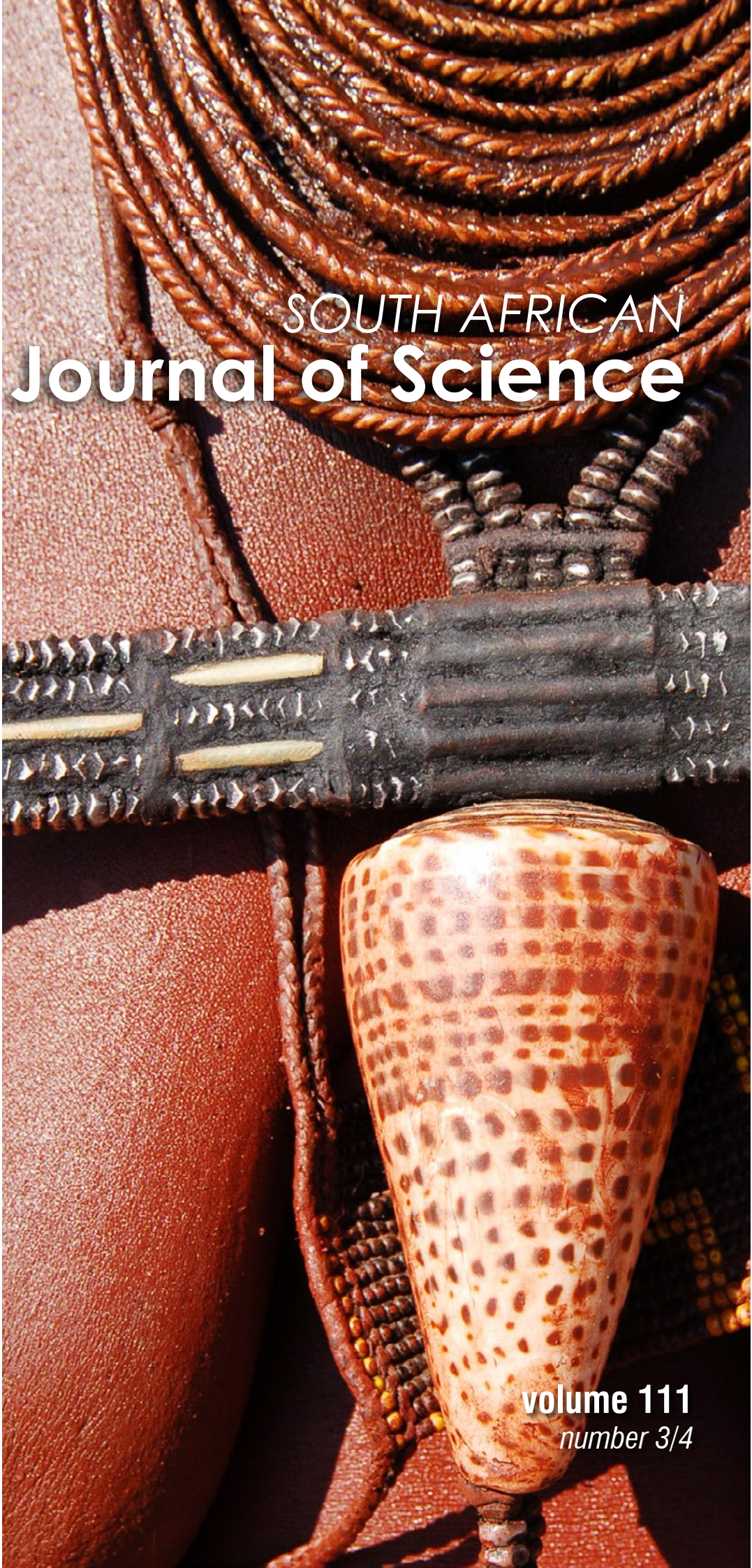

Photoprotective effects of red ochre may have conferred an adaptive advantage

Energy from shale gas: Consider the effects on the native biota

Satellite laser ranging measurements in South Africa: Contributions to global systems

Youngest dinocephalian fossils extend the Tapinocephalus *Zone of the Karoo Basin*

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Research Letter

Erratum

In the Leader on page 3 of Volume 111 (1/2) Dr Rob Davies was referred to as the new Director of the Square Kilometre Array (SKA). The new Director is, in fact, Dr Rob Adam. The Editor-in-Chief extends his sincere apologies for the error to both Dr Adam and Dr Davies.

Reference:

Butler-Adam J. What is on the horizon for science, technology and education in 2015? S Afr J Sci. 2015;111(1/2), Art. #a0096, 1 page. http://dx.doi.org/10.17159/sajs.2015/a0096

IAMP Statement: "A Call for Action to Strengthen Healthcare for Hearing Loss"

Trieste, Italy, 3 March 2015: International Ear Care Day

The InterAcademy Medical Panel (IAMP) has issued a statement on 'A Call for Action to Strengthen Healthcare for Hearing Loss'. The release was timed to coincide with the World Health Organization's International Ear Care Day[1], which takes place on 3 March each year.

In the statement, IAMP highlights the fact that, worldwide, 360 million people suffer from hearing loss – including 32 million children. If left undiagnosed and untreated, then such children typically experience delays in developing speech, language and cognitive skills – with knock-on effects such as unnecessary learning difficulties in school and difficulties interacting with family and friends. In adults (it is estimated that about two-thirds of adults over the age of 70 suffer from hearing loss) evidence is accumulating that associates hearing loss with a greater risk of dementia and disability.

Hearing loss, therefore, doesn't just affect the individual, it is a problem that also affects how whole sections of society function.

As Manfred Gross, of the Department of Audiology and Phoniatrics, Campus Virchow-Klinikum (Language, Speech and Hearing), Berlin, Germany, says:

> *The figures are concerning, but it is a fact that many of the conditions that lead to hearing loss can be detected and either avoided or treated. Simple tests on newborn children, for example, can reveal if the child has hearing problems. Regular childhood vaccinations that prevent diseases like rubella can avoid complications that lead to hearing loss. And simply reducing exposure to loud noises in the workplace can prevent impairment of hearing function in adults.*

Despite the range of solutions available for diagnosing and treating hearing loss, the problem persists especially in developing countries where awareness of the issues and access to suitable medical care is often limited.

The IAMP Statement, therefore, specifically calls on governments and other healthcare providers to implement a number of practices, including:

- improved healthcare provision in the area of hearing loss, such as universal hearing screening in birthing centres and making hearing aids and cochlear implants accessible and affordable;
- ensuring public health measures account for the causes of hearing loss;
- addressing hearing loss in both children and adults while acknowledging the differences between these groups;
- addressing broader societal needs, such as providing educational programmes for children with hearing loss, their relatives and communities; and
- establishing research and innovation programmes targeted at hearing loss priorities, including the development of novel screening and diagnostic techniques to improve the early identification of hearing loss in children and encouraging innovation to develop affordable high quality low-cost hearing aids and low-cost batteries.

Lai Meng Looi, of the Academy of Sciences Malaysia and IAMP co-chair, says: "The fact that so many of the problems associated with hearing loss are preventable means that we already have solutions in hand. In many cases, especially in low- and middle-income countries, the challenge is not just funding, but also raising awareness. That is what we hope to do by releasing this Statement. We expect that IAMP's 73 member academies will now present it directly to their national governments and that they will start to implement some of our recommendations."

"Like all IAMP Statements, this current Statement has been thoroughly reviewed and presents the best impartial advice from our member academies, based on the latest evidence, that we can provide to policy-makers, whether at national or international level, as well as to healthcare providers and others in the medical and aid professions," says IAMP's other co-chair, Detlev Ganten, of the German National Academy of Sciences - Leopoldina.

"Hearing loss is a major global health challenge, but because it is often preventable and avoidable, the time has come to rally round the key areas highlighted in the IAMP Statement," adds Looi. "What is needed is a global, concerted and sustained effort to improve the lives of everyone who suffers from hearing loss. Such an effort will be worth it – not only to those who suffer directly, but also to their families, friends and wider societies."

The IAMP Statement on "A Call for Action to Strengthen Healthcare for Hearing Loss" is available at: http://tinyurl.com/q4rk27w

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1 WHO International Ear Care day: http://www.who.int/pbd/deafness/news/IECD/en/

A different kind of rising star

The Leader in the previous issue alluded that this Leader would focus on the Rising Star palaeontological programme at the new research site in the Cradle of Humankind. Various processes at *Nature* have delayed the release of the initial findings related to the programme and so, instead, this Leader looks at the emergence of a different rising star: the *South African Journal of Science* (SAJS).

The SAJS was first published in 1905 and has evolved through the contributions of a number of publishers, editors, editorial staff members and editorial boards. The 110th anniversary of SAJS in 2014 witnessed some stellar indicators of the Journal's performance and scientific calibre as well as its impact, reach and visibility. The Web of Science impact factor for SAJS rose from 0.84 in 2013 to 1.03 in 2014, placing it at 20th in the Web of Science ranking of 55 multidisciplinary journals. That list is topped, and skewed, by *Nature* and *Science*, suggesting that 20th place is not, in fact, an unenviable position.

However, a growing number of experts in bibliometrics is coming to the carefully determined conclusion that impact factors are a misleading indicator of quality (as articles often are cited for negative rather than positive reasons), and that journal rejection rates are a far more reliable indicator of quality. In this respect, too, the SAJS performs exceptionally well, with an overall rejection rate of 89% for all 648 submissions received during 2014.

The Journal also ranked second, at 14% – marginally behind the *South African Medical Journal* at 16% – of total visits to all the titles on the SciELO SA platform. Together with the *South African Journal of Education* and *Water SA*, at 13% and 12%, respectively, these top four journals receive more than half (55%) of all visits to the 51 South African journals on the platform.

During the course of 2014, there were 44 500 visits to the Journal's website (excluding the submission site), of which 32 000 were new visitors – an increase of 18% over the previous year. About 40% of visits to the website emanate from South Africa. The average daily number of visits almost doubles on days on which the Table of Contents are distributed electronically. The article receiving the most visits in 2014 – which was published online on only 26 November 2014 – received nearly 1000 visits by the end of 2014. Forthcoming developments on the website will include a more comprehensive set of impact indicators at article level, which will enable numerous ways to assess online impact.

To enhance its visibility and accessibility, the Journal is indexed by various local and international aggregators. We do not have SAJS usage data for all these sites, but a well-known local platform – the Sabinet Reference platform – gives an indication of the extent of the visibility of SAJS via these databases. During 2014, there were 53 000 views of SAJS articles via Sabinet's SA ePublications Collection. The SAJS article downloaded most frequently in 2014 was downloaded 1015 times.

In May 2014, an entirely new development for SAJS moved its presence into the realm of 'social media', giving the Journal a greater online presence than ever before – an important development if the Journal is to capture, hold and develop the interest of young and emerging scholars. In a few short months, the Journal has gained almost 200 Twitter followers and just over 400 Likes on Facebook.

Another new development during the anniversary year was that of a new reading format – an 'easy-to-read' online form of the entire issue was established that allows for page swipes (http://issuu.com/sajs), ideal for browsing on tablets and other mobile devices.

Of course, the reality is that numbers are just numbers. And as William Cameron (and not Albert Einstein as some believe) notably pointed out: 'Not everything that can be counted counts, and not everything that counts can be counted.' And so, going forward, the focus will continue to be on what content is accepted, rather than what the Journal's impact factor is.

That said, for quality content to have an impact, it needs to be as visible and widely accessible as possible. So the endeavour for a visible and well-respected journal that effectively serves the interests of science and scholarship continues.

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Areal and biological approaches in Khoesan linguistics

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Beyond 'Khoisan': Historical relations in the Kalahari Basin

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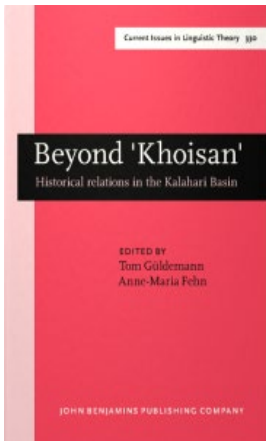

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This well-designed and data-rich book is a most welcome addition to the literature, and will undoubtedly stimulate vibrant debate. It is true that popular misconceptions abound concerning the Khoesan (or Khoisan) languages, and that colleagues in fields such as southern African history, anthropology, archaeology, and even population genetics not uncommonly base their arguments on a mistaken premise, such as the assumption that linguists believe all Khoesan languages are related. In fact, when Joseph Greenberg[1] postulated the notion of a Khoisan family in 1963 (and even earlier), his primary intention was to dismantle the dubious Hamitic category – and in this he succeeded. Historical linguists were quick, though, to reject his method of mass comparison, so that the idea of an actual Khoisan family has never been more than a hypothesis. During the 1960s and 1970s, the doyen of African languages in South Africa was Ernst Westphal, who famously maintained an extreme 'splitter' position throughout his long career. While a handful of foreign linguists have sustained an interest in Khoisan studies for many decades, it was essentially post-1994 that a new generation of linguists from overseas entered the field, to join forces with local scholars such as Jan Snyman, Tony Traill and Patrick Dickens. These linguists continued to use the term Khoesan as a catch-all term for the very diverse click languages of southern and eastern Africa that do not belong to the Bantu family (or in the case of Dahalo, the Cushitic family). It seems then, that in titling the present collection of essays *Beyond 'Khoisan'*, the editors are knocking down a straw man, as the readership is unlikely to extend much beyond the small circle of linguists who have a specialist interest in these languages and are familiar with the history of the field. But this is a small quibble.

The book begins with an overview by Tom Güldemann of the current classification of the Khoesan languages, in which he re-states his steadily unfolding theory that it may be possible to project a hypothetical Khoe-Kwadi language 'spoken by a pastoral population which was a later arrival in the Kalahari Basin area but one which preceded the Bantu expansion' (p. 29). These adventive speakers are suggested to have mingled with a pre-incumbent population ('indigenous foragers') with various consequences, including 'borrowing and shift-induced substrate interference, cultural reorientation and shift, and genetic admixture', while it is further suggested that some local groups 'shifted to a Khoe-Kwadi language', to give rise to those numerous languages of the Khoe family spoken by communities who were traditionally hunter–gatherers. (Despite the wording of the sub-title, the relations implied are not historical in the conventional sense of the word, and readers should be aware that other scenarios are possible.) The thesis that the Kalahari region was an area characterised by considerable linguistic diffusion is the impetus for the main undertaking of the book, which is to demonstrate the occurrence – undeniably extensive – of cross-Khoesan borrowings. (Of course, the mere fact that linguistic relationships cannot be satisfactorily demonstrated is not proof in itself that the languages concerned *are* unrelated; just as evidence of wholesale borrowing does not mean that the languages in question cannot nevertheless still be related.)

The first part offers 'cross-areal perspectives', and includes a paper on Khoisan sibling terminologies by Gertrud Boden, Tom Güldemann and Fiona Jordan, as well as a paper by Ed Elderkin titled 'Clicks, prosodies and Khoisan'. In subsequent parts, a number of authors present generously detailed contributions. Linda Gerlach and Falko Berthold, for example, discuss spatial terms from the N!aqriaxe variety of ǂ'Amkoe, which is closely related to E. ǂHoan, and for which only a scant amount of material has previously been made public. They compare their data with equivalent terms from two very different languages with which speakers of N!aqriaxe are in contact, namely West !Xoon of the Taa group, and G|ui of the G‖ana sub-group of West Kalahari Khoe. Authors such as Tom Güldemann, in his discussion of the 'Lower Nossob varieties of Tuu', and Christfried Naumann, in his paper titled 'Towards a genealogical classification of Taa dialects', add a finer grain to our picture of the internal relations between languages and dialects within specific groups. (Tuu is the name proposed by Güldemann[2] for the group previously labelled Southern Bushman by Dorothea Bleek[3] and subsequently split into !Kwi – later spelled !Ui – and Taa by Westphal[4].) Other contributions are from Wilfrid Haacke on 'Verb serialisation in northern dialects of Khoekhoegowab', from Florian Lionnet on 'Demonstrative and relative constructions in Ju', and from Bonny Sands, with the late Henry Honken, on ǂ'Amkoe terminology for parts of the body.

