members, illustrated in Figures 129- 130, reveals a notable up-section increase in ^{13}C abundances similar to those recorded at Farm Aar (Hall *et al*., 2013) and elsewhere in the basin (Saylor *et al*., 1998). At Pokenbank the rise in d^{13}C values in the Aar to Mooifontein transition coincides with perceived increases in the organic carbon contents of the strata.

Thus, the carbon isotope excursion may have been driven by the enhanced deposition and preservation of photosynthetically-produced organic matter in the sediments leaving seawater carbonate (and proxies) progressively enriched in ^{13}C.

Fig. 131. Pteridinium *in Dabis Fm., just above the Mara Mbr.*

Fig. 132. Baggy structures in the Kliphoek Member – external covering of Pteridinium*.*

Fig. 133. Close up of Pteridinium *at Pockenbank.*

FIELD CONFERENCE GUIDE – DAY 3. SWARTPUNT

Marc Laflamme, Simon Darroch, Guy Narbonne

Fig. 134. Swartpunt from a distance (J. Kaufman).

Background

The fossil-bearing horizons at Farm Swartpunt are part of the latest Ediacaran Nama Group, Spitskop (Spitzkopf) Member at the top of the Urusis Formation. These are the youngest Ediacaran rocks preserved in southern Namibia (Fig. 134) and contain the youngest Ediacaran macrofossils preserved anywhere in the world. Ediacaran macrofossils were first reported near the top of the prominent cuesta by Grotzinger *et al*. (1995), and then described by Narbonne *et al*. (1997), who also provided detailed stratigraphic and paleoenvironmental interpretations for these units. The fossils in these horizons are numerous and spectacularly well preserved in (or near to) life position, and thus provide a valuable glimpse into marine ecosystems less than 1 million years before the onset of the Cambrian. Jensen and Runnegar (2005) noted the occurrence of complex trace fossils (*Streptichnus*) from horizons ~10 m above horizons bearing Ediacaran macrofossils, demonstrating that Farm Swartpunt in the latest Ediacaran was a setting where both Ediacaran organisms and bilaterian metazoans (*i.e*. modern animals) likely coexisted within the same ecosystems. In the larger context of the Ediacaran-Cambrian transition, Farm Swartpunt is a key locality for testing evolutionary and ecological hypotheses behind the apparent decline of Ediacaran organisms, and the Cambrian Explosion of animals that was to follow soon after.

Regional Stratigraphy and Geological Setting

The Nama group records mixed siliciclastic–carbonate sedimentation into a foreland basin related to convergence along the Damara and Gariep deformational belts, and was deposited into two sub-basins separated by the paleo-topographic high of the Osis Arch (Germs, 1983; Saylor *et al*., 1995, 1998; Grotzinger *et al*., 2005). The sediments exposed on Farm Swartpunt belong to the southernmost Witputs sub-basin (Fig. 135). The upper part of the Schwarzrand Subgroup near the fossil locality is a ~1km thick succession of mixed siliciclastic and carbonate platform sediments, which comprises (in ascending order) the Huns, Feldschuhorn and Spitskopf members. The Spitskopf Member is separated from overlying Cambrian-aged Fish River Subgroup sediments by a regional unconformity, which is spectacularly preserved at Farm Sontaagsbrunn to the Northeast as a series of incised valley-fill deposits (see Wilson *et al*., 2012).

Five 10-60 cm thick ash beds have been identified at Swartpunt, an ash bed low in the Spitskopf has been dated at 542.68 ± 1.25 Ma (Schmitz, 2012; Narbonne *et al.*, 2012; recalibrated from 545.1 ± 1 Ma in Grotzinger *et al*., 1995), while a second ash bed ~85 meters below the fossiliferous horizons has yielded an ages of 540.61 ± 0.67

Ma (Schmitz. 2012; Narbonne *et al*., 2012; recalculated from 543.3 ± 1 Ma; Grotzinger et al., 1995). Cambrian-aged sediments (Nomtsas Formation) from the Swartkloofberg Farm directly north of Swartpunt contain an ash bed dated to 538.18 ± 1.11 Ma (Schmitz, 2012; Narbonne *et al*., 2012; recalibrated from 539.4 ± 1 Ma in Grotzinger *et al.*, 1995).

These ages are effectively identical to ages for the inferred Ediacaran–Cambrian boundary in Oman (Bowring *et al*., 2007) and Siberia (Bowring *et al*. 1993), confirming that the Ediacaran fossils and bilaterian tracemakers at Swartpunt lived in the last ~1 million years before the Ediacaran–Cambrian boundary.