It is to the credit of the editors that they include a paper by Chris Rapold which brings into question an earlier proposal by Güldemann[5] that verb-compounding in the Khoekhoe branch of the Khoe family reflects the influence of a !Ui substrate in the context of a mooted Cape linguistic area. Rapold uses carefully assembled evidence to reason that the phenomenon is an inherited feature of Khoe languages rather than contact induced.

The more controversial aspects of the book lie in the belief that speakers of the !Ui-Taa (or Tuu) and so-called Kx'a languages were the pristine inhabitants of southern Africa, intruded upon first by speakers of the notional Khoe-Kwadi, and later by speakers of Bantu languages. (The term Kx'a was proposed by Bernd Heine and Henry Honken[6] for the family created by their unification of the Ju languages – Dorothea Bleek's Northern Bushman – with the previously unplaced Eastern ǂHoan. The reader should be aware that both Khoe-Kwadi and Kx'a are debatable entities.) The overarching concept seems to have its origins partly in the elevation of cultural descriptors such as 'forager' and 'pastoralist' to the status of absolute categories that seem disquietingly close to being racial. This impression is heightened by the inclusion of a paper that examines the broad themes of the book from the perspective of molecular anthropology, which is to say, the study of population genetics and models of peopling. Certainly the paper in question is valuable for its pointing out of much that has been quite simply (and obviously) wrong in the assumptions made by geneticists in recent studies of Khoesan populations. It is not clear, though, that this relatively new field has avoided the pitfalls highlighted more than a decade ago in a thoughtful paper by

Jonathan Marks[7], for whom problematic assumptions about biological race are a concern. And in the end it is equally unclear that the book as a whole reflects a sufficient awareness of such issues and the ways in which they can distort our thinking.

Despite the last misgiving, I would urge university librarians to acquire a copy for their African Languages and Linguistics collections, because the book may become a catalyst for a new phase of informed and progressive multidisciplinary research touching on the pre-colonial past of southern Africa.

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The writing on the landscape

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Engraved landscape Biesje Poort: Many voices

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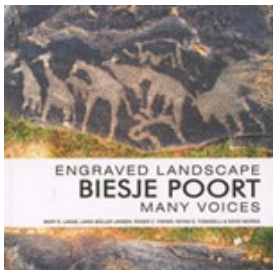

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> *The language of landscape is our native language. Landscape was the original dwelling; humans evolved among plants and animals, under the sky, upon the earth, near water. Everyone carries that legacy in body and mind. Humans touched, saw, heard, smelled, tasted, lived in and shaped landscapes before the species had words to describe what it did. Landscapes were the first human texts, read before the invention of other signs and symbols. Clouds, wind, and sun were clues to weather; ripples and eddies signs of rocks and life under water; caves and ledges promise of shelter; leaves guides to food; birdcalls warnings of predators.*[1]
>
> *We have to read the scene. Understand the message that it contains, and who it was meant for.*[2]

The relationships among people, their wide natural surroundings, their 'places' of greatest comfort and the immediate landscapes that encompass those places are older than the emergence of *Homo sapiens sapiens*, while maps of local areas, drawn on cave walls, exist from as far back as 18 500 years BP. More recently, in one of the earliest Western texts readily available to us, Homer[3] writes of Hermes visit to Calypso:

> *Around the cave grew a thick copse of alder, poplar and fragrant cypress, where large birds nested, owls, and falcons, and long-necked cormorants whose business is with the sea. And heavy with clustered grapes a mature cultivated vine went trailing across the hollow entrance. And four neighbouring springs, channelled this way and that, flowed with crystal water, and all around in soft meadows iris and wild celery flourished. Even an immortal passing by might pause and marvel, delighted in spirit…*

The sense of a place and location, with meaning to the observer, emerges very clearly in this and many other texts of the time and has done ever since. But how best to conceptualise and come to terms with our human encounters with, and our use and interpretation of landscapes, has been of theoretical and analytical interest to geographers, biologists, political scientists, landscape architects and literary critics, amongst others, for decades. We live in landscapes, shape them and then leave them behind as texts, often as complicated as palimpsests – worked, shaped, 'written' and then 'rewritten'. The message left behind is sometimes interpretable, yet still present for latecomers to 'read' as a way of understanding what has gone before and, possibly, what it might have meant to those former dwellers.

The above is the substance of *Engraved Landscape Biesje Poort: Many Voices* – a book oddly dedicated 'to all silent voices of times past and ever present at Biesje Poort' and presumably not, therefore, to the many voices that the text aims to reveal to the reader. This contradiction is, however, just one of many unusual twists to the book, as it is a montage (in this case, a textual collection of both images and analyses) of personal observations, poems, translated poetry and serious scholarly chapters. The chapters cover the project methodology, and also history, rock art, archaeology, conservation, and the nature of indigeneity as they pertain to the landscape of Biesje Poort. An appraisal of the list of references quickly attests to the serious attention that has been afforded the scholarly contributions.

Some readers might find the poetry a little distracting – while the lead chapter, largely a personal physical journey into the southern Kalahari world of Biesje Poort, offers a rather unexpected entrée into what is a serious engagement with the significance of the landscape and the analyses and insights in the chapters that constitute the remainder of the book. The 'conversations', however, deserve careful attention as they are an integral element in the chain of meanings to be disinterred ('engaging the absence of storyline' in the words of Chapter 3) through the scholarly work of the authors.

Some previous reviewers of the book have referred, in various ways, to the 'absences' and 'silences' in the text (what, for example, might be said about the people who left few or no traces behind?) reminiscent of the now rather discredited school of post-modernism, but I believe that that there is much more of value to be offered by the authors. In fact, apart from the new discoveries, information, insights and imaginings presented, one of the most valuable collective contributions that the book offers in the field of landscape analysis is that it is one of very few recent texts that speaks directly to the interpretation and meaning of the messages that *people* leave behind as additions to, and statements about, their places. As long ago as 1993, Susanne Küchler[4] wrote that landscape is 'the most generally accessible and widely shared *aide-mémoire* of a culture's knowledge and understanding of its past and future' and that the 'conception of landscape as inscribed surface implies a link between mapping and image-making….'. And it is these two ideas that are consistent throughout the book, making it, what I believe to be, amongst the first and, possibly, most comprehensive studies of the many voices that speak to us from the landscapes of South Africa. For it is not just the rock art but also the 'Western' and 'indigenous' mapping of the Biesje Poort landscape and its meanings that receive careful attention.

The scope of the book, coupled with its thorough scholarship, make it a perfect 'multidisciplinary' text, which will make fascinating reading for readers of the *South African Journal of Science* from across a wide range of research areas

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Develop energy from shale with local ecosystems in mind

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In South Africa, there currently are plans to develop shale-based gas extraction in arid and semi-arid landscapes of the Karoo. The extraction of gas from shale in the Karoo through hydraulic fracturing, also known as 'fracking', remains a contentious issue, with stakeholders often criticised for not being forthright in their reporting of the possible risks to local water resources.[1] Indeed, what I find the most striking among all the debate and polemical essays is how very few scientific reports there are on the possible local effects of fracking on the native Karoo biota.

A recent review underscored this shortfall in hydraulic fracturing development globally.[2] The authors concluded that energy development from shale gas often suffers from being ambiguous and incomprehensive across space: far too few peer-reviewed research papers particularly address the impact that fracking might have on the *biotic* elements in the landscape. This review therefore addresses the much-needed emphasis on including biodiversity conservation in assessing a fracking-targeted landscape.

A lack of focus from shale gas energy developers with regard to local biodiversity in the Karoo landscape would be naïve for two reasons. Firstly, it is generally accepted that intact ecosystems provide the necessary goods and services to sustain a society.[3] Secondly, considering that the Karoo is also a dryland ecosystem, it is important to note that there is a global pattern indicating dryland plant species richness as strongly related to sustainable dryland ecosystem function.[4] Thus, the appropriate management of biota in the landscape would ensure a sufficient buffer against environmental threats such as climate change and desertification.[4]

In view of the above, the findings by Souther et al.[2] should function as a stark wake-up call to all stakeholders of shale gas energy development in the Karoo; the locally targeted ecosystem needs to be considered in full to ensure cognisance of the realised impacts of fracking on the whole ecosystem. This biotic focus is especially relevant for the South African Karoo region because the method in question is directly threatening an already water-limited environment.

It is shortsighted to review the potential for shale gas development in South Africa and disregard the biotic influences when considering the vagaries of the successes and impact of fracking globally (see also Inman[5]). It would also be in direct contrast to the character of science as serving the whole community.

What biotic sacrifices are we about to make to extract shale gas energy? I believe more people would be at peace with the matter if they had access to more locally relevant scientific evidence – across all hierarchies of needs.

Photo: CJ Crous

Figure 1: A Karoo landscape near Prince Albert, showing the structural (topographical) and functional diversity (e.g. hill and riverine areas). This diversity increases and sustains biodiversity and ensures critical ecosystem functioning. What would the surface effects of shale gas extraction be on this pristine yet complex environment?

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State of green technologies in South Africa

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'There can be no green economy without green technologies and technological innovation'[1(p.31)]. Could this perhaps be the quintessential message conveyed in the recently published Academy of Science of South Africa (ASSAf) report *The State of Green Technologies in South Africa*?

The promise of the green economy surrounds us. Internationally, we have the United Nations Environment Programme's report titled *Towards a Green Economy*[2], published in 2011; the Organisation for Economic Co-operation and Development's 2011 report *Towards Green Growth*[3]; and the World Bank's report *Inclusive Green Growth*[4], published in 2012. And, as the ASSAf report shows, there is no shortage of South African policy documents that support the notion of the green economy – the New Growth Path[5], the National Development Plan[6] and the Green Economy Accord[7], to name but a few.

The green economy is a seductive notion – it presents a positive and optimistic view of a better and more sustainable future. It promises a cleaner environment, a solution for climate change problems, and, perhaps most important of all, the creation of new green jobs.

We are pinning so many of our hopes and aspirations on a transition to a green economy, but no country seems to have yet achieved that transformation. Is the green economy destined to be an aspiration for a better future that continues to elude us, or could green technologies be the key to unlock this transitional inertia?

If the byline quoted above – 'there can be no green economy without green technologies and technological innovation', which was originally attributed to Gisbert Glaser – is to be believed, then the report *The State of Green Technologies in South Africa* is poised to play a pivotal role in South Africa's transition to a green economy. The report systematically unpacks the state of green technologies, identifying opportunities sector by sector. However, given that technology is advancing so rapidly, this review is not where the report's real value lies. There are many more strategic and fundamental guidelines for policymakers; some of these guidelines are included in the recommendations at the end of the report, while others lie embedded in the report, and require a careful read.

The recommendation that there should be policy coherence and policy coordination is not a surprising one and provides an opportunity for the Department of Science and Technology (DST) to take a lead in bringing relevant government departments to the table to give effect to this recommendation. The nudge towards a 'developer role' for South Africa, rather than just an 'implementer role', is interesting. It is argued that local innovation and manufacturing should be the ultimate goal, emphasising the importance of a robust National System of Innovation (NSI) and investment in research and development (R&D) and skills development. Again this recommendation speaks directly to the DST as custodian of the NSI and the development of appropriate human capital. If one follows the logic, it is basically saying that investment in R&D is a prerequisite for a green technologies thrust and, by implication, a transition to the green economy.

There is a thoughtful chapter on the role of business which provides a useful starting point for a much-needed conversation between government and the private sector on how to cooperate in the green technology space.

The recommendation for systematic evaluations of failed or discontinued projects is one that is applicable very broadly. Too often, failed projects are never scrutinised to boost learning experiences but findings are rather kept under wraps. There should be no embarrassment in failure provided one learns and does better the next time. It is argued in the report that because many green technologies are at an early developmental stage, they are more likely to pose risks and be potential failures – a situation which is not to be feared but rather welcomed, as through the conduct of systematic assessments an opportunity to improve and progress is presented.

Finally, there are some all-important messages that touch on human behaviour. One can have all the innovation in the world, but ultimately, technologies have to be adopted by users. Some reasons for the failure of people to adopt technologies are unpacked. Adoption is described as a process that takes time and requires intervention. The power of the media, both traditional and social, early adoption by celebrities and the role of government incentives are stressed.

This report is not one in which responsibility for implementation of recommendations rests with a particular government department. It is relevant for many, as well as industry, the non-governmental organisation sector and the private citizen. Ultimately, each of us has a role to play in ensuring that the green economy becomes a reality and not simply an aspiration.

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The precautionary principle: Making managerial decisions on GMOs is difficult

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The precautionary approach of the Cartagena Protocol on Biosafety, if incorporated into legislation of countries as a precautionary principle (PP), could cause great difficulty in decision-making on genetically modified organisms. No consensus seems to be possible on the interpretation of the PP, as responsibility often is passed on to political decision-making and, eventually, to court rulings. A case study on the assessment of possible unintended effects of endogenous allergens illustrates the complexity decision-makers may experience. We review the descriptions of the PP and the debate on the interpretation and conclusions that a number of authors have come to, as a step closer to a solution in decision-making. South Africa may have to consider the PP in the broader context of its food security needs, which would require improved communication as an additional step in the process of risk analysis.

Introduction

A lack of coherence is observed in decisions made by governments for control of genetically modified (GM) crops. Examples include rejection by some African countries of donor GM maize; increased regulatory requirements; indecisiveness regarding new applications for permits with many delays and negative consequences to producers and consumers; and creation of negative perceptions towards genetically modified organisms (GMOs). There are many reasons for this situation, one of which is the variable application of precaution in decision-making, in particular different interpretations of the precautionary principle (PP). The control of GMOs by legislation and international interventions in this respect jointly speak of a cautious approach to risks from new technologies. However, genetic modification is no longer a new technology. Although international agreement exists on the general approach to risk and safety assessment of food from genetic modification, and many countries follow the international guidelines, debates on matters such as possible unintended effects from this technology are currently prominent. The difficulty that decision-makers often experience is illustrated by issues of possible unintended effects of the genetic modification on endogenous allergens. An understanding of the PP could give perspective to the burning issues, such as food security, with which decision-makers are confronted.

Description of terms and concepts

Risk, risk assessment, uncertainty

Risk analysis describes a dynamic iterative process composed of risk assessment, risk management and risk communication.[1] The term 'risk' describes the probability of an adverse (health, environmental) effect (leading to harm or undesired consequence) and the severity of that effect, consequential to a hazard(s) or threat(s).[1,2] In scientific terms, zero risk is non-existent.[3] Some uncertainty is always present[4] and forms an inherent and integral element of scientific analysis and risk assessment[5-7].