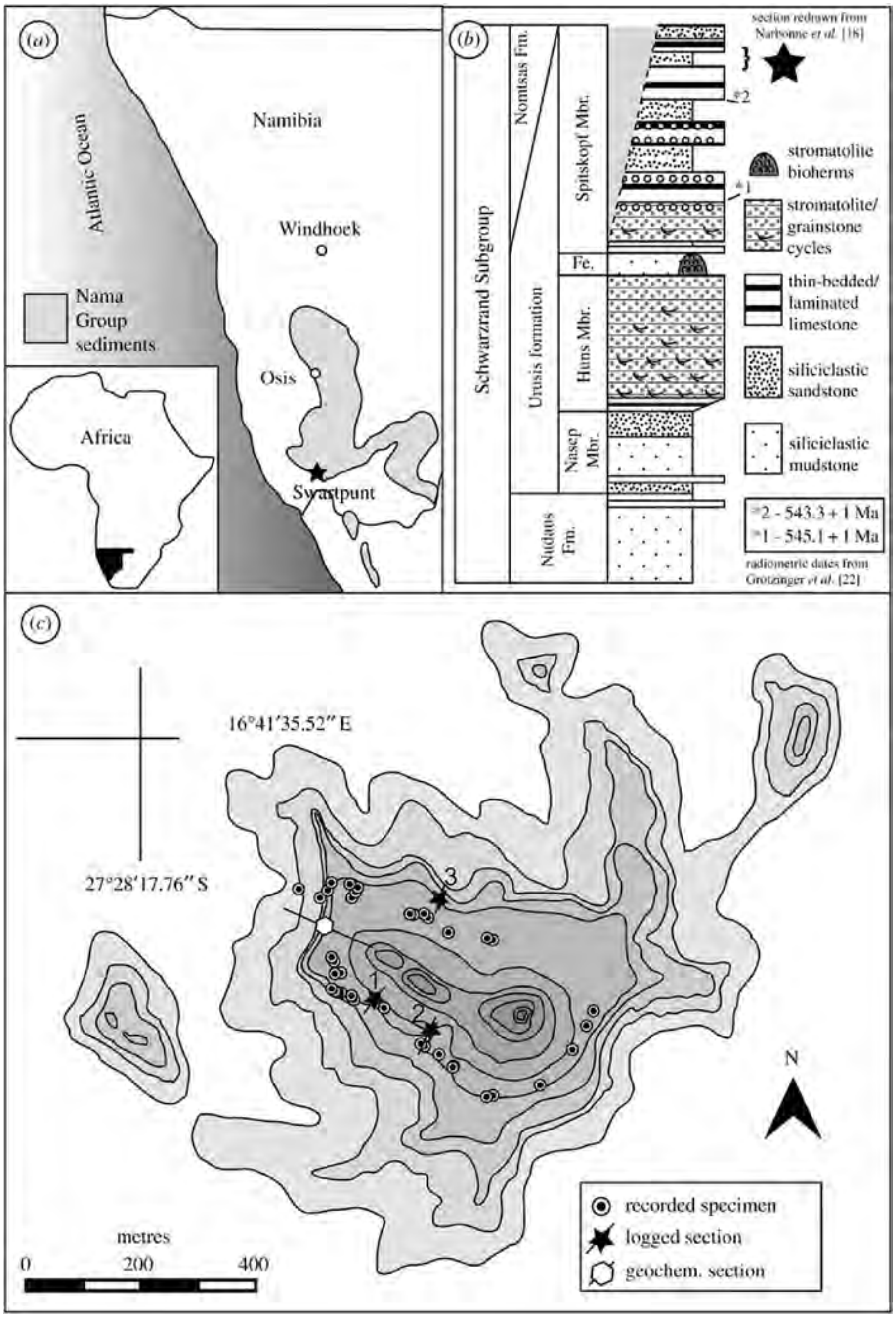


Figure 135. (a) Distribution of Nama-Group sediments in southwestern Africa (adapted from Saylor et al.*, (1998); (b) generalized stratigraphic column for the latest Ediacaran Urusis Formation (Schwarzrand Subgroup) in the southernmost Witputs sub-basin (from Narbonne* et al. *(1997); and (c) the distribution of Ediacaran fossils and logged sections treated in this study. Graduations represent contours (from Darroch* et al.*, 2015).*

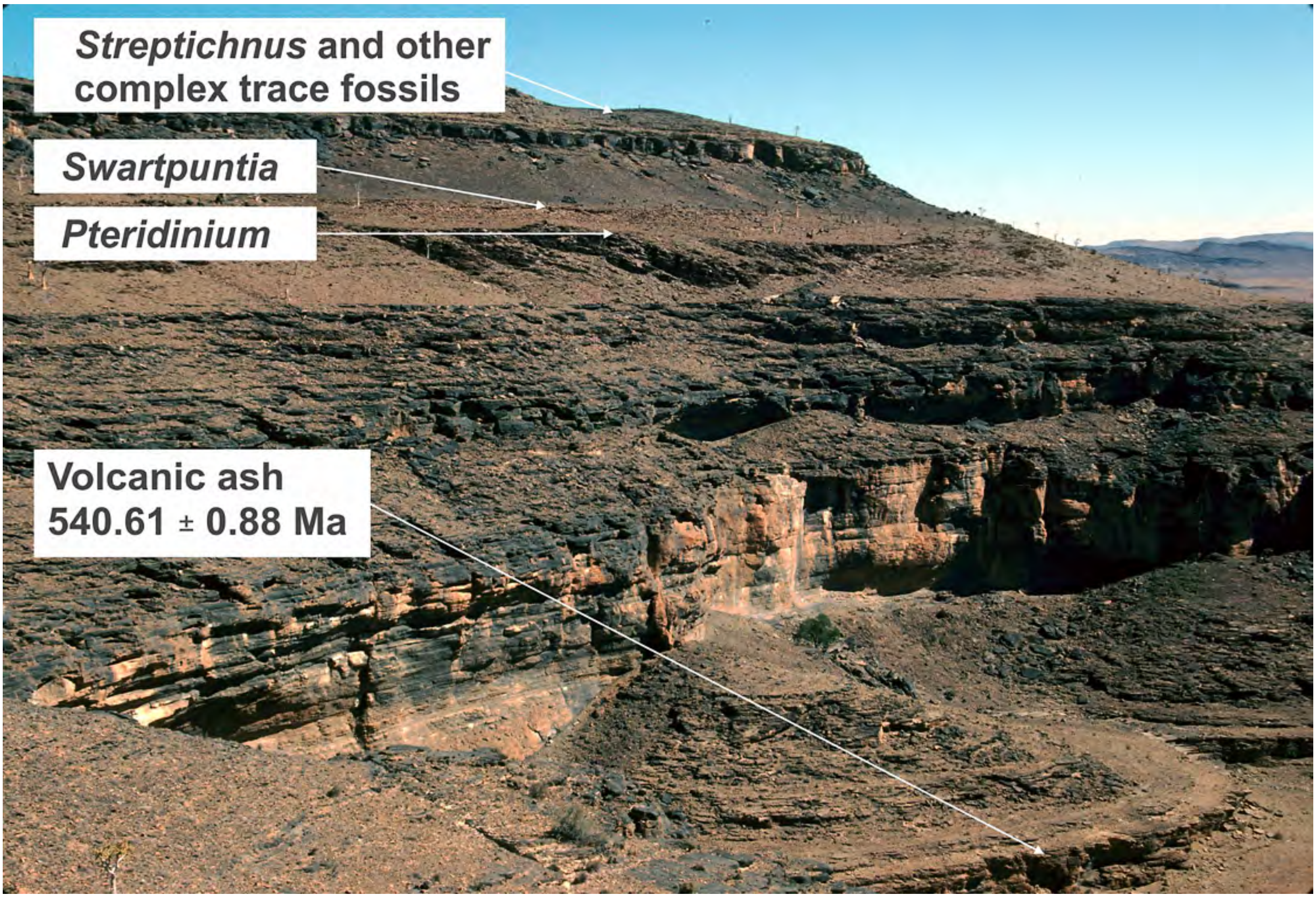


Fig. 136. Northern exposure at Swartpunt constraints on the Ediacaran fossils at the top of Swartpunt (from Narbonne et al.*, 2014, Fig 18.1F).*

Facies and Paleoenvironmental Reconstruction:

The lower ~70 m of Spitskopf sediments exposed at the koppe are resistant, thick-laminated to thin-bedded calcisiltite and minor skeletal wackestone (Fig. 136). Small (5-10 cm) knob-shaped stromatolites are frequently found either side of the trail towards the top of the carbonates. Beds of flat-pebble conglomerate and mottled, finely brecciated limestone indicate occasional reworking by storm waves and suggest a general low-energy, deeper ramp setting (Narbonne *et al*., 1997).

The middle part is a ~20 m thick interval of slumped siliciclastics exhibiting a transition from gentle to near vertical dips interpreted as a 'megaslump' (Narbonne *et al*., 1997). Its base is marked by a prominent ~30-50 cm thick layer of limestone breccia which can be found most of the way round the koppe. The overlying siliciclastics comprise mudstones and fine-grained sandstones that become generally courser and thicker-bedded towards the top of the section. These thicker, prominent beds marking the first break in slope ('Ridge 1' in of Darroch *et al*., 2015; Fig. 137) preserve a variety of sedimentary structures, including hummocky cross stratification ('HCS'), ripple marks, gutter casts, slumped/convolute bedding and a variety of microbial mat fabrics including *Kineyia*. Strata within the megaslump unit are erosionally truncated and depositionally overlain by thinly inter-bedded shale, sandstone and lime mudstone that grades upward into resistant thin-bedded lime mudstone, similar to those at the base of the koppe (Narbonne, 1997) and supporting the view that the megaslump formed due to synsedimentary distruption (Narbonne *et al*., 1997). The facies in these siliciclastic (and fossil-bearing) units support interpretation as a quiet and open-marine, prograding delta-type paleoenvironment near fairweather wave base, that shows evidence for periodic disruption by storms (Narbonne *et al*., 1997; Darroch *et al*., 2015).