Evolution of crop plants

Plant breeding

The assessment of the safety of food from GM crops should be placed in the context of the evolution of crop plants which started thousands of years ago when plants were first domesticated. A recent example is the Chinese gooseberry, which is not edible, but with breeding has become palatable, and is now called kiwi fruit. Today every crop plant that is grown is related to a wild species that occurred naturally in its centre of origin. Dramatic phenotypic changes occurred through new mutations and natural hybridisation that farmers selected for and then maintained as landraces. Scientific developments in agriculture, such as knowledge of genetics, contribute to improved plant-breeding practices. An array of scientific tools is now used to increase existing genetic variation, for example: hybrid embryo rescue; application of colchicine, a chemical employed to induce polyploidy; ionising irradiation; mutagenic chemicals and somaclonal variation (cell culture). Gene transfer techniques to develop GM crops are considered a logical extension of the continuum in the scientific development to improve plant breeding.[8]

Interesting new developments

Recent molecular techniques have shown that the techniques used in traditional (non-transgenic) plant breeding are associated with genetic changes such as mutations, deletions, insertions and rearrangements.[9] These changes occur in addition to the movement of mobile genetic elements such as transposons (jumping genes) that are responsible for most genome plasticity.[9] Many of these genetic alterations occur in nature.[10] Plant breeders traditionally eliminate observed off-types during the evaluation process. Despite the dynamic nature of the genomes, and the effect of traditional breeding on the genome, only a few safety concerns from traditional plant breeding have been recorded over years. Several recent articles have shown that traditional breeding causes more inherent variability than GM.[11,12]

Arguments for less stringent requirements or exemption from regulation are heard frequently.[13,14] There may also be a need for policy reform to take into account the new developments.[15]

Food safety assessment of GM crops

The Codex Alimentarius Commission, a body under the joint auspices of the Food and Agriculture Organization and the World Health Organization, played a prominent role in the development of guidelines for the risk and safety assessment of food products from GMOs.[16] These guidelines outline the safety and risk assessment of food from GMOs in a precautionary way by proposing the steps to be taken in the assessment. Substantial equivalence, a concept mentioned in the Codex guidelines, was previously mistaken as the endpoint of the assessment. The concept has been replaced by an improved description of the approach for safety and risk assessment, which involves a comparative analysis of the composition and of the phenotype.[17,18] This approach is preferred as animal toxicity studies would be difficult because of the complex nature of food compared with chemical molecules such as pesticides. Molecular characterisation is included in this starting point of the assessment to identify hazards. The composition of the edible parts of the genetically modified crop is compared with those of its near-isoline with a history of safe use. A broad range of parameters (macro- and micronutrients, antinutrients, toxicants and secondary compounds) is considered in the comparative analysis. Safety assessments of intended changes and of unintended significant differences are the next step in the safety assessment. Differences need not necessarily be unintended effects of genetic modification, but can be caused by slightly different genetic backgrounds or environmental effects. Compositional safety is considered in the context of the normal composition of the crop by including a number of commercial non-GM crops in the trials that are conducted across several environments. Safety is informed by considering the normal array of compound levels present in crops that have a history of safe consumption[19] including the antinutrients, toxicants and endogenous allergens of the crop. The nutritional value of the crops is an important consideration in the assessment. Endogenous allergens had not received serious attention from regulatory authorities until recently.[20]

South African precautionary approach to GMOs

The establishment in South Africa of SAGENE (South African Committee for Genetic Experimentation)[21] in 1978 is evidence of the environmental and human health concerns of scientists when progressing with a new technology such as genetic engineering (also known as genetic modification or modern biotechnology). The need for a precautionary approach to possible environmental threats and concern for human health is illustrated by several South African laws. A precautionary approach in managing risks is included, for example, in the two South African environmental management Acts,[22,23] which provide for 'a cautious approach which takes into account the limits of current knowledge about the consequences of decisions and actions'. The *Genetically Modified Organisms Act of 1997*, as amended, incorporates the requirements of the Cartagena Protocol on Biosafety (CPB), and, in the regulations to the Act, requirements are described for the protection of human health and the environment against possible risk from GMOs.[24] No mention is made of cost/benefit or risk/benefit, or proportionality of risk in applying the PP;[24(p.3)] although the GMO Act does refer to 'socio-economic impact', with the implication that an impact could be positive or negative.

South Africa has published a number of guiding documents. However, different South African government departments represented on the GMO Council apparently hold different positions. The absence of specific policies is obvious in the recent mandatory GMO labelling requirements in which regulations were promulgated by the Department of Trade and Industry[25] without consideration of existing GMO labelling regulations of the Department of Health. The Department of Environmental Affairs, in its 'framework'[26], refers to 'null risk', 'avoid' and 'prevent', which describe precaution at its extreme, whereas other government departments do not seem to have any specific interpretation of the GMO Act in terms of their mandate.

There seems to be a need for policy and guidance on matters such as the PP, new breeding technologies and dealing with possible unintended effects from endogenous allergens. The new strategy on bio-economy is a step in the right direction to address national policies.[27]

The precautionary principle

Cartagena Protocol on Biosafety

Against the background to risk assessment and the decisions with which regulatory authorities are confronted when dealing with genetic modification of crops, an understanding of the PP is important.

A precautionary approach was originally developed to provide risk managers with a tool for making decisions on environmental threats from processes or substances that had not undergone safety evaluation or regulatory approval.[28] Cooney[29] has summarised the history of the development that resulted in a number of international agreements.

The CPB[30] is one of a number of important agreements among nations to consider possible harm to the environment and human health. It requires countries to introduce measures to safely manage transboundary movement of living modified organisms. Countries that became signatories to the CPB were expected to incorporate the CPB into legislation and to adhere to the requirements for environmental safety and human health. A precautionary approach in consideration of risks, articulated in the CPB as well as in other international agreements and environmental law, is the cause of ongoing debates on the interpretation and implementation of precaution.[29]

The PP was first incorporated into the World Trade Organization's (WTO) Agreement on Sanitary and Phytosanitary Measures (SPS Agreement) in 1994.[31] Article 5.7 makes it possible to obtain additional information within 'a reasonable period of time'[31(p.72)] when existing information is inadequate, whereas Article 3.3 allows for more stringent protection than relevant international standards, if there is 'scientific justification'[31(p.70)]. The Codex standards are accepted by WTO as references.

Many debates seem to have ignored the fact that the point of departure in assessing biosafety of living modified organisms is determined in Article 4 of the CPB. The focus of the Protocol is on LMOs [living modified organisms] that may have adverse effects on biodiversity as well as risks to human health (Article 1)[30(p.3)] and 'risk assessments shall be carried out in a scientifically sound manner' (Annex III, para 3)[30(p.28)]. Furthermore, the directive for application of a precautionary approach has been set in Principle 15 of the Rio Declaration,[32] namely, 'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'[32(p.2)]. Neither of these approaches demands that all applications of biotechnology or of genetic modification must undergo extensive assessments to comply with the precautionary approach and neither implies that biotechnologies are inherently unsafe. The interpretation of the requirements of the CPB in many aspects has been debated for a number of years. Some of the implementation procedures seem not to be in proportion to the risk or a cost/benefit analysis; for example, the need for milling GMO commodities such as maize in the Southern Africa Development Community.

A principle or an approach?

Legislating GMOs by pre-market regulatory requirements for risk assessment and by managing risks at the different steps of the development and production of GM crops are precautionary measures. On the other hand, the 'precautionary approach' as applied according to the CPB, intends to address uncertainties that occur in risk assessment. 'Precaution' is generally recognised – not as a hypothesis, theory or methodological rule – but as a normative principle for making practical decisions under conditions of scientific uncertainty.[33] A normative principle implies obligations to 'anticipate harm and moral obligations in judging the adequacy of available knowledge'[34(p.263)]. 'Normative' is defined in the Collins English Dictionary as (1) Implying, creating, or prescribing a norm or standard, as in language: *normative grammar;* (2) Expressing value judgements or prescriptions as contrasted with stating facts.[35] In teaching of religion, distinction is very broadly made between the 'regulative principle' of worship meaning binding in exact accordance to the Holy Scripture, whereas 'normative principle' of worship in general means nonbinding.[36]

The implementation of the PP 'requires different normative commitments and choices'[37(p.2)]. Ahteensuu describes the PP as a principle of 'practical decision-making which may be justified on the basis of ethical and socio-political grounds and/or as a form of rational action'[37(p.2)]. The obligatory nature of this normative principle has resulted in more than policy design criteria, but becomes a 'regulatory philosophy'[38(p.23)] when included in legislation, which, in turn, has to be interpreted by regulators. Von Schomberg[39] explains the normative challenges for application and implementation of the PP. The scope of PP deliberations stretches across broad political debate, policy level (political and societal), science–policy interface and risk management.

Authors such as Recuerda[40(p.5)] analysed the legal interpretations of the US versus the European system. The conclusion was that 'principle' had the connotation of legal language, of law, a 'principle of law', which is the status of the PP in Europe, whereas the USA considers it an approach with no legal connotation. The English language version of the CPB[30] uses the word 'approach', French 'l'approche de précaution', German 'Vorsichtprinzip' and Spanish 'principio'. It seems that the words 'approach' and 'principle' are used without clear distinction in different languages.

The precautionary approach is recognised as a precautionary principle when included in legislation with obligations, as explained by authors such as Levidow et al.[34] and Löfstedt[38]. Cooney[29] reasoned that the PP would not determine a specific outcome or decision, unless a specific formulation required it. Therefore, the terms 'precautionary approach' and 'precautionary principle' were used interchangeably. The PP nomenclature is followed in this paper.

Definitions

A normative principle may be interpreted in various ways. This multi-interpretation is illustrated by about 19 definitions of the PP (Table 1). Central to the PP is the obligation of action to reduce harm to the environment and human health, and the moral obligation that action be taken even if scientific evidence is inconclusive. These obligations are formulated in different ways – strong 'obligatory' versions and weak 'optional' versions (Table 2). The strong form of the PP, for example the Wingspread Statement (1998), is advocated by Greenpeace[41] and UNESCO-COMEST[42], while an example of a weak form is included in the Rio Declaration. The difference between weak and strong precaution lies mainly in the greater emphasis on risk avoidance, provision of safety and the obligation to take safety measures. Variations in the scope of 'precaution' from narrow to broader accounts are reflected in (1) prior risk assessment, (2) what triggers the use of the PP and (3) the scope of action.[7,34,43]

Table 1: Definitions and description of the precautionary principle

Codex Alimentarius Commission[16]: *Precaution is an inherent element of risk analysis. Many sources of uncertainty exist in the process of risk assessment and risk management in food related hazards to human health. The degree of uncertainty and variability in the available scientific information should be explicitly considered in the risk analysis. Where there is sufficient scientific evidence to allow Codex to proceed to elaborate a standard or related text, the assumption used for the risk assessment and the risk management options selected should reflect the degree of uncertainty and the characteristics of the hazard.*
Rio Declaration, Principle 1532 and the Cartagena Protocol on Biosafety to the Convention on Biological Diversity[30]: *In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as reason for postponing cost-effective measures to prevent environmental degradation.*
The precautionary principle, South Africa's position[44]: *Proportional to risk, non-discriminatory, consistent, based on cost-effect assessment, subject to review, capable of assigning responsibility for producing scientific evidence.*
UNESCO-COMEST[42(p.14)]: *When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish harm ... Morally unacceptable harm is ... (1) threatening to human life or health, (2) serious and effectively irreversible, (3) inequitable to present or future generations, (4) imposed without ... consideration of ... human rights ... The judgment of plausibility should be grounded in scientific analysis ... Uncertainty may apply to, but need not be limited to, causality or the bounds of the possible harm. Actions are interventions that are undertaken before harm occurs that seek to avoid or diminish the harm. Actions should be chosen that are proportional to the seriousness of the potential harm, with consideration of their positive and negative consequences and with an assessment of their moral implications of both action and inaction. The choice of action should be the result of a participatory process.*
Wingspread Statement on the Precautionary Principle[41]: *Where an activity raises threats of harm to human health or the environment precautionary measure should be taken even if some cause and effect relationships are not fully established scientifically. In this context the proponent of the activity, rather than the public, should bear the burden of proof.*

Core of the debate on the precautionary principle

As threats to health and the environment become more complex, uncertain and global in nature, the PP is increasingly being debated.[45] Cognisance has to be taken of the debate. At the core of the debate on the PP is the degree of scientific uncertainty in risk assessment and what decisions should be made by managers in the face of uncertainty, when to apply precaution, and what precautionary measures should be taken to achieve certain levels of protection.[46]

Klinke and Renn[47] identified five major noteworthy themes in this debate. These themes can be grouped into two very closely related issues: how risks are perceived by different people and how regulatory authorities deal with these risks.

Perception of risks and evaluation of uncertainties

There are two camps on the perception and evaluation of risks. One claims that risks are mental constructs that originate in human minds and are only real within a specific group of people. The opposing camp argues that technical estimates of risks are true representations of observable hazards and that the effect is predictable, regardless of the analyst's beliefs. In between these two viewpoints are those who believe that a combination of the two is more realistic.[48]

The concept of 'sound science' that is included in international agreements and guidelines[16,30,49] is being challenged. It is questioned[7,34,43,50] whether scientists can conduct objective analyses of risks because they interpret information according to their scientific knowledge and values. Anti-commercial sentiment is also often observed in literature on the PP, by remarks on the integrity and independence of scientists, the regulators' public accountability and those with 'financial stake in scientific development'[51(p.376)].

Charnley[52], former president of the Society for Risk Analysis, has it that risk analysis is 'threatened by a serious, growing, anti-risk analysis sentiment that is challenging the legitimacy of science in general, and risk analysis in particular'[52(p.3)]. Scientists and managers receive blame for many 'risky' incidents, although there is perhaps an implication here that the PP replaces risk assessment. Berry[53(p.7)] responded to the accusations:

> *Evaluation of data obtained from scientific investigations is not easy and the process often seems counter-intuitive to the uninformed. Some hold the conviction that ideological motives colour all deliberations – this makes it easy to suggest that in any scientific debate an opponent's reason for holding a particular viewpoint or belief depends on his or her motives rather than their knowledge base. This position may be useful in providing the*

> *grounds on which to mount a polemic against any perceived threat (drugs in modern medicine, pesticides in intensive agriculture or genetically modified organisms). The conviction that opinions cannot be based on independent thought, has led to a disregard of professionalism and the development of the view that who pays you determines your opinion – not your science.*

The debate also includes evaluation of uncertainty in risk assessment, the validity of animal models[54], variability in data[19] and lack of sufficient knowledge[47]. Approaches to assessment of GMOs, for example the substantial equivalence, and concepts of familiarity and 'history of safe use' have been criticised as pseudoscience.[55] As an alternative, a 'holistic' approach is advocated by some.[55-57]

Instead of gaining more knowledge about uncertainties, alternative management strategies could be proposed – for example, human interventions that are manageable.[47] Additional and more stringent control to the point of embargos or refusal to avoid any risk as a precautionary measure might be detrimental to progress. Steering direction is difficult in these situations without clear policies at every level of decision-making.

There is no well-established classification of uncertainty in risk assessment.[47] Renn and Klinke[48] have described six groups of risks named from Greek mythology. They grouped GMO technology with disintegrating polar ice sheets because of uncertainty in both probability of occurrence and extent of damage.[48] Vlek[58] grouped GMOs with risks such as the AIDS epidemic as a 'diffuse source' with the potential risk of long-term and extensive effects. Risks associated with conventional agricultural plant breeding are not mentioned; neither are far less precise techniques such as induced-mutation breeding in which plants or seeds are exposed to ionising radiation for which regulatory control does not exist or is more lenient than that for GMOs.

Public interest

Public perception on how uncertainty in risk assessment is handled is a valid issue to some[47] and engagement of interested and affected parties in appraisal is also a matter of scientific rigour[7]. In a survey on people's opinions on some scientific issues in the UK, some responded that most scientists are poor communicators,[59] resulting in a gap in knowledge transfer to the public at large, while some sensational media contributions have led to misguided public perceptions. The debate also focuses on the legitimate role of public deliberations in risk analysis and management. The International Risk Governance Council's position on values is that all dimensions of risk, both the factual and the socio-cultural[60(p.12)], need to be considered.

The 'contextual variables of risk' as they affect perceptions of consumers are important.[47(p.1077)] One of the many issues is trust in regulatory agencies and risk handling, often described as credibility.[38]

Table 2: Accounts of the precautionary principle[7,34]

Narrow accounts	Broad accounts
Prior risk assessment	
The burden of evidence is inherently shifted from demonstrating risk to demonstrating safety	The burden of evidence depends on the questions asked: asking the right questions needs stakeholder involvement
Trigger for precautionary principle	
The precautionary principle can be triggered only by an objective scientific evaluation, indicating reasonable grounds to expect potentially dangerous effects (or established scientific uncertainty)	The precautionary principle can be triggered also by initial suspicions about risk. The precautionary principle can justify measures to control undesirable effects (including potentially dangerous ones)
Scope of action	
Analyse policy: regulatory action versus inaction e.g. through a cost–benefit analysis	Provide the means to demonstrate that alternative solutions are less harmful. Establish a dialogue on social issues, e.g. what options are desirable and feasible?

The debate in perspective

Risk is a societal construct as well as a physical reality.[49] Results from the continued debate are observed in changes in the process of risk analysis, the critical assessment of approaches to risk assessment and proposals for improved structured communication.[61] Some valid arguments have been raised. Inclusion of public concern/social criteria needs further research. The inclusion of sociological issues in decision-making is anything but simple. There are many aspects – such as cultural differences, country needs, human nature, philosophies, religions and political issues – to take into account.