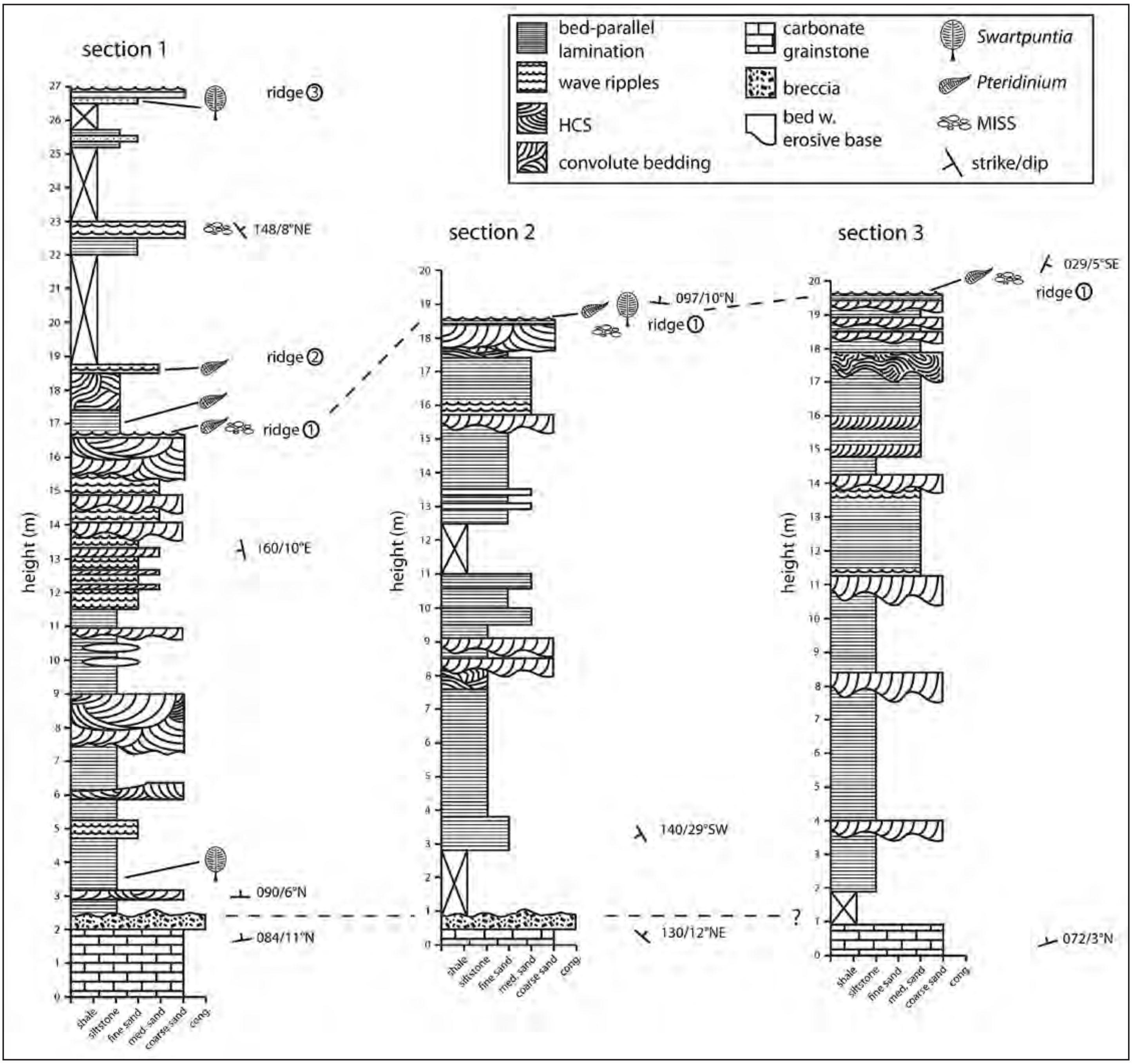


Figure 137. Measured sections showing the straigraphic distribution of Ediacaran fossils encountered during measurement. From S.I. in Darroch et al.*, 2015.*

Ediacaran Macrofossils

Narbonne *et al*. (1997) originally identified two fossiliferous horizons at Swartpunt (termed fossils beds ‘A’ and ‘B’). Subsequent work by Darroch *et al.* (2015) recovered Ediacaran macrofossils from several other beds (Fig. 138, Plate 3), including ~1m above the base of the siliciclastic horizons, as well as from float material in a wide variety of lithologies. It, therefore, seems likely that fossils are distributed throughout the section. The original two beds identified by Narbonne *et al*. (1997) do, however, remain the best exposed and most easily studied. Fossil bed ‘A’ (equivalent to Ridge 1 of Darroch *et a*l., 2015; Figs. 136, 139) marks a prominent break in slope around the outside of the koppe (affording spectacular views across the basin and neighboring farms), and preserves abundant *Pteridinium simplex* in association with ripple cross-bedding and microbial mat textures. Fossil bed ‘B’ (equivalent to Ridge 2 of Darroch *et al*., 2015; Figs. 136, 139) occurs ~2m above fossil bed ‘A’, and preserves both *Pteridinium simplex* and *Swartpuntia germsi*. Darroch *et al*. (2015) reported a third prominent fossil bed composed of fine-grained and thin-bedded yellow-green sandstones ~8.5 m above ridge 3, which preserves additional *Swartpuntia*. In addition to these two taxa, Darroch *et al*. (2015; Plate 3) recovered a form closely resembling *Ernietta,* an individual *Nasepia* (although this might be synonymous with *Ernietta*; see Ivantsov *et al*., 2015), a large rangeomorph taxon (possibly *Bradgatia?*), and several slabs preserving accumulations of the circular fossil *Aspidella*, which likely represent the rooting holdfast of larger frondose organisms (Fig. 138). The fossils are almost universally preserved as 2D casts and molds on the top- and bottom-surfaces of beds. Fossiliferous horizons frequently also preserve evidence for microbial mats, and thus were likely preserved in the ‘death mask’ style common to many other Ediacaran localities, including Mistaken Point (Narbonne, 2005) and South Australia (Gehling, 1999). The 3D taphonomic mode, characterized by moldic infills (which can be isolated from the surrounding matrix) is not evident here, despite being frequently seen elsewhere in Namibia (see *e.g.* Vickers-Rich *et al*., 2013), reinforcing the inference that these fossils represent an autocthonous accumulation.

With the exception of *Bradgatia?*, the vast majority of Ediacaran macrofossils preserved at Farm Swartpunt are ‘erniettomorphs’, which are united by a modular construction in which modules are smooth, unbranched, and cylindrical in shape, and organisms grow by adding new modules at distal tips (Erwin *et al*., 2011) (Plate 3, Fig. 138). Erniettomorphs exhibit a variety of growth forms and life habits, including as benthic ‘recliners’ (*Pteridinium*), upright multi-foliate fronds (*Swartpuntia*) and as loose ‘bags’ (*Ernietta*) that likely lived at least partially buried in the sediment (Ivantsov *et al*., 2015). Although some authors have noted the similarity between erniettomorphs and certain cnidarian groups that are found preserved in the Cambrian, these similarities are largely cosmetic, and the erniettomorphs (along with the rangeomorphs) are best interpreted at large eukaryotes with uncertain relationships to crown Metazoa, and which went extinct at or shortly after the onset of the Cambrian.

Plate 3. Ediacaran fossils at Farm Swartpunt: a-b) Swartpuntia*, c)* Pteridinium*, d-e)* Ernietta*, f)* Aspidella*, g) poorly-preserved rangeomorph?, possibly* Bradgatia*? Scale bars 1 cm*

Community Paleoecology

Competing hypotheses (see *e.g*. Laflamme *et al*., 2013; Budd and Jensen, 2015) surrounding the evolutionary and ecological context behind the Ediacaran-Cambrian transition, in particular the disappearance of Ediacaran organisms and the Cambrian radiation of animals, puts the fossil assemblages at Farm Swartpunt in a critical position. When compared to older Ediacaran fossil sites in Australia and Russia, the paleocommunity at Swartpunt appears depauperate, with low overall diversity, and a community structure that suggests a marginal paleoenvironment and/or ongoing ecological stress. A central question surrounding the Swartpunt fossil communities is – are they symptomatic of an Ediacaran evolutionary fauna that is already in decline?