Analysis of the precautionary principle and its application

Critique of the precautionary principle

Vlek[58] groups the multiple criticisms of the PP into ten objections. Some of the objections are that: the PP is vague and broadly ambitious[62]; serious or irreversible harm is ill defined[62,63]; it is dependent on plausibility reasoning[64]; it is a policy of risk avoidance[65]; it is too absolute and obligatory, thereby blocking or slowing down technology innovation and progress[66]; it demands 'impossible' proof of safety; identifying the nature and likelihood of possible serious harm may yield high costs of safety tests and long delays in relevant policy decisions[67]; and it can be misused by powerful interest groups[51].

Vlek's[58(p.533)] conclusion was that the PP has 'an unusually protective inclination towards foregoing an activity or imposing strict(er) safety measures upon it, both of which are induced by large uncertainty about possible disastrous consequences'.

Peterson[63] rejected the use of the PP as a basis for decision-making, citing examples of decisions on conducting clinical trials, mobile phones and GM-derived foods. He said, 'the precautionary principle therefore replaces the balancing of risks and benefits with what might best be described as pure pessimism' [63(p.306)]. He argued:

> *We need a principle that tells what to do and what not to do for each possible input of qualitative information…no generally accepted formulation will ever emerge as the PP is not a single well defined idea…it makes more sense to describe it as a cluster of vague related intentions about risk aversion, burden of proof, irreversible damage and normative obligations* [and] *any reasonable formulation of the PP will imply a value judgment that no rational decision maker would be prepared to accept.*[63(p.306,307)]

With respect to the burden of proof, Petersen claimed, 'It rests with anyone who makes a claim, regardless of what is being claimed' and concluded, 'There is nothing wrong with the precautionary principle – as long as it is not used for decision-making'[63(p.308)].

Berry[53(p.7)] commented that 'convictions with ideological motives colour all deliberations'. He mentioned the PP as a good example of only considering results that fit a preconceived viewpoint. He asserted:

> *But it should be made clear when political or socio-economic judgments are being made and the pretence that they are scientific judgment, should be eschewed. It is comforting to pretend*

> *that we know more than we think, but damaging to pretend too much.*[53(p.7)]

In summary, Vlek[58] said that the PP is mostly derogated for its general inclination and motivation, its dependence on plausibility reasoning, its lack of comparative risk evaluation, its lack of explicit decision-making considerations, its openness with regard to legal obligations, and its implied shift of the burden of proof of safety.

Decisions from arbitration

Proof of the difficulty in interpretation of the meaning of the PP concept lies in the opinions of jurists who are grappling with it because of its 'philosophical characteristic, inherent uncertainty, and ambiguous and arbitrary nature'[66(p10)]. The PP is open ended and undefined, which 'gives regulators almost unlimited discretion to impose restrictions'[66(p.32)]. Ultimately, the courts will have to flesh out the principle.[51,66,68,69] The reality is that prevailing social and political values influence to some degree the trend in case law. In legal formulation, UNESCO-COMEST[42(p.22)] advises: 'first, the recognition of a value by a society is worthy of protection, and, second, the provision of a legislative tool [is] in order to protect this new recognised value'.

A WTO[31] ruling on GMOs illustrates the application of the PP in international trade. A long-standing dispute existed between the USA and Europe over the European Commission and several European member states' *de facto* moratorium on approval of GMOs. The moratorium lasted from 1998 to 2004. In 2003, the USA, Canada and Argentina sought legal recourse at the WTO under WTO SPS (Sanitary and Phytosanitary) law based on unjustified and illegal denial of access to European markets (EC Biotech Products case) that resulted in financial losses to US farmers. The WTO based its final decision in 2006 on failure of the defendant to conduct 'adequate' risk assessments (SPS Article 5.1 and Annex A (4)) by not taking into account risk assessment techniques (protocols) of relevant international organisations. Although their scientists' conclusions were based on scientific methods, the WTO panel found that legislators often based decisions on 'unverifiable facts and public fears'[70(p.2)]. The European Commission's arguments apparently rested on concerns by regulators on 'scientific uncertainty', thereby ignoring their own risk assessments. The WTO panel rejected the defendant's arguments (Articles 5.1 and 2.2). The argument that there was 'insufficient scientific evidence' (Article 5.7) was also rejected as the European Commissions' scientific committees indeed reviewed the relevant information and did not question their previous conclusions. Therefore, additional information in this case was not an issue. 'Scientific uncertainty' and 'insufficient scientific evidence' are not the same (SPS Article 5.7). The WTO also concluded that the European Commission had acted inconsistently with its obligation under Annex C (1) (a) and Article 8 because of the undue delay. The European Commission accepted the ruling.

Europe introduced legislation to improve the framework for assessing the application of GM plants and introduced strict labelling and traceability requirements for GMOs in 2003 to accommodate public perception and address fears. An assessment of the WTO panel's decision is not pursued further in this study.

The interpretation of uncertainty, and perhaps consumer perceptions, is further illustrated by the November 2011 ruling of the two highest courts in the European Union – the European Court of Justice and the Conseild'Etat of France – against the French ban on planting of GM *Bacillus thuringiensis* maize (Bt maize). The ban was based on a European Union 'safeguard clause' and legal provision for 'emergency measures' in case of evidence of serious hazards to human health and the environment. The courts ruled that France did not present any such new evidence to substantiate their ban on Bt maize. France responded by stating that it will reinstate the ban.[71]

In South Africa, appeals[72] against several decisions made by the GMO Executive Council on the general release of Bt11 maize, the use of biofortified sorghum for greenhouse studies and planting of cassava field trials, resulted in the Appeal Board ruling in favour of the applicants, although in the latter two cases certain conditions which require more stringent management were added.[72] In the case of an appeal by Biowatch against the decision to grant general release of Bt11 maize, the appeal board ruled against the appellant.[73] Valuable lessons were learned from this case, one of which was that demands for additional data, as a matter of 'nice to know', illustrating the interpretation of 'precaution' by some groups in the society could result in costly delays to the applicant, as well as the complainant and government.

Acceptable solutions in the precautionary principle debate?

Key issues in the precautionary principle

Having summarised the issues in the debate, the reality is that clear guidance is needed to facilitate regulatory decisions based on an even-handed approach to precaution. In order to come to acceptable solutions, the key issues at this stage are:

- Key inherent problems with the application of the PP and the corresponding precautionary approach were identified by Vlek[58]; for example, (1) substantive issues such as determining the plausibility, nature and seriousness of possible harm or damage and (2) procedural issues, for instance optional versus obligatory precaution, and the need for further research and policy development. These problems are also described as factors triggering recourse, which is the decision to act or not to act, and the measures on how to act.
- The PP applies to serious uncertain risks or threats; it is inclined to be unusually protective or even preventative; the proponent has a large burden of demonstrating the likelihood of safety; and there is the tendency to delay risk-taking until sufficient new information becomes available.[58,74]
- A number of authors have described models for decision-making based on assessment of risks in general.[58,74,75] These risks rest upon axioms and assumptions that are not always valid in practice, such as perceptions of cultural differences.

In trying to find a way forward, the following comments on the application of the PP by Feintuck[51] are noteworthy: 'The PP is currently applied as a procedural rather than a substantive device' and 'substantive content and value-orientation' are necessary. Feintuck[51] contended that if the 'PP is devoid of intrinsic values, these may simply be filled by the values of dominant groups'. His conclusion, after studying the development and implementation of the PP, was that it is a 'complex picture of interaction between science, economics, public policy and law'[51(p.377,392)].

Risk governance of GMOs

The European Commission[46] places the burden of determining an acceptable level of risk for society as a judgement of an eminently political responsibility: 'Decision-makers faced with an unacceptable risk, scientific uncertainty and public concerns have a duty to find answers'[46(p4)]. Guidance from the European Commission perspective is followed by, for example, the South African regulatory authorities for GMO governance (Table 1).[44]

The International Risk Governance Council – a private, independent, not-for-profit foundation – was established in 2003 to support governments, industries, non-governmental organisations and other organisations to deal with major and global risks and to foster public confidence in risk governance. Debates within the PP protagonist circles focus on the relative importance of substance versus procedure. At the very least, it is important to be in agreement on the importance of procedural steps in instances of great uncertainty about the available evidence, possible consequences, feasible options, long-term effects and minority views. The International Risk Governance Council has developed a framework to assist governments in decision-making on all kinds of risks.[60]

The designers of the International Risk Governance Council's framework[60] emphasise the importance of stakeholder participation. This is also elaborated on by a number of proponents of the PP.[37,43,76] One can conclude that interaction at different levels is required, but it would have specific challenges.

Vlek[58] suggested that the parties involved might do well to attend carefully to the kind of participants, structure, content and process making up the relevant assessment and management strategy. Vlek[58] also warned against 'individual judgements and social decision-making, for example allowing room for prior beliefs and biases, selective information processing, authoritative dominance and groupthink at the cost of minority views'[58(p.535)]. In participative, multi-stakeholder situations, these could lead to disputable judgements, decisions and actions.[51]

In a democratic political situation, and to improve credibility of risk governance, improved interaction with stakeholders (for example the public, scientists and the owners of the technology) has to be considered. Much more thought will have to go into defining the nature and substance of such interactions. Participation has to be correctly defined, as accountability remains with the regulatory authority. Codex[1] describes an interphase for determination of 'risk assessment policy' as a specific component of risk management interaction among risk managers, risk assessors and stakeholders that governments could consider to improve communication.

Case study: Assessment of endogenous allergens

This case study illustrates some of the complexities with which decision-makers could be confronted in the governance of risks.

Codex's guidance for risk assessment, as a precautionary approach, describes the case-by-case process to be followed in the safety/risk assessment of GMO products (see section on safety assessment of GM crops). Keeping in mind the conclusions from the molecular characterisation, phenotypic and agronomic comparative studies as well as comparative analyses of the nutrients, toxicants and antinutrients would follow. Codex[16] considers that endogenous allergens should be included in the compositional comparative safety assessment. The safety/risk assessments of possible unintended effects of endogenous allergens pose problems, as described in the sections following.

Step: Risk assessment framing

Policy development

A precautionary/risk assessment debate regarding inclusion of endogenous allergens in the safety and risk assessment may proceed as follows.

GM-derived foods are assessed according to regulatory requirements and, if approved for human consumption, different laws of a country may have additional requirements (e.g. labelling of food). Labelling in many countries includes information on the eight food allergens (Box 1). A possible question is: Would it be necessary to include endogenous allergens in the compositional analysis of those eight foods when derived from GMOs when allergenicity labelling is a standard required? Another question could be: What about possible unintended increased levels of the endogenous allergen in these eight allergenic foods? It is difficult to determine the prevalence of allergenicity, as consumers tend to avoid foods to which they are allergic. Although allergenicity to some foods, such as peanuts and tree nuts, could affect up to 1% of the population, none of these foods has been withdrawn from the market. However, some countries do require analysis of these allergenic foods.[20]

Another question could be: What about possible unintended increased levels of endogenous allergens in GM-derived food in addition to the eight allergenic foods? This question provokes a number of issues; hypothetically, it is possible for someone to be allergic to any food, processed or raw. A question on concentration levels would be: What level would trigger a tolerance level that could serve as a point for decision-making by regulators? Information that could stimulate more questions is given in Box 1.

Box 1: Endogenous food allergen information

The prevalence of food allergenicity is unknown, but it is estimated that over 90% of reported food allergies are those to the eight most common allergens – peanuts, soybean, tree nuts, wheat, cow's milk, eggs, fish and crustaceans[77,78] – which affect up to 3% of adults and up to 6% of infants in the population.[79,80] Each of the allergenic foods contains multiple allergens. It is not possible to predict who will become allergic and to which foods and which proteins in foods.[81] There are stable and abundant proteins that do not cause allergy as well as moderately abundant proteins that do cause allergy.[82] Sensitivity reactions to the same concentration of allergen vary between mild rashes to anaphylactic shock.[83] There is a wide variation in IgE binding to different varieties of the same species of non-GM crops.[84]

Natural variability in plant components is a result of genetics, environmental factors and post-harvest conditions, but the variation in expression of levels of various allergenic proteins has not been documented. Food processing and interactions with the food matrix also affect the allergic potential.[20]

Specific serum screening to confirm allergenicity may not be possible for many food allergens because of difficulties in the identification of a sufficient number of donors, cross-reactivity and other problems.[20,82] The number of sera samples needed is dependent on the required degree of protection to the population. Animal models are in general considered not validated and inconclusive for assessment.[20,85] Sufficient sensitivity and specificity to guarantee absence of false negative and false positive results are not yet possible. Analytical and profiling techniques or in-vitro protein analysis and proteomics methods need to be assessed for accuracy, sensitivity, specificity and feasibility before being routinely used for allergenicity assessment.[20]

Uncertainty in answering these questions because of a lack of sufficient scientific information is illustrated in the following discussion in the case of maize.

Maize – a staple food for many people – is a crop that has been genetically modified to introduce a number of new traits. To better understand the complexity encountered in decision-making, a hypothetical case is made for endogenous allergens of maize. Known allergen information is given in Box 2. A general conclusion from this information is that there are a number of issues that would make it difficult to make a decision of absolute safety unless more information is generated. The shortage of serum donors would be critical in most cases.

Box 2: Consideration of endogenous allergens in maize

The main allergen in maize, Zea m 14, is a lipid transfer protein – a true pan-allergen[86,87] that maintains its structure after cooking at high temperatures.[88] Cross-sensitivity with other fruits and vegetables occurs.[86] Prevalence is unknown. Incidences of allergenicity have been reported from regions in Italy[86] and Mexico.[89] Serum tests would be very difficult to conduct because of the scarcity of allergic consumers.[82]

The population in general, has been exposed for many years to fluctuating concentrations because of environmental effects and hybrid variability. Normal variation of lipid transfer protein in maize could be up to 15-fold across genetic and environmental differences.[90]

There are more questions and issues. It would only be possible to consider the tolerance levels once the range of endogenous allergen levels has been determined for each crop plant. How sensitive are the tests and what serum sample size is required? What percentage (or concentration) increase above the range of natural biological variation is acceptable? What percentage of the population should be protected?

What levels would cause reactions in patients, from mild to severe? What percentage of severe reactions such as anaphylactic shocks has been documented for the population?

There is also a question on the labelling regime for those GM-derived foods which are not one of the mentioned eight allergenic foods. And should elevated levels of the endogenous allergens be detected, could it be shown that they were explicitly caused by the genetic modification

and not by normal variability? Would an Identification Preservation System be feasible, practical and affordable?

More recently, the results from information accumulated over more than 20 years, as described in this paper, showed no significant differences in the composition of tested components (excluding endogenous allergens) between GM crops and the near-isolines. Furthermore, consumers have been exposed to GM-derived foods through a number of different crop species and traits – all assessed case-by-case – with no adverse effects recorded. These are important observations that regulators should take into consideration.

The final question that a managerial team could ask might be: Does the case under consideration qualify as a situation of serious uncertainty and an irreversible risk? This question may not be easy to answer.

Regulating the assessment of endogenous allergens of GMOs?

Decision-makers are confronted with a number of challenges. A study of the literature on natural allergens and GM crop plant endogenous allergens shows that many questions remain unanswered. It seems that some regulatory authorities are overreacting by asking for more and more information to confirm possible unintended differences between the endogenous allergens of the GMO and its non-GMO near-isoline. Adequacy of the assessment of allergenicity is debated. A school of allergen specialists[81] commenting on the validation of the tests, and particularly availability of serum for testing, contended that the 'extreme precautionary position is not scientifically defensible'[81]. They opined that 'we need to know more about endogenous allergen levels and natural variation and have not seen data that demonstrate an enhanced risk to the consumer, based on the observed variation'. Upregulation of allergen levels is contested by Herman and Ladics[91]. There is no evidence tabled on consumers showing adverse reactions owing to allergens from eating approved GMO products. Therefore, the postulated risk remains a hypothetical one.

Regulatory authorities have to make decisions, while scientists continue to debate at technical level. Before requesting additional studies, policies on risk to consumers should be placed in the broader context of the country's needs. The example shows the need for proactively considering the approach to be followed. These should be included in a risk assessment policy interface that does not exist in many risk governance situations. Consequences for additional precautionary requirements that are not well thought through are far reaching. Knowledge gathered over many years and now assessed, brings new perspectives on the effect of different plant-breeding practices, including genetic modification. The need for assessment of endogenous allergens is under debate. The case study with endogenous allergens illustrates the difficulty decision-makers may experience in implementing Codex guidelines. These guidelines are not compulsory regulatory instruments, but are significant in international trade. New knowledge of the genome and the place of genetic modification compared to traditional plant-breeding technologies, with respect to unintended effects, could influence the outcome of potential international trade disputes.

Conclusions and recommendations

The debate on the PP illustrates the diverse opinions on safety requirements for GM crop plants. Some consider GM crops irreversibly harmful, while others view them as representing only a continuum of existing knowledge and agricultural practices. The key problem with the PP is that it is a normative principle – ill-defined and vague. The rational way forward seems to be that a number of experts, including stakeholders, should be included in a structured way to contribute to policy development and to frame the risk assessment.

Recommendations for South Africa

- A new dispensation in South African risk governance of GMOs should be considered that requires benefits of modern biotechnology (including genetic modification) to be given adequate consideration and applied to the advantage of the population.
- The new Bio-Economy Strategy for South Africa[27], published in 2013, addresses, inter alia, food security and economic growth as some of the key imperatives. The strategy specifically mentions: identifying 'areas of public policy that can remove barriers' and 'improve cooperation between stakeholders'[27(p.7)]. These matters should be investigated with a view to establishing an interface between risk management (decision-making) by the GMO council member departments, the scientific GMO advisory committee and stakeholders. Stakeholders should include the relevant scientific communities, such as specialist agricultural scientists, as the most trusted parties for credibility of information. Socio-economic matters should be proactively considered during this phase of the iterative interactions of risk analysis.
- Development of policy and guidelines on issues of risk assessment is a matter of importance. These include, inter alia, the principle of precaution; consideration of dealing with possible unintended effects from genetic modification; and a policy on new plant-breeding techniques.

Relevance to other countries

A number of countries are in the process of finding a way forward in terms of the regulation of GM crops, and, in so doing, are determining their own approaches to decision-making and the application of the PP. The issues raised in this paper may be useful in their deliberations on the way forward.

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Authors' contributions

F.W.J.v.R authored the manuscript; E.J.M. and J.N.E co-supervised the study.

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Satellite laser ranging measurements in South Africa: Contributions to earth system sciences

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This contribution reassesses progress in the development of satellite laser ranging (SLR) technology and its scientific and societal applications in South Africa. We first highlight the current global SLR tracking stations within the framework of the International Laser Ranging Service (ILRS) and the artificial satellites currently being tracked by these stations. In particular, the present work focuses on analysing SLR measurements at Hartebeesthoek Radio Astronomy Observatory (HartRAO), South Africa, based on the MOBLAS-6 SLR configuration. Generally, there is a weak geometry of ILRS stations in the southern hemisphere and the SLR tracking station at HartRAO is the only active ILRS station operating on the African continent. The SLR-derived products – such as station positions and velocities, satellite orbits, components of earth's gravity field and their temporal variations, earth orientation parameters – are collected, merged, achieved and distributed by the ILRS under the Crustal Dynamic Data Information System. These products are used in various research fields such as detection and monitoring of tectonic plate motion, crustal deformation, earth rotation, polar motion, and the establishment and monitoring of International Terrestrial Reference Frames, as well as modelling of the spatio-temporal variations of the earth's gravity field. The MOBLAS-6 tracking station is collocated with other geodetic techniques such as very long baseline interferometry and Global Navigation Satellite Systems, thus making this observatory a fiducial geodetic location. Some applications of the SLR data products are described within the context of earth system science.

Introduction

The study of the gravity field, size, shape and rotation of the earth constitute the three main scientific pillars of space geodesy. Recently, Combrinck[1] proposed the inclusion of the geometry of space-time as a fourth pillar, as the other pillars are dependent on highly accurate knowledge of spacetime geometry. Geodesy can be defined as the science that determines the size and shape of the earth, the precise positions and elevations of reference points, lengths and directions of lines on the earth's surface, and variations of terrestrial gravity.[2] The three conventional pillars of space geodesy are realised through the use of space geodetic techniques such as Global Navigation of Satellite Systems (GNSS), very long baseline interferometry (VLBI), Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), lunar laser ranging (LLR) and satellite laser ranging (SLR) and support from terrestrial measurements.[3] In order to achieve high accuracy, all space geodetic techniques incorporate general theory of relativity corrections as a fourth geodetic pillar.[1] These corrections are performed in both the observational as well as in data reduction components.

While each of these techniques has different observational strategies (and inherent strengths and weaknesses), most of the products derived from these techniques have common scientific applications in atmospheric research, gravity field modelling, and determination of site coordinates and velocities, geocentre motion and earth rotation parameters. For example, SLR utilises signal propagation between earth observing stations and satellites to derive station positions, earth orientation parameters (EOPs) and terrestrial reference frames (TRFs), among others. In VLBI technique, the radio propagation between distance celestial objects (quasars) and telescopes on earth or in space is used to derive station positions, EOPs and celestial reference frames. Furthermore, VLBI operates at radio frequencies while LLR and SLR operate at optical frequencies. Most of the geodetic sites are co-located with multiple geodetic instruments, allowing them to contribute towards derivation of combined geodetic products. These combined products are unique in terms of accuracy because of the utilisation of individual technique strengths as well as mitigated technique weaknesses.

A summary of geodetic techniques and their applications is presented in Table 1. In this contribution, we particularly review milestones of the SLR technique, including its inception in South Africa as well as its role for the African geodetic research community. The reader is referred to various published literature for detailed information on other geodetic techniques, e.g. GNSS[4], VLBI[5], DORIS[6-8] and LLR[9].

Basic principle of satellite laser ranging

The SLR technique measures the two-way travel time of a short laser pulse which is reflected by an orbiting satellite. This method of measurement is possible for orbiting satellites equipped with corner cube retro-reflector mirrors made from glass prisms. A schematic diagram illustrating the operation of a typical SLR system is presented in Figure 1.

In a typical SLR system, a transmitting telescope emits short laser pulses with energy of between 10 mJ and 100 mJ at a pulse repetition frequency ranging between 5 Hz and 20 Hz. Some modern systems have lower power levels and higher firing rates of up to 2 kHz. The emitted laser pulse has a typical duration of 200 ps or less, most often specified by the full width at half maximum of the pulse. Laser pulses propagate through the atmosphere to the orbiting satellite, and those which illuminate any of the retro-reflectors are reflected back through the atmosphere to the ground station where they are collected via the receiving telescope. The receiving telescope collects and focuses the reflected pulse energy onto a transmission photocathode (a radiation sensor located inside the vacuum envelope of a photomultiplier tube). Some systems use a single-photon avalanche diode; the LLR system being

developed at Hartebeesthoek Radio Astronomy Observatory (HartRAO) in South Africa will utilise such a diode.

In the case of a photomultiplier tube, photons entering the glass vacuum tube are directed to the photocathode where electrons are generated as the photons impinge on the photocathode. The electron yield from the photocathode is dependent on the material of the cathode and this electron yield is quantified by the quantum efficiency, ε (the ratio of emitted electrons to the number of incident photons). Typical SLR systems have efficiencies in the order of 10–15%.[11] The emitted photoelectrons are directed by an appropriate electric field to an adjacent electrode or dynode within the envelope. As a result of the acceleration between the dynodes, the number of emitted electrons multiplies in a cascading process. For each primary photoelectron interacting with a dynode, secondary electrons are emitted. These secondary electrons in turn are directed to a second dynode and this process repeats between the first and second dynode until a final gain of the order 10^6 is achieved. The electrons from the last dynode are collected by an anode which provides the round-trip time-of-flight (TOF) of the pulse. The measured TOF can then be used to compute the distance (d) travelled by the pulse when the speed of light of propagation in free space is known. This range is approximately given by Equation 1:

$$d = \frac{TOF \times c}{2}. \qquad \text{Equation 1}$$

In Equation 1, the speed of light, c, is the signal propagation speed and a factor of two is included to reduce the round trip distance to the one-way range. Various factors contribute to the accuracy with which the TOF is measured by the SLR tracking systems. These factors include:

- calibration (performed before and after each satellite pass) and drifts or stability of the laser ranging system during target calibration
- the noise of the instrument or uncertainty in computing the exact position of the pulse
- maintenance of time system synchronisation
- atmospheric conditions

For a more in-depth discussion the reader can refer to Combrinck[12]. Apart from the accuracy capability of a typical SLR system, the success of the laser ranging process (receiving photons back from the orbiting satellite) is also governed by its maximum range. Most SLR systems accomplish such high accuracy by operating at higher signal levels (e.g. a received signal level of five photoelectrons per shot). In such cases, the success of receiving any returns is governed by the standard radar link equation (see Equation 2). The radar link equation gives the average number of detected photoelectrons, N_{pe}, for each transmitted laser pulse and is described as per Equation 2 found in Degnan[13]:

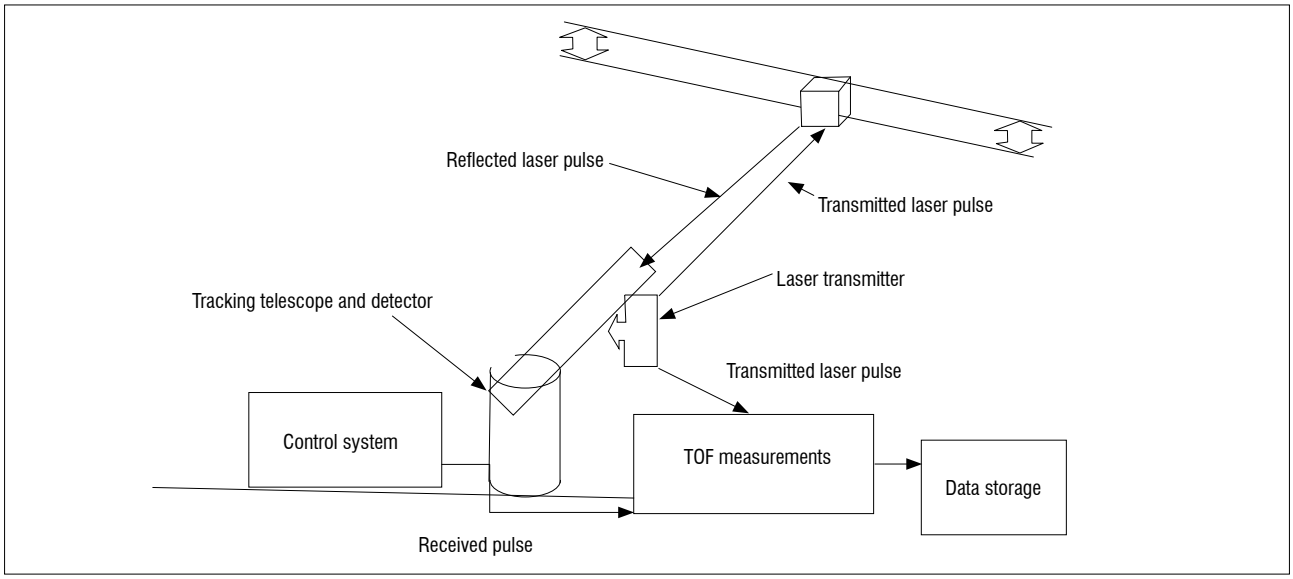
$$N_{pe} = \eta_q \left(E_T \frac{\lambda}{hc} \right) \eta_T G_T \sigma_{sat} \left(\frac{1}{4\pi R^2} \right)^2 A_T \eta_r T_a^2 T_c^2 . \qquad \text{Equation 2}$$

Here, η_q is the detector quantum efficiency, E_T is the energy of the laser pulse, λ is the wavelength of the laser, h is Planck's constant, c is the speed of light in a vacuum, η_T and η_r are the transmit and receive

Table 1: Summary of geodetic techniques and their applications as reported in Rothacher[10]

Parameter type	Derived products	Technique			
		VLBI	GPS	SLR/ LLR	DORIS
Celestial reference frame	Quasars	x			
	Orbits		x	x	x
Earth orientation parameters	Nutation rates	x	x	x	x
	UT1-UTC	x			
	LOD	x	x	x	x
	Polar motion	x	x	x	x
Terrestrial reference frame	Station positions	x	x	x	x
Gravity field	Geocentre		x	x	x
	Low degree		x	x	x
Atmosphere	Troposphere	x	x		x
	Ionosphere	x	x		x

VLBI, very long baseline interferometry; GPS, Global Positioning System; SLR/LLR, satellite laser ranging/lunar laser ranging; DORIS, Doppler Orbitography and Radio-positioning Integrated by Satellite; UTC, coordinated universal time; LOD, length of day.



TOF, time of flight.

Figure 1: Illustration of the satellite laser ranging concept. The timing component is critical and needs to be accurate to a picosecond level.

part efficiency, respectively, and G_T is the gain of the transmitter. The satellite at slant range R has optical cross-section given by σ_{Sat}. A typical spherical geodetic satellite has σ_{Sat} in the order of 10^7 m^2 and for the small arrays on modern altimetry satellites, σ_{Sat} is an order of magnitude less.[13] Furthermore, in Equation 2, A_r is the area of the receiver aperture, and T_a and Tc are the one-way atmospheric transmission and one-way transmissivity, respectively, of cirrus clouds (when present). The slant range can be calculated using Equation 3:

$$R = -(R_E + h_\ell)\cos\Theta_{zen} + \sqrt{(R_E + h_\ell)^2\cos^2\Theta_{zen} + 2R_E(h_s - h_\ell) h_s^2 - h_\ell^2} \quad \text{Equation 3}$$

where R_E is the radius of the earth, h_ℓ and h_s are the heights of the station and satellite above sea level, respectively, and Θ_{zen} is the zenith angle of the satellite as observed from the SLR station and is the complement of the elevation angle. A general expression of transmitter gain for a Gaussian beam is given as per Equation 4:

$$G_t = \frac{4\pi A_t}{\lambda^2} g_t(\alpha_t, ß, y_t, X), \quad \text{Equation 4}$$

where $A_t = \pi^2 a_t^2$ is the transmitting aperture and $g_t(\alpha_t, ß, y_t, X)$ is a geometric factor dependent on whether the collimating telescope is perfectly focused and whether the target is in the far field of the transmitter. Equation 4 accounts for the radial truncation of the Gaussian beam and central obscuration in a Cassegrain telescope. The effective receiver area is computed as per Equation 5, in which the radiation lost to the blockage by a secondary mirror and spillover at the spatial filter and/or detector is taken into account.[13]

$$A_r = A_p(1 - y_r^2)\,\eta_D\left(y_r \frac{kR_D}{2F_s}\right). \quad \text{Equation 5}$$

Here A_r is the effective area of the telescope receiver aperture, $A_p = \pi a_r^2$ is the area of the receiver primary, $y_r = b/a_r$ is the receiver obscuration ratio, $(1 - y^2)$ is the fraction lost as a result of blockage by the receiver secondary, F_s is the F-number of the receiving telescope and $k = 2\pi/\lambda$ where λ is the wavelength and lastly, η_D is the fraction of the incoming light intercepted by a detector of radius R_D.