Darroch *et al*. (2015) examined this question using a series of rarefaction analyses, and concluded that the local community structure at Swartpunt was consistent with a 'biotic replacement' scenario, whereby Ediacaran organisms immediately prior to the Cambrian were in the process of being marginalized and outcompeted by grazing and burrowing metazoans. The presence of complex trace fossils attributable to metazoans here and elsewhere in the Schwarzrand Subgroup (*e.g*. Jensen and Runnegar, 2005; McDonald *et al*., 2014) would seem to support this model. However, the subsequent discovery of a higher diversity at Swartpunt (and there are certainly more fossils to be found) would put this interpretation into question.

Multi-Proxy Geochemistry

A critical component of interpreting the depauperate ecology at Swartpunt is accurate paleoenvironmental reconstruction. Fossil biotas often show low diversity as a response to unfavorable paleoenvironmental conditions. Low oxygen levels and euxinia are significant habitat barriers, and typically lead to low diversity communities dominated by opportunistic taxa with broad niche tolerances and/or small-sized organisms with reduced oxygen requirements (Sperling *et al*., 2013). A multi-proxy analysis performed by Darroch *et al*. (2015) (Fig. 139) of highly reactive iron to total iron (FeHR/FeT) ratios, iron to aluminium (FeT/Al) ratios and total organic carbon weight per cent (TOC) indicated a relatively uniform and well-oxygenated environment throughout the fossiliferous horizons, thus making it unlikely that a restricted paleoenvironment is responsible for the depauperate community signal. However, a much larger geochemical study performed by Wood *et al*. (2015) indicates fluctuating oxygen conditions throughout the Witputs subbasin and thus suggests the abiotic controls on Ediacaran communities may be more complex on regional scales.

Figure 138. Ediacaran fossils frond with well-preserved holdfast disc (D) with poorly preserved stem (S) and likely petaloid (P) from Farm Swartpunt. Scale bar 1 cm.

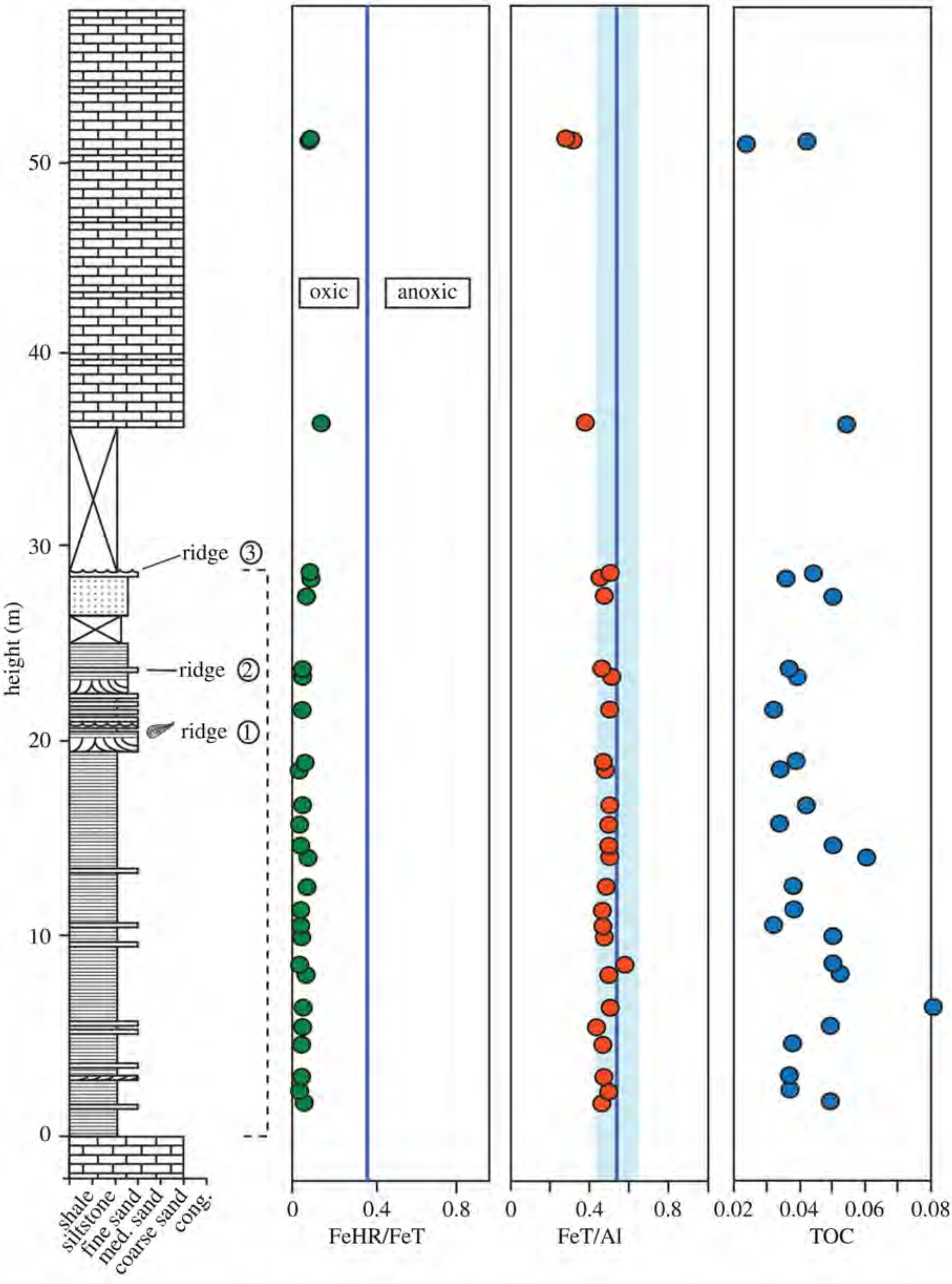


Figure 139 (right). Geochemical profile for section 1 from Figure 135. From left to right, highly reactive iron to total iron (FeHR/FeT) ratios, iron to aluminium (FeT/Al) ratios and total organic carbon weight percent (TOC) values. The FeHR/FeT ratio of 0.38 separating anoxic from oxic water columns and the average Palaeozoic oxic shale value of Fe/Al = 0.53 are shown as vertical blue bars (from Darroch et al.*, 2015).*

Farm Swartpunt and the Ediacaran Extinction

As mentioned above, the fossil-bearing horizons at Farm Swartpunt offer a rare glimpse of the terminal Ediacaran biosphere, and can offer clues as to the true nature of ecological interactions between Ediacara biota and bilaterian tracemakers shortly before the onset of the Cambrian. However, there remain a number of outstanding issues and questions that would benefit from new eyes on the rocks and fresh perspectives. Below we've listed a few of these that might serve as the basis for productive discussion among field trip participants:

1.) Are the fossils preserved at Swartpunt autochthonous?

This question is key to deciphering the true community signal for the Ediacaran organisms preserved here, and is a key piece of evidence cited by Darroch *et al.* (2015) in favor of the 'biotic replacement' model for the Ediacaran-Cambrian transition. Both Narbonne *et al.* (1997) and Darroch *et al*. (2015) provided evidence to suggest that the fossils at Swartpunt were preserved *in situ* (as they are in many other Ediacaran localities worldwide) and thus preserve an original community signal. However, if subsequent evidence were to suggest that the organisms were transported (discussion here could turn to interpretation of the 'mega-slump' structure), as they are elsewhere in Namibia, then the depauperate community structure could instead represent biostratinomic processes, such as winnowing, size-selective sampling and transport, etc. Detailed observations of the iconic fossil surfaces at Swartpunt may shed some light on this question.

2.) How do the paleoenvironments preserved at Swartpunt compare with those at other Ediacaran localities, both in Namibia and elsewhere in the world?

The predominance of Erniettomorphs and Rangeomorphs (and conversely, the absence of iconic Ediacaran groups such as the Dickinsonimorphs and Triradialomorphs) in the latest Ediacaran has been noted by many previous workers and is frequently cited as evidence for a period of biotic and ecological turnover prior to the onset of the Cambrian. However, a critical aspect of this rationale is accurate paleoenvironmental reconstruction. Ediacaran organisms can show strong facies associations (see e.g. Grazhdankin, 2004; Gehling and Droser, 2013), and thus the important question is *to what extent is latest Ediacaran diversity merely a reflection of limited (or marginal) paleoenvironmental sampling?*

A close look at the sedimentology and fine-scale stratigraphy of the fossil-bearing horizons at Farm Swartpunt may offer fresh evidence in favor of a marginal or 'stressed' paleoenvironment, and one which would be expected to support a limited-diversity fauna.

3.) To what extent did Ediacara biota and bilaterian tracemakers at Swartpunt directly interact?

Budd and Jensen (2015) have recently offered an alternative to the 'biotic replacement' model in the form of the 'Savannah' hypothesis, whereby stands of benthic (and sessile) Ediacaran organisms would have produced patches of bioavailable organic matter in the sediment subsurface. This heterogeneous spatial distribution of resources would then have encouraged and spurred evolution among bilaterians as they burrowed for this resource. The siliciclastic horizons at Farm Swartpunt preserve both Ediacara biota and bilaterian trace fossils, and so it is an ideal place to test this hypothesis. The 'Savannah' model would predict frequent associations between soft-bodied Ediacaran and trace fossils as bilaterian tracemakers scavenged recently dead organisms in the subsurface. Previous groups have not noted any close association between these two fossil types, but new observations and new fossil material will be required for a thorough appraisal.

Fig. 140. Structures atop Swartpunt and other high peaks southern Namibia are still under study as to their significance. In such high places and with lack of water it is likely that they were ceremonial sites – but of which culture?

Fig. 141. The Aloe Quiver Trees grace much of the landscape of Swartpunt.

FIELD CONFERENCE GUIDE – DAY 4. FISH RIVER CANYON

Gisla Hinder, Ministry of Mines and Energy publications, Patricia Vickers-Rich

Fig. 142. The Traditional story of how the Fish River Canyon formed – a snake to blame (see Hinder, et al.*,2016. 35th IGC Heritage volume)*

Overview

The Fish River Canyon, located in the south of Namibia, is the second largest canyon in the world and the second most visited tourist attraction in Namibia. It features a gigantic ravine, in total about 160 km long, up to 27 km wide and in places almost 550 meters deep. The Fish River is the longest interior river in Namibia, but its flow in the present is minute when compared with the immense volume of water that poured down its length in ages past. The springs feeding the Fish River are located in the Naukluft Mountains.

The entire Canyon bottom can be flooded during heavy rain fall periods or after opening of the Hardap Dam that collects the water of the river further north spilling its ephemeral waters into the mighty Orange River, which forms the border between Namibia and South Africa. The river is cutting through sedimentary rock units of the Nama Group, hosting the Ediacaran Fauna down to igneous rocks of the Namaqua Metamorphic Complex about 1.2 billion years old.

The surrounds of Fish River Canyon contain archaeological and historical heritage assets such as caves, rock paintings and engravings bearing witness of human habitation thousands of years ago. This area has an exceptional plant diversity, part of the Succulent Karoo Biome, an acknowledged biodiversity hotspot in the world with an abundance of indigenous plants. The fauna mainly consists of mammals with a wide variety of antelope and predators, reptiles and a diversity of birdlife.