Various ILRS tracking stations operate with an observation rate of approximately one measurement per second.[14] In such a case, a pass over an SLR station may contain more than 2000 data points, depending on the quality of the station and the atmospheric conditions. These data points are often cleaned up and compressed into normal points (NP), resulting in about 10–15 NP over a pass. During data compression, data points are first converted into a NP range (NPR, in metres) by using Equation 6:

$$NPR_i = \frac{\frac{NP_{tof_i}}{1 \times 10^{12}} \times 2}{2(m)}, \quad \text{Equation 6}$$

where NP_i (m) is the normal point range, NP_{tof_i} is the normal point TOF in picoseconds at a given epoch and c is the speed of light in a vacuum (299792458.0 m/s). The normal point range as determined by Equation 6 requires certain corrections corresponding to atmospheric effects, centre of mass of the satellite and biases which are related to the tracking and relativistic effects. Taking such corrections into account, Equation 6 can be re-written as:

$$NPR_i = \frac{\left(\frac{NP_{tof_i}}{1 \times 10^{12}} \times c\right)}{2} - \Delta a_i + \Delta CoM_i - \Delta R_{bi} - \Delta GR_i - \Delta \varepsilon_i. \quad \text{Equation 7}$$

In Equation 7, Δa_i denotes the error by the atmospheric delay, ΔCoM_i the correction to the position and centre of mass of the orbiting satellite, ΔR_{bi} the system delay error, ΔGR_i the error from relativistic theory and $\Delta \varepsilon_i$ is for un-modelled observational errors. Currently, the precision of the NP data (as averaged from a number of observations per satellite pass) is between 10 mm and 15 mm.[15]

Historical development of satellite laser ranging

The photographic tracking method pioneered in the late 1950s was arguably one of the first techniques used to measure angular positions of artificial satellites. This method was carried out using the Baker–Nunn satellite cameras developed by the Smithsonian Astrophysical Observatory (SAO). Using photographic satellite tracking, the Baker–Nunn camera (a Schmidt telescope with refinements designed to improve its optical performance) photographed satellites against a reference star field. Light entered the camera via a three element lens assembly (this was corrected for spherical and chromatic deviations) and was reflected from a spherical pyrex mirror onto the photographic film. Exact directions of the artificial satellite were commonly found by measuring the satellite's distance from the reference stars on the photographic film. This method of satellite tracking involved a global network of 12 Baker–Nunn cameras. One of the results from photographic satellite observations was the development by SAO of the first gravitational field model, Standard Earth (SE) – a set of spherical harmonic coefficients that described the gravity field of the earth and consistent station coordinates.[16] The accuracy of the measurements obtained via photographic satellite tracking was limited to about 2 arc seconds. In addition to photographic observations using the Baker–Nunn cameras, smaller cameras were also used to track satellites such as ECHO or PAGEOS.[16] These cameras included the Wild BC4 camera of the Coast and Geodetic Survey in the USA and the IGN (Institut Géographique National) camera in France. Furthermore, Schmidt telescopes were also used for observing satellites such as ANNA-IB, GEOS-A and B launched by the USA.[17]

By the early 1960s, progress in laser technology had advanced and slowly replaced the photographic observations. The SLR technique was developed to measure the range to an orbiting satellite equipped with corner cube reflectors. The first laser ranging experiment was reported in 1964 and involved the tracking of the Beacon Explorer-B (also known as Explorer-22) satellite using a telescope mounted with a dye-cell Q-switch ruby laser.[17] During this campaign, the Goddard Space Flight Center (GSFC) team in the USA was the first to record laser returns in December 1964, followed by the French team from CNRS (Centre National de la Recherche Scientifique) at the Haute Provence Observatory in January 1965. Using a telescope mounted with a dye-cell Q-switch ruby laser, the reported precision based on the root mean square (rms) of the measurements was about 1.0–1.5 m. Because of the success of the first experiment, laser corner cube reflectors were also placed on other satellites, e.g. BEC, GEOS A, GEOS B and GEOS C.

As laser technology continued to progress, laser ranging became the most accurate technique for determining precise satellite orbits for geodetic applications.[18] During the 1970s, the Baker–Nunn cameras were completely replaced and SLR tracking stations were established and participated in a laser network to track eight satellites. These tracking stations provided new and improved data sets that were used to generate new gravity field models, e.g. SE and SE III developed at SAO, GEM (Goddard Earth Model) series at GFSC and GRIM (GRgs/IMunich) series at Toulouse and Munich. By the mid-1970s, two dedicated satellites were launched to fully optimise the use of laser tracking. These satellites were: (1) STARLETTE, launched in 1975 in a low altitude orbit (to achieve high sensitivity of gravity field and its temporal variations) and (2) LAGEOS 1, launched in 1976 in a very high altitude orbit (to be as insensitive as possible to the gravity field and to the atmospheric drag effects). Later, other dedicated satellites similar to STARLETTE and LAGEOS were launched: STELLA, LAGEOS 2, AJISAI, ETALON and GFZ-1. Each of these satellites have different but comparable characteristics: for instance, they are all compact and dense, and are used in gravity field solutions, in determining polar motion and the earth's rotation, and are sensitive to the tidal potential, which can be used to determine the tidal potential parameters.

The SLR technique has continued to improve in terms of range precision. For example, orbital laser residuals computed over 10-day periods from

normal points acquired on LAGEOS 1 varied from 500 mm (rms) in 1976, 100 mm in 1980, 50 mm between 1985 and 1986, and 30 mm in 2000 to 10–20 mm currently. Such improvements are attributed to the following improved laser technology:

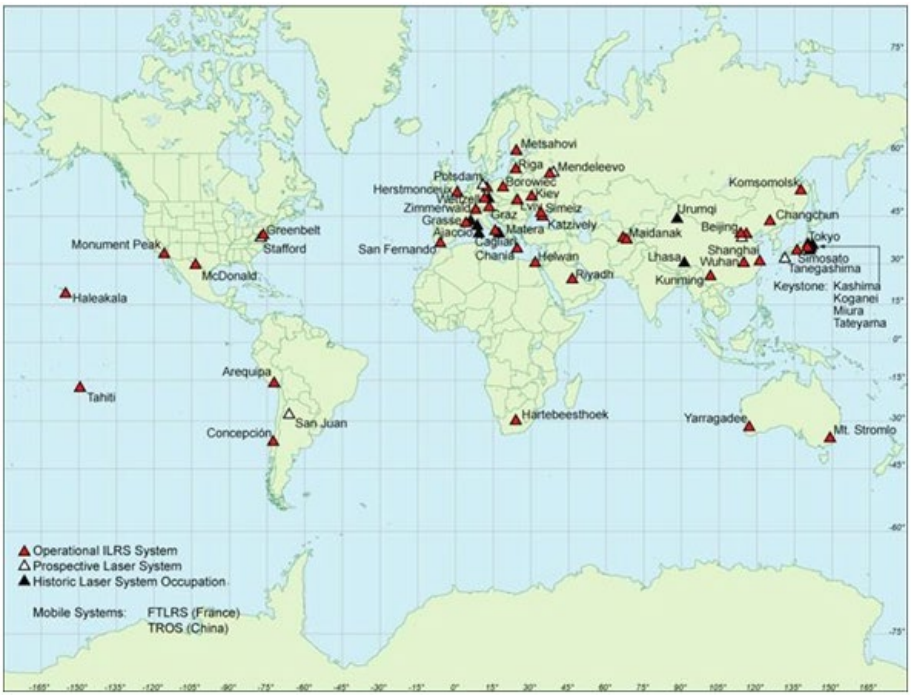
- the replacement of a ruby laser with a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser,
- lower energy laser beams (10–250 mJ),
- pulse widths of 30–200 ps,
- higher emission frequency rates (5 Hz – 2 kHz),
- faster and more sensitive detectors,
- improved timers (<10 ps) and
- improved clocks (<100 ns).

Today, the number of SLR tracking stations has increased globally, as depicted in Figure 2. These stations are coordinated by the ILRS, which was established in September 1998 as a service within the International Geodetic Association. The objectives of the ILRS are to support programmes in geodetic, geophysical and lunar research activities and to provide data products to the International Earth Rotation and Reference Systems Service (IERS) in support of its prime objectives.[19]

The current ILRS tracking stations involved in artificial satellite tracking consist of over 30 stations. As depicted in Figure 2, most of the SLR tracking stations are located in the northern hemisphere, leaving the southern hemisphere with weak coverage. Over the past years, the majority of these stations has undergone several upgrades to enhance SLR operations. These stations include the TLR-3 system at Arequipa, the Mt. Haleakala station, McDonald, MOBLAS-7 (GSFC), MOBLAS-4 (Monument Peak), Mt. Stromlo and MOBLAS-6. In Africa there are two stations – Helwan in Egypt (inactive) and MOBLAS-6 located at HartRAO in South Africa. Similarly to ILRS tracking stations, the number of artificial satellite missions has also increased from a mere 8 in the 1970s to more than 50. These satellites include passive geodetic (geodynamics), earth sensing, navigation and engineering missions and they all are tracked by the ILRS systems. Table 2 summarises the historical development of some of the satellite missions. Satellites listed in Table 2 include both past and currently tracked satellite missions.

South African satellite laser ranging observations: MOBLAS-6

The MOBLAS-6 SLR system is located in a natural bowl of hills at Hartebeesthoek just south of the Magaliesberg mountain range in the Gauteng Province of South Africa, about 50 km west of Johannesburg. The area is an ideal remote site with limited frequency communications and clear weather conditions and hence meets the primary requirements for artificial satellite tracking. The MOBLAS-6 station is operated by HartRAO; a national research facility of the National Research Foundation in South Africa and the only major radio astronomy observatory in Africa. Its operation is an ongoing collaboration between the National Aeronautics and Space Administration (NASA) and HartRAO. Initiatives for this collaboration began in 1992 with discussions between the South African government and NASA. A final agreement was reached in February 1999, which was followed by the signing of a memorandum of understanding between NASA and the National Research Foundation. MOBLAS-6 arrived at HartRAO in June 2000 and its installation and collocation tests took place between June and August 2000, followed by training of on-site staff. Two staff members went to NASA Goddard Space Flight Center for advanced training. The HartRAO SLR station was formally inaugurated and commenced with operations on 20 November 2000. It uses a 0.75-m Cassegrain telescope built in a 12-m mobile trailer. The trailer also contains a 100-mJ, 532-nm, 200-ps pulse length laser and peripheral equipment. Some of the MOBLAS-6 technical specifications are summarised in Table 3.



Source: International Laser Ranging Service[35].

Figure 2: Global distribution of the International Laser Ranging Service (ILRS) tracking stations.

The MOBLAS-6 SLR station has been operational at HartRAO for over a decade now and is the major contributor of SLR data from Africa and an important node of the ILRS network in the southern hemisphere. Table 4 provides a summary of the station's performance in terms of averaged NP data volume since its inception in 2000. Based on the information given in Table 4, MOBLAS-6 meets the performance standards as set by the ILRS. These standards include yearly data quantity (1000 for LEO, 400 for LAGEOS and 100 for HEO), data quality (10 mm LAGEOS NP precision, Figure 3) and operational compliance (e.g. data delivery within 12 h).

At HartRAO, the MOBLAS-6 SLR station has been collocated with other space geodetic techniques – the Global Positioning System (GPS), VLBI, DORIS and the soon to be developed LLR (the first LLR system to be operated in the southern hemisphere) – forming a multi-technique fundamental station as depicted in Figure 4. Differential coordinates (local ties) between the measuring reference points of the collocated instruments play an essential role in the computation and combination of the International Terrestrial Reference Frames (ITRFs). The quality and accuracy of the ITRFs depend on the availability and quality of the local ties computed in co-location sites as well as on the number and distribution of these sites over the globe. As the distribution of most of the space geodetic techniques is sparse in the southern hemisphere, particularly in Africa, the HartRAO collocated site and the derived local ties therefore play an important role in providing combined products (such as site co-ordinates and velocities, earth rotation parameters, atmospheric correction and geocentre motion), which are central for computing quality and reliable ITRFs, gravity field modelling as well as for defining geodetic data for South Africa. The HartRAO site forms part of the Global Geodetic Observing System (GGOS). The GGOS system was conceived by the geodetic community to provide the observational basis for maintaining a stable, accurate global reference system. The global reference system has practical applications related to monitoring the earth system and for global change research, in addition to providing observations in support of the three fundamental pillars of geodesy

Table 2: Historical development of satellite missions and their applications

Satellite	Launch date	Height (km)	Application
GOCE	2009	295	Earth sensing
ICESat	2003	600	Earth sensing
Larets	2003	691	Geodynamics
GRACE	2002	481	Earth sensing
Envisat	2002	800	Earth sensing
Jason-1	2001	1336	Earth sensing
CHAMP	2000	454	Geosciences
GFO-1	1998	800	Geodynamics
ERS-2	1995	785	Earth sensing
GFZ-1	1995	385	Earth sensing
Stella	1993	810	Geodynamics
LAGEOS 2	1992	5900	Geodynamics
TOPEX/Poseidon	1992	1350	Earth sensing
ERS-1	1991	780	Earth sensing
Etalon 1 & 2	1989	19100	Geodynamics
Ajisai	1986	1500	Earth sensing
SEASAT	1978	805	Earth sensing
LAGEOS 1	1976	5900	Geodynamics
GEOS-3	1975		Earth sensing
Starlette	1975	960	Geodynamics
GEOS-2	1968		Earth sensing
GEOS-1	1965		Earth sensing
BE-C	1965	1000	Earth sensing

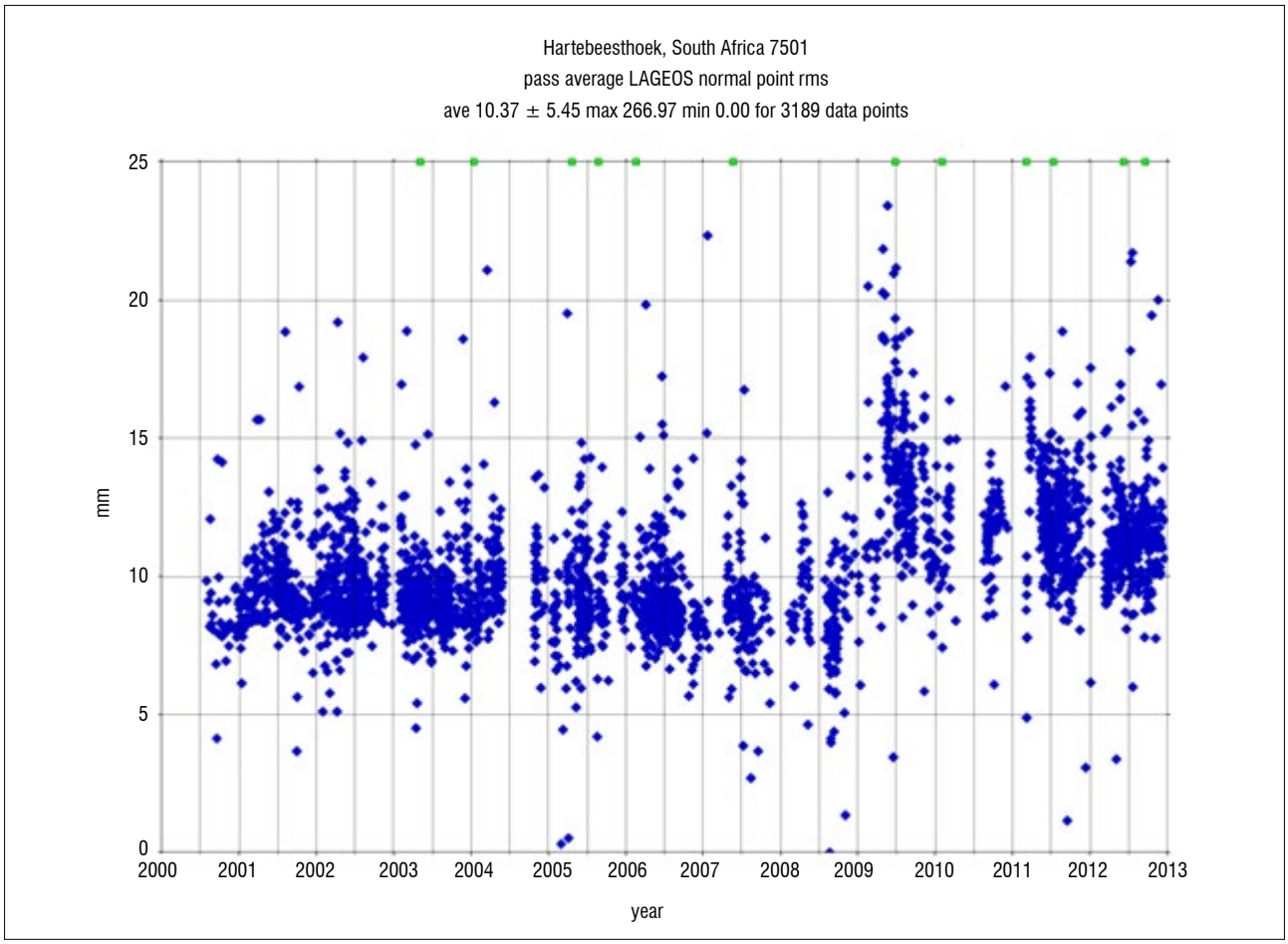
Table 3: Some technical specifications of the MOBLAS-6 SLR station

Receiving telescope type	Cassegrain
Mount	Azimuth-elevation
Transmitting telescope type	Refractor
Transmit aperture	0.163 m
Receive aperture	0.75 m
Transmit efficiency	0.94
Laser type	ND:YAG
Primary wavelength	1064 nm
Primary maximum energy	220 mJ
Secondary wavelength	532 nm
Secondary maximum energy	100 mJ
Full power tracking	120 mJ
Pulse width (FWHM)	200 ps
Laser repetition rate	1–10 Hz

FWHM, full width half maximum.