Story of a River

The Fish River originates between Rehoboth and Maltahöhe. For the first 450 km of its course (overall length approximately 650 km) its gradient is comparatively low, and it flows within a broad valley. Only ca.50 km south of Seeheim, downstream of the confluence with the Löwen River, the gradient increases, causing the Fish River to incise more strongly into the underlying rocks. Initially it must have flowed slowly over a flat land surface where it could meander freely as reflected by its numerous bends, but continental uplift after the break-up of Gondwana ca. 130 m.y. ago resulted in the deep incision of the river into this surface to its present day level. At first, it cut through the horizontal layers of the Nama sediments, but later reached the underlying gneisses, amphibolites and migmatites of the Namaqua Complex. The same uplift brought disturbances in the earth´s crust as evidenced by the bordering faults in the northern upper canyon along which the valley subsided.

While the upper canyon (8 km wide, 160 to 190 m deep) is a tectonic trough, the southern lower canyon (5 km wide, 460 to 550 m deep) was simply incised into the Nama and Namaqua rocks. From the first waterfall north of the northernmost viewpoint, to a point opposite the Chudaub trigonometrical beacon, the canyon is 56 km long. The Fish River hiking trail follows the river course for 85km from the main view point near Hobas to Ai-Ais Hot Springs.

Located at the southern end of the Fish River Canyon the recently refurbished Ai-Ais Hot Springs Spa is a veritable oasis in the middle of a grandiose mountain scenery teeming with wildlife and birdlife, part of the Ai-Ais/Richtersveld Transfrontier Park. The sulphate and fluoride-rich hot spring, which is supposed to have natural curative properties, was discovered in 1850 by a Nama shepherd searching for his lost sheep (Ai-Ais meaning "burning water" in the local Nama language). Along the fault zones forming the canyon sides groundwater rises to the surface to create a number of hot springs. The two best known are Ai-Ais (60°C) and, a little upstream, Sulphur Spring (56°C).

Geological History

The Namaqua Complex originated as layers of sediments and volcanic rocks were deposited more than 1800 million years ago in a shallow sea. After deposition they were buried to a depth exceeding 20 km by the slow accumulation of more sediment. During this process they were intruded by granitic magma and transformed under high pressures and temperatures to gneiss, amphibolite, schist and granulite (ca. 1200 Ma). Some 770 million years ago these metamorphic rocks were again invaded by doleritic magma, which formed prominent dark dykes that can be seen in the canyon walls. Another 300 m. y. later the Namaqua rocks once more became exposed on the Earth´s surface through erosion of the overlying strata to form the floor of another shallow sea in which the sandstone, shale and limestone of the Nama Group were laid down. As no major phase of deformation or metamorphism followed that deposition, these rocks today lie still nearly horizontal and have preserved their original sedimentary structures – thus forming a sharp contrast to the underlying massively deformed Namaqua metamorphic rocks (Figs. 142, 143).

Geology

The Greater Fish River Canyon landscape stretches from the Orange River in the south (where it borders onto the Richtersveld National Park in South Africa) to the Naute Recreational Resort in the north. In the west it borders onto the Sperrgebiet National Park, thereby forming a vital corridor of land between the Ai-Ais and Sperrgebiet National Parks, and in the east it reaches the top of the Klein Karas Mountains.

The landscape encompasses a vast diversity of topographic features and habitats. The geology of the area ranges from the relatively young rock formations of the Karoo and Nama Groups, 200 Ma and 550 Ma respectively, to rocks of the Namaqua Metamorphic Landscape (about 1,200Ma), to some of the oldest rocks known, along the Orange River valley, which are over 2,000 Ma. The geology is highly visible and accessible. The key areas include the Fish River Canyon, the Konkiep Valley, the Orange River Valley, the Huns Mountains and the Klein Karas Mountains. Between these are an array of rocky and sandy plains, rocky hillsides, plateaus, drainage lines, incised valleys and ephemeral river courses.

In terms of landforms, the landscape falls on the transition of the ‘high mountains of the escarpment’ and the ‘foothills and slopes of the plateau country’, having elements of both. The drainage is virtually all to the south into the Fish and Orange River system.

Situated some 80 km west of Grünau, the Fish River Canyon starts about 30 km upstream of Ai-Ais Hot Springs and winds its way more than 50 kilometres to the main view point on Farm Hobas. Altough a mere trickle during the dry season, the Fish River over millions of years has managed to cut a 160 to 550 m deep gorge through both the flat-lying Nama sediments of the Huns Plateau and the underlying deformed and metamorphosed gneisses of the Namaqua Complex, which can be easily distinguished in the canyon walls. Second in size and grandeur only to the Grand Canyon of the Colorado in Arizona (USA), it is a National Monument.