Table 4: MOBLAS-6 performance parameters based on data volume. Low Earth Orbiter (LEO) data surpasses the higher satellites, as they are much easier to range to due to their lower orbital heights.

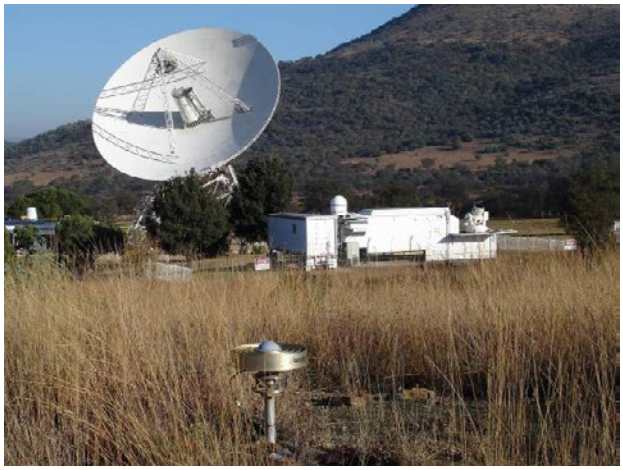
Year	NP for LEO	NP for LAGEOS	NP for HEO	Total NP
2012	40727	7925	3089	44187
2011	40490	8044	3509	52043
2010	15391	2057	609	18057
2009	25597	4259	601	19057
2008	13857	1827	89	15773
2007	19676	2708	214	22598
2006	39226	7632	1953	48811
2005	29889	3583	1158	34630
2004	25009	4404	1081	30494
2003	45615	10344	2622	58611
2002	37795	9015	2877	49687
2001	21756	7265	2783	31804
2000	3026	773	163	3962



Source: International Laser Ranging Service[36].

Figure 3: HartRAO's MOBLAS-6 station performance in terms of LAGEOS normal point root mean square.

and their variations. Furthermore, the SLR tracking station at HartRAO, together with other collocated geodetic systems, supports the ongoing development of the African Geodetic Reference Frame Project (AFREF)[20] and the African geoid.



Source: Hartebeesthoek Radio Astronomy Observatory[37].

Figure 4: Geodetic techniques collocated at HartRAO: on the far left is the 26-m telescope for very long baseline interferometry and other astronomical observations; in the middle is the NASA MOBLAS-6 satellite laser ranging station; and in the foreground is the GPS antenna.

The data collected from the MOBLAS-6 station and the other geodetic systems are sent to NASA's data centre, the Crustal Dynamic Information System, and are freely available to the space geodesy and geodynamics community for research purposes. Numerous products are derived from the SLR data and these include the earth's gravity field, ocean tide models, EOPs, precession and nutation parameters which are necessary for satellite positioning applications, mapping, geographical information systems, monitoring of global change and the global hydrological cycle, the dynamics of the atmosphere, oceans and natural hazards and disasters. At HartRAO, various research studies are being undertaken which use LAGEOS data collected from MOBLAS-6. The research studies include testing the general relativity theory (see for example Combrinck[1,21]) and assessment of global gravity field models, research work published by Botai and Combrinck[22].

As part of strengthening its operations, the MOBLAS-6 station underwent major repairs and upgrades between 8 October and 7 November 2008. The repairs and upgrades performed to the system included the replacement of the old Q-switched dye with a CR4 saturable absorber (a special doped crystal manufactured for ND:YAG 1032 nm Q-switched mode locking) and a new laser table. Since the time of the upgrade, MOBLAS-6 is believed to perform much better in terms of laser beam quality and stability and has since required less maintenance.

Today the MOBLAS-6 station continues to be involved with both the ILRS activities and the other services of the International Geodetic Association. In particular, the station continues to track all priority satellites as assigned by the ILRS. Some of the artificial satellites (and their properties) tracked by the MOBLAS-6 station and other ILRS stations are depicted in Table 5. Recently, MOBLAS-6 has increased its laser ranging

Table 5: Priorities of satellites tracked by MOBLAS-6 system

Satellite	Satellite identification code satellite	Altitude (km)	Application
GOCE	499	295	Gravity field determination and calibration of GPS orbits
GRACE-A & B	8003 & 8004	485	Gravity field determination and validation of GPS; precise orbit determination
CRYOSAT-2	8006	720	Measure ice thickness and orbit determination
TANDEM-X	6202	514	Orbit determination
TERRASAR-X	6201	514	Orbit determination
BLITS	5559	832	Orbit determination
HY-2A	5558	971	Oceanography related research
Jason 1 & 2	4378 & 1025	1336	Calibrate satellite altimeter
LARETS	5557	691	Orbit determination
Starlette	1134	812	Orbit determination
Stella	643		Orbit determination
LARES	5987	1450	Test general relativity
LAGEOS 1 & 2	5986 & 1155	5860 & 5620	Test general relativity, orbit determination
QZS-1	1581	~40000	Positioning and calibration of GPS orbits
AJISAI	1500	1490	Orbit determination
BEACON-C	317	927	Ionospheric and geodetic research
ETALON 1 & 2	0525 & 4146	19120	Geodetic research
COMPASS M3 & I3	2004 & 2003	21528 & 42161	Positioning and orbit determination
GLONASS-115	9115	19000	Positioning
GPS-36	36363	20030	Positioning and orbit determination
GALILEO-101	7101	23220	Positioning

activities to include tracking of the NASA Lunar Reconnaissance Orbiter (LRO) spacecraft in polar orbit around the moon. The laser tracking of LRO involves recording of one-way range measurements made by the use of laser pulse TOF from the ground station to the LRO spacecraft whenever the spacecraft is in view of the ground station. The LRO's high altitude (~400 000 km) allows the distance from MOBLAS-6 station to the LRO to be measured with an accuracy of about 200 mm.

Geodetic applications of satellite laser ranging observations

The global terrestrial reference frame

A terrestrial reference system is mainly concerned with connecting and comparing measurements over space, time and evolving technologies. This capability is realised through a reference frame – a set of geocentric coordinates and velocities for a network of stations.[19] Such coordinates are derived from SLR and other geodetic observation techniques (VLBI, LLR, GPS, DORIS), and are then combined to form products such as the International Terrestrial Reference Frame (currently ITRF2008). In this way, each space geodetic technique provides unique data sets used in the realisation of the ITRF.[19] The ITRF forms the fundamental reference system for accurately solving geodetic and geodynamical problems. In particular, the ITRF represents the most precise global terrestrial reference system and is the source for the realisation of other world reference systems, such as WGS84, and of continental and regional reference systems.[19] The regional reference systems have various applications such as mapping, agriculture and environmental planning, engineering (road, rail and civil), surveying, tracking- and location-based services, and navigation. The ITRF is monitored, maintained and constantly updated by the IERS. Within this system, each TRF is either directly or after transformation expressed as a realisation of the ITRS.

Earth's gravity field models

Satellite laser ranging tracking data have been used to determine the earth's gravity field both at global and regional scales.[23] Because the orbital motion of artificial satellites is influenced by gravitational forces, precise satellite tracking measurements provide orbit solutions which can be inverted to derive the gravity field. For instance, the long wavelength gravity information can be derived through SLR range measurements by high-altitude satellites such as LAGEOS.[24,25] In contrast, the short wavelength components of the gravity field often decay rapidly with distance above the earth's surface.[26,27] Hence their accurate detection requires low-altitude satellites (e.g. CHAMP, GRACE and GOCE). These satellites have on-board GPS receivers and dual frequency K-band microwave ranging systems (e.g. GRACE) allowing for accurate kinematic positioning, spatial-temporal coverage and continuous monitoring of the changing gravity field of the earth.[28] Temporal variations of the earth's gravity field are caused by geological and geophysical processes associated with mass redistribution at the earth's surface and mass distribution in its interior. The seasonal variations in the earth's gravity field result from surface mass changes in the atmosphere, oceans, hydrosphere and lithosphere. Processes associated with isostatic glacial recovery and sea-level changes are manifested in long-term quasi-secular variations. In particular, data collected from CHAMP and GRACE missions have been used to compute various gravity field models including EIGEN-2[29], GGM02[30], EIGEN-GL04C[31] and EGM2008[32]. The operational compliance of most ILRS tracking stations and availability of high-quality data greatly contribute to the ongoing computation of gravity field models. With the availability of new and high-quality data, developments in gravity field modelling include both the derivation of new models and upgrading and updating of some of the old models to a higher degree and order (e.g. EGM96 has been upgraded to EGM2008 with degree and order up to 2160). The derived models allow for continuous monitoring of changes in the geoid (the equipotential surface of the earth's gravity field that corresponds

closely with mean sea level in the open oceans, ignoring oceanographic effects) and the geoidal height (the separation between the geoid and the ellipsoid) on both global and regional scales as well as on basin scales.[33]

Precise orbit determination and verification

Satellite tracking operations involve identifying the operational status of equipment on board a satellite in orbit and appropriately controlling and maintaining the satellite's specified orbit. To achieve this function, it is important to accurately determine the satellite's location and establish a link between a ground tracking station and the satellite. Here, the most important parameter is the precise orbit ephemerides of the satellite which are derived by precise orbit determination (POD) (the precise identification of the movement of a satellite in terms of its position and velocity using technology such as SLR). Results from complementary POD are needed to support the planning and scheduling of operations of other satellite missions.[19] For these purposes, SLR data play an important role in POD for satellites. The accuracy of the computed satellite orbits depends on the quality and number of SLR data sets available. This determination often imposes certain challenges as SLR is weather dependent. For example, in most areas, approximately 50% of the time, weather conditions such as cloud cover and rain do not allow for laser ranging. In such cases, terrestrial and altimetry data are combined with SLR data to improve the precision of the computed satellite orbits. The technique is also applied as a tool for verification of POD results or for independent calibrations of observations from other tracking systems such as GPS.[19]

Geophysical applications

Changing mass distribution within system earth causes variations in the earth's gravity field. Time variations in gravity as quantified from SLR data, particularly from CHAMP and GRACE satellite missions, can be used to compute fluctuations in the earth's mass distribution. In particular, gravity variations computed from CHAMP and GRACE data are transformed into time series of global maps of surface mass anomalies. Mass variations on and near the earth's surface, as derived from CHAMP and GRACE data, often provide information about geophysical processes taking place within the earth's systems and/or subsystems. Such information is vital in our understanding and modelling of geophysical mass transfer within the earth. In addition, because mass variations (caused by the continental water cycle) are believed to be the dominant signal component after the removal of contributions from the solid earth tides, atmosphere and ocean, SLR data, particularly from CHAMP and GRACE missions, also have application in hydrological research.[34]

The role of MOBLAS-6 tracking station on the African continent

The earth system we live in is not constant; earth is a restless planet affected by various dynamic processes occurring on a wide range of spatio-temporal scales. As a result of these unsettling dynamic processes (driven by interior and exterior forces within the earth system as well as by anthropogenic effects), various regions of the earth are exposed to a variety of natural hazards. These hazards include earthquakes, tsunamis, volcanic eruptions, tectonic deformations, deglaciation, sea level rise, floods, desertification, storms, storm surges and global warming, particularly in the solid earth, the atmosphere and the ocean. In addition, resources such as clean water, arable land, minerals, energy, access to food and the capacity of the earth system to maintain a delicate equilibrium under increasing anthropogenic pressure are limited, adding additional stress on the finite resources of our planet. The lack of understanding of earth systems and processes, whether natural or modified by humans (anthropogenic), affects our lives and the lives of future generations. Any application, service or product to be used to tackle the challenges of the restless earth and its dynamic processes, requires a uniform coordinate reference system (geo-spatial reference or geo-reference) and other geographic information. The geo-reference defining position is often given as a set of coordinates (e.g. latitude, longitude and height above mean sea level) referenced to a well-defined origin. Previously, each country used to select its own origin and reference points for its national coordinate system for mapping, surveying and positioning. Such reference points were useful when working within the borders of a single country but tended to create difficulties when undertaking regional development projects that crossed the borders of neighbouring countries.

In order to overcome the cross-border heterogeneous reference frames, most continents around the world have established their own geodetic reference systems (e.g. EUREF for Europe, NAREF for North America, APREF for Asia Pacific) that are used for national surveying, mapping, remote sensing, geographical information systems, development of training programmes that enhance earth system science, and hazard mitigation (such as earthquake studies, fault motion detection, volcano monitoring, and severe storms detection and monitoring). To avoid inconsistent and ambiguous maps and geographical information in large projects (e.g. environmental management, transportation and trading) across the African continent, certain objectives were set out by African heads of government in the New Partnership for Africa's Development (NEPAD). These objectives include the establishment of a unified reference frame across each country and, ultimately, Africa. For this purpose, a network of continuous permanent GPS stations is being established to support a unified geodetic reference frame (AFREF), across more than 50 African countries. AFREF forms the fundamental basis of the national and regional three-dimensional reference networks and is consistent and homogeneous with the standard reference frame, ITRF. Implementation of AFREF (including a unified vertical datum and establishment of a precise African geoid) will allow users anywhere in Africa to have consistent access to GPS data collected from the installed permanent GPS stations. In this regard, the contribution of MOBLAS-6 tracking station to support AFREF is critical because it is one of the most accurate space geodetic techniques. Overall, the accuracy requirements of AFREF ought to meet those of the GGOS of 1 mm TRF origin at an epoch and 0.1 mm/year scale stability. This constraint can be met only by a combination of SLR (used for TRF origin definition) and VLBI (for absolute scale) measurements.

Conclusions

Satellite laser ranging plays an important role in the definition, monitoring and realisation of the TRFs as well as in the computation of long- to medium-wavelength spherical harmonic coefficients of gravity fields. The SLR tracking technique is also vital for precise satellite orbit determination – a key requirement for navigation, geo-location and communication. Weather dependency and poor geometry of ground stations (especially in the southern hemisphere) are some of the drawbacks associated with the SLR space-based technique and often lead to non-uniform SLR data. To widen the applications of SLR geodetic products, the SLR instrument is collocated with other space-based techniques (e.g. GNSS, VLBI and DORIS). Overall, the MOBLAS-6 SLR station at HartRAO plays an important role in the ILRS network as far as data coverage is concerned; in particular, it fills a gap in an area under-represented by SLR equipment and therefore strengthens the geometry of the global network. MOBLAS-6 is the only SLR station on the African continent involved in ILRS activities. In this way, HartRAO provides geodetic measurements that support the development and implementation of a unified geodetic reference frame, AFREF, in the southern hemisphere as well as general support to various earth system science studies. Hence the HartRAO SLR station plays a significant role in terms of network geometry in the southern hemisphere and is an important component of the only geodetic fiducial station in Africa (HartRAO), featuring collocation of SLR (MOBLAS-6), GNSS, VLBI and DORIS instruments.

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Authors' contributions

M.C.B. conceptualised, designed and wrote the manuscript; J.O.B. conceptualised, designed and edited the manuscript; L.C. conceptualised, designed, edited and approved the manuscript.

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An assessment of South Africa's research journals: Impact factors, Eigenfactors and structure of editorial boards

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Scientific journals play an important role in academic information exchange and their assessment is of interest to science authorities, editors and researchers. The assessment of journals is of particular interest to South African authorities as the country's universities are partially funded according to the number of publications they produce in accredited journals, such as the Thomson Reuters indexed journals. Scientific publishing in South Africa has experienced a revolution during the last 10 years. Our objective here is to report the performance of the country's journals during 2009 and 2010 according to a number of metrics (i.e. impact factors, Eigenfactors® and the international character of editorial boards); to identify and compare the impact of the South African journals that have been recently added to the Thomson Reuters' Journal Citation Reports®; and to elaborate on issues related to science policy.