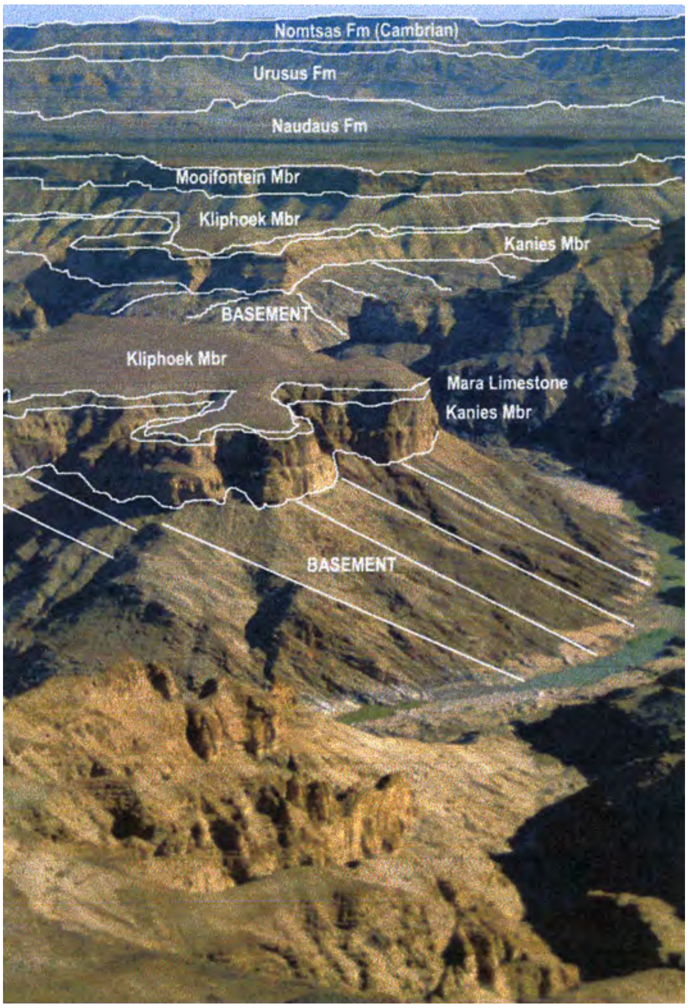


Fig. 143. The Nama Group is well exposed in Fish River Canyon.

Around 350 million years ago erosion had removed most of the Nama Group sediments and the initial river valley had formed as a wide depression. During the Dwyka glaciation it was deepened by south flowing glaciers, and eventually filled with glacial sediments, sandstones and shales of the Karoo Sequence. Today’s canyon began to form during post-Karoo uplift of the new-formed African continent. During this period the glacial deposits were nearly completely eroded. The rocks exposed today in and around the Fish River Canyon belong to the Namaqua Metamorphic Complex, with only the lower portion of the Nama Group (sandstone and black limestone) preserved in the vicinity of the Canyon.

FIELD CONFERENCE GUIDE – DAY 5.
FISH RIVER CANYON TO WINDHOEK VIA KEETMANSHOOP

For the trip from Fish River Canyon back to Windhoek a different route will be taken via the C37, C12, B4 and B1 route. Gabi Schneider's *Roadside Geology of Namibia* (2003) [*excerpts included*] will be your best reference for this journey.

RESEARCHERS ACTIVE IN THE NAMA – UNESCO IGCP PROJECTS 493/587 from 2003-2016

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Chia-wei Li, Barbara Boehm-Erni, Guy Narbonne, Mike Hall, Andrey Ivantsov (l- r)

Marc Laflamme

Ulf Linnemann, Ines Linnemann and Jens Ulrich (l-r)

Kombada Mhopjeni (r) and Ayihe Kavela

Barbara Boehm-Erni and Bruno Boehm

Patricia Vickers-Rich

Gabi Schneider by Mooifontein "Singing Rock" which hosts Cloudina

Jay Kaufman with his favourite rock at Pockenbank

Peter Trusler sketching unfortunate Aardwolf found as road kill near Farm

Maxim Leonov

Nicole Morton

Carolyn Greentree

Les Kriesfeld

Simon Darroch

Gisela Hinder

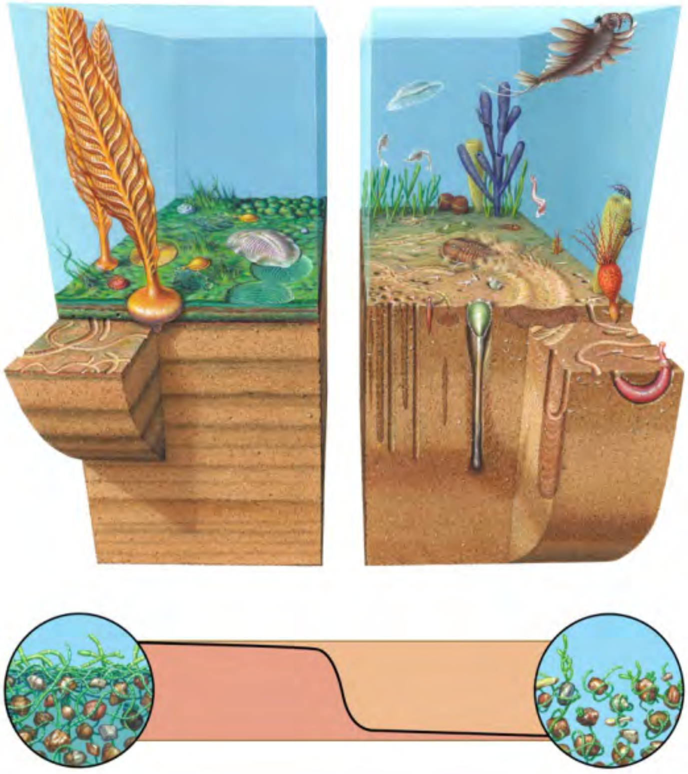
Jeff Smith

Steve Pritchard

David Elliott

Alana Sharp

AND THEN THE EDIACARANS WERE GONE!



The Proterozoic-Phanerozoic transition. The Ediacarans were replaced by the modern forms, many with hard parts (P. Trusler).

Cambrian Vendotaenids from the Schwartzrand sediments south of Anusi.

Geological Survey Museum, Aviation Road, Windhoek

The fossil record of Namibia is well on display at the Namibian Geological Survey Headquarters on Aviation Road across from the Safari Hotel. It is well worth a visit, and exhibits include not only material from the Nama Group, shown here, but from the entire geologic timescale that is preserved in Namibia. Collections in this museum can be arranged by contacting the Survey for an appointment.

Museum display on Ediacarans.

Ernietta *specimens in the museum research collections.*

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Those References in blue are included on your data compilation supplied on DVD with the field guide.

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