Introduction

Journals are the main vehicle for scholarly communication within the academic community. As such, assessments of journals are of interest to a number of stakeholders from scientists and librarians to research administrators, editors, policy analysts and policymakers and for a variety of reasons.

Researchers would like to know where to publish in order to maximise the exposure of their research, and what to read in order to keep abreast of developments in their fields within the time constraints they face. Librarians would like to keep available the most reputed journals within their budget constraints. Research administrators use journal assessments in their evaluations of academics for recruitment, promotion and funding reasons. Editors are interested to know the relative performance of their journal in comparison with competitor journals. Finally, policymakers have to monitor the quality of journals as they use published articles as indicators of success of the research system, for identification of priorities, for funding and other similar reasons.

In South Africa, the assessment of scholarly and scientific journals is of particular importance and the subject of policy debate. The importance of the issue arises from the fact that higher education institutions receive financial support from the government for their research activities. Financial support is received by these institutions according to the number of publications produced and published in predetermined journals by their staff members.

Two approaches are used for the comparison and assessment of journals – expert opinion[1] and citation analysis[2]. In expert opinion assessments, experts such as well-known researchers and deans of faculties are asked to assess particular journals. Subsequently, the collected opinions are aggregated and a relative statement can be made. The approach suffers from the normal deficiencies of peer review. Will the opinions remain the same if the experts were different? How can an astronomer assess a plant science journal? Are there unbiased researchers in scientifically small countries?[3], and so on.

The second approach is using citation analysis in order to rank journals. Citations are the formal acknowledgement of intellectual debt to previously published research. The impact factor of a journal is a measure of the frequency with which the average article in that journal has been cited in a particular year. Despite the continuous debate related to the validity of Garfield's journal impact factor for the identification of the journals' standing,[4,5] citation analysis has prevailed historically.

It should be mentioned that the availability of journal impact factors from Thomson Reuters means that the journals have been assessed by their own experts and meet their criteria for inclusion in the citation indices. Such criteria include the availability of adequate articles to the journal, publication on time (timeliness) and peer review of the articles submitted to the journal. A journal with a high impact factor means that the journal has not only qualified for inclusion in the indices, but also that researchers often cite its articles.

Scientific publishing in South Africa has experienced a revolution during the last 10 years. In 2000, the South African government terminated its direct financial support to research journals,[6] and only the *South African Journal of Science* and *Water SA* continued to receive financial support. An investigation in 2005[6] showed that the termination of government involvement in the affairs of the journals had on average a beneficial effect on the impact factors of the journals.

During 2006, the Academy of Science of South Africa (ASSAf), at the request of the Department of Science and Technology (DST), produced a new strategic framework for South Africa's research journals. This strategic framework recommends, among others, the periodic peer review of the country's journals and a change in the publishing approach, i.e. a move into an open-access system. Finally, during 2008, Thomson Reuters increased substantially the coverage of South African journals. The number of journals indexed in the Science Citation Index increased from 17 in 2002 to 29 in 2009 – an increase of 70%. The coverage of social sciences journals in the Social Sciences Index showed an even more substantial increase: from 4 in 2002 to 16 in 2009 – a 400% increase.

In this article, we aim to answer two questions related to South African research journals. Firstly, we compare the performance of the journals indexed in Thomson Reuters' Journal Citation Reports® (JCR) during 2002 with their performance during 2009 and 2010. The year 2002 was chosen as it is the time after the government terminated financial support to what used to be called 'national journals'. The years 2009 and 2010 were decided upon by the availability of relevant data. Secondly, we identify whether the newly added South African journals in the JCR are of similar quality as the pre-existing journals. Both findings are of policy interest. The relevance of the investigation is emphasised by the fact that South African researchers do not engage actively and do not publish research investigating the assessment of scientific journals. A search in the citation indices (excluding the authors of this article) identified only three relevant articles emphasising specific disciplinary journals.[7-9]

Ten years of change in scientific publishing in South Africa

During 2000, the South African government, based on a relevant investigation[10] terminated the financial support of the country's scientific journals. Comparing the journals' performance during 1996 (before the termination of funding) and during 2002 it was stated that[6]:

> *The South African journals are identified as performing better without government interference imposed by the constraints attached to financial support offered to them. The impact factors of six out of the eight journals that received financial support were higher in 2002 than in 1996. Evidently the editors and the editorial boards have been able to support their journals better without the interference of the bureaucracy.*

During 2006, ASSAf published the results of its investigation related to research publishing in South Africa.[11] This publication reported on the country's research publishing profile, the availability and practices of local research journals, and the global e-research trends and their implications for South Africa, and advanced a number of recommendations. The recommendations included the adoption of best practice by editors and publishers in the country, the undertaking of an external peer review and quality audit of all research journals in 5-year cycles, and the adoption of an open-access publishing model enhancing the visibility and accessibility of the country's research.

In the above context, ASSAf, with the support of the DST, established a forum of editors of national scholarly journals – the National Scholarly Editors' Forum (NSEF). The NSEF, through annual meetings, has reached the following decisions: (1) A mandate was given to sustain the NSEF as a consultative and advisory body managed by ASSAf; terms of reference for the NSEF were drafted and adopted, (2) a National Code of Best Practice in Editorial Discretion and Peer Review[12] was drafted and adopted and (3) a mandate was given for the envisaged quality assurance regime of ASSAf, based on peer review of discipline-grouped journal titles. NSEF also held plenary consultations on topics such as copyright issues, open access conversion, open-source software, and economies of scale in publishing logistics.

ASSAf, following on its recommendations, initiated an external peer review and associated quality audit of all South African research journals in 5-year cycles. The panels carrying out the reviews comprise six to eight experts, at least half of whom are not directly drawn from the disciplinary areas concerned. The reviews focus on: the quality of editorial and review processes; fitness of purpose; positioning in the global cycle of new and old journals listed and indexed in databases; financial sustainability and scope and size issues.

The approach comprises a detailed questionnaire which is sent to the editors, independent peer review of the journals in terms of content and a panel meeting to review these materials and all other available evidence in order to make appropriate findings and recommendations. The reports with recommendations are considered by the ASSAf Committee on Scholarly Publishing and are released to the publishers and editors of the journals concerned as well as other relevant stakeholders and the public.

In addition, an open-source software-based system called Scientific Electronic Library Online (SciELO) has been adopted in South Africa. A pilot site for the SciELO SA, initially on the SciELO Brazil site, has been established and has been live since 1 June 2009. A number of training visits took place between South Africa and Brazil. During 2010 the SciELO platform was successfully installed on the ASSAf infrastructure.

Currently, 51 journals are available on this open-access platform. It is expected that almost 200 South African journals will eventually be available on the platform.

In 2008, Thomson Reuters added 700 regional journals to the Web of Science. According to a press announcement of Thomson Reuters[13], 'The newly identified collection contains journals that typically target a regional rather than international audience by approaching subjects from a local perspective or focusing on particular topics of regional interest'. The press release emphasised:

> *Although selection criteria for a regional journal are fundamentally the same as for an international journal, the importance of the regional journal is measured in terms of the specificity of its content rather than in its citation impact.*

The criteria used for selection include publication on time, English language bibliographic information (title, abstract, keywords) and cited references must be in the Roman alphabet.

The number of South African journals increased by 19 in this intake. Other countries that experienced a large increase in the number of journals indexed were Brazil, with 132 additional journals, Australia with 52, Germany with 50, Chile with 45, Spain with 44, and Poland and Mexico each with 43 additional journals. From the African continent, Nigeria's and Kenya's collections each increased by one journal.

Methodology

Assessment and comparison of journals according to their impact factors is a well-established approach in scientometrics[14,15], despite the limitations and shortcomings[16]. The impact factor of a journal is defined as the quotient between the number of times an article published in the journal in the previous 2 years is cited in the year of observation and the number of articles this journal has published in these previous 2 years. Today, the journal impact factor, as estimated by Thomson Reuters in the JCR, is one of the most important indicators in evaluative bibliometrics.[17] It is used internationally by the scientific community for journal assessments, research grants, academic subsidy purposes, for hiring and promotion decisions, and others.[18,19]

More recently, the Eigenfactor® approach has been developed and used for journal assessment.[20,21] The Eigenfactor ranking system is also based on citations but it also accounts for differences in prestige among citing journals. Hence, citations from *Nature* or *Cell* are valued highly relative to citations from third-tier journals with narrower readership. Another difference is that whilst the impact factor of a journal has a 1-year census period and uses the previous 2 years for the target window, the Eigenfactor metrics have a 1-year census period and use the previous 5 years for the target window.

An additional indicator that we use to assess journals is the internationalisation of the editorial boards of the country's journals as it is manifested in the number of foreign academics in the journals' editorial boards. The composition of the editorial boards is an indicator of the internationalisation of the journal. It should be clarified that the editorial boards are both indicators of quality and inputs in the process of publishing a journal. For example, researchers are selective on how they spend their time and they would prefer to be associated with 'top' journals. On the other hand, international researchers introduce standards and approaches in the peer review of the articles that may improve the relevant journals.

The performance of South African journals

Table 1 shows the impact factors, the quartiles and the scientific categories of the South African journals covered by the JCR during 2002 for that year and for 2009 and 2010. The ranking to quartiles has been undertaken in order to take into consideration the variation in citations among the various scientific disciplines. Of the 17 South African journals in JCR, 4 journals declined in terms of quartiles from 2002 to 2010. Only one journal – the *African Journal of Marine Science* – improved its performance and moved from the third quartile to the second quartile. The *South African Journal of Geology* moved definitively into the second quartile in the list of the relevant disciplinary journals during 2009, while it was exactly in the middle of the second and third quartiles during 2002. During 2010 this journal moved into the fourth quartile. The journal's impact factor dropped from 1.013 during 2009 to 0.638 during 2010.

Examination of the impact factors indicates that 12 journals increased their impact factors. However, these increases were insufficient to move them into higher quartiles. It seems that, as in the domain of institutions,[22] in the domain of journals it has become more and more difficult to compete internationally. It is interesting also to note that the *South African Journal of Science* – the country's flagship journal – exhibited a substantial drop in its impact factor and its position among the multidisciplinary journals internationally during 2009. However, it recovered during 2010 and it was part of the second quartile journals. It can be argued that this variability is the result of changes in the management structure of the journal. Prior to 2009, the journal had a full-time editor and from 2009 moved into a model with a part-time editor assisted by an editorial board.

Table 1: Impact factors and quartiles of pre-existing South African journals in Thomson Reuters' Journal Citation Reports® Science Citation Index in 2002, 2009 and 2010

Journal	Impact factor 2002	Impact factor 2009	Quartile 2002	Quartile 2009	Quartile 2010	Category
African Entomology	0.455	0.420	3	4	4	Entomology
African Journal of Marine Science	0.754	1.520	3	2	3	Marine & Freshwater Biology
African Zoology	0.516	0.746	3	3	2	Zoology
Bothalia – African Biodiversity and Conservation†	0.358	0.242	2	4	3	Plant Science
Journal of the Southern African Institute of Mining and Metallurgy	0.052	0.216	4	4	4	Metallurgy & Metallurgical Engineering
				3	–	Mining & Mineral Processing
Journal of the South African Veterinary Association	0.366	0.224	3	4	3	Veterinary Science
Onderstepoort Journal of Veterinary Research	0.506	0.430	3	3	3	Veterinary Science
Ostrich	0.149	0.250	4	4	4	Ornithology
South African Journal of Animal Science	0.381	0.412	3	3	3	Agriculture, Dairy & Animal Science
South African Journal of Botany	0.394	1.080	2	3	4	Plant Science
South African Journal of Chemistry	0.265	0.429	4	4	4	Multidisciplinary Chemistry
South African Journal of Geology	0.659	1.013	2/3	2	4	Geology
South African Journal of Science	0.7	0.506	2	3	2	Multidisciplinary Science
South African Journal of Surgery	0.25	0.429	4	4	4	Surgery
South African Journal of Wildlife Research	0.224	0.562	4	4	4	Ecology
SAMJ: South African Medical Journal	1.019	1.325	2	2	2	General & Internal Medicine
Water SA	0.481	0.911	3	3	3	Water Resources

†*Previous title was* Bothalia.

Table 2 shows the impact factors, the quartiles and the scientific categories of the South African journals newly added to JCR. With the exception of *African Invertebrates,* which is positioned in the second quartile of the relevant journals with an impact factor of 1.216, all other journals fall within the fourth quartile of their categories.

In order to compare the quality of the pre-existing journals with that of the journals new to Web of Science, as it is manifested in their impact factors, we undertook a two-sample *t*-test. In this test, two sample means are compared to discover whether they come from the same population (meaning there is no difference between the two population means). The null hypothesis is that the means of the two samples are the same (i.e. they come from the same population). The alternative hypothesis is that the two means are statistically different (i.e. they come from different populations).

Table 3 shows the results of the test of equality of means of the two series: the identified $t=1.785$ and $p=0.0855$. As the p-value is bigger than 0.05 (level of significance), we cannot reject the null hypothesis that the two sets of journals come from the same population.

This finding indicates that even though Thomson Reuters stated that 'the importance of the regional journal is measured in terms of the specificity of its content rather than in its citation impact', at least the newly added South African journals are coming from the same population as the journals which were already in JCR. The newly added journals did not have a significantly different impact factor from the original set in the index. The index continues to cover good-quality journals.

Table 2: Impact factors and quartiles of South African journals newly added to Thomson Reuters' Journal Citation Reports® Science Citation Index

Journals	Impact factor 2009	Quartile 2009	Quartile 2010	Category
African Invertebrates	1.216	2	3	Zoology
African Journal of Herpetology	0.455	4	4	Zoology
AJAR – African Journal of AIDS Research	0.569	4	4	Public, Environmental & Occupational Health
International Sportmed Journal	0.171	4	4	Sport Science
Journal of the South African Institution of Civil Engineering	0.125	4	4	Civil Engineering
Quaestiones Mathematicae	0.267	4	4	Mathematics
South African Journal of Enology and Viticulture	0.314	4	3	Food Science & Technology
Southern African Journal of HIV Medicine	0.457	4	4	Infectious Diseases, Virology
South African Journal of Industrial Engineering	0.093	4	4	Industrial Engineering
SAJOG – South African Journal of Obstetrics	0	–	4	Obstetrics & Gynecology
South African Journal of Psychiatry	0.409	4	4	Psychiatry
Southern Forests	0.5	4	3	Forestry

Table 3: Test for equality of means between pre-existing (Group A) and newly added (Group B) South African journals in Thomson Reuters' Journal Citation Reports® Science Citation Index

Included observations: 17				
Method		**d.f.**	**Value**	**Probability**
t-test		27	1.785096	0.0855
Variable	**Count**	**Mean**	**s.d.**	**s.e.m.**
GROUP_A	17	0.630294	0.401585	0.097399
GROUP_B	12	0.381333	0.318232	0.091866
All	29	0.527276	0.384073	0.071320

Table 4 shows the South African journals in the JCR Social Sciences Citation Index. The asterisk indicates the journals which were indexed during 2002. South Africa is represented by 16 journals during 2009, whereas only 4 journals were indexed in 2002. Only four journals fall in the third quartile of the lists of the relevant journals in the index; all others fall in the fourth quartile.

We undertook a two-sample *t*-test to compare the two sets of journals in order to identify whether they were from the same population (Table 5). The results again indicate that all journals were from the same population in terms of their impact factors.

Table 6 shows the Eigenfactors of the South African journals. The *SAMJ: South African Medical Journal* has the highest Eigenfactor score followed by the *South African Journal of Botany* and the *South African Journal of Science*. These journals are cited by highly ranked journals.

Table 4: Impact factors and quartiles of South African journals in the Thomson Reuters' Journal Citation Reports® Social Sciences Citation Index

Journal name	Impact factor 2009	Quartile 2009	Quartile 2010	Category
AJAR – African Journal of AIDS Research	0.569	4	4	Public, Environmental & Occupational Health
Anthropology Southern Africa	0.222	4	4	Anthropology
Education as Change	0.170	4	4	Education & Educational Research
Lexikos	0.667	3	2	Linguistics
*Perspectives in Education**	0.387	3	4	Education & Educational Research
Politikon	0.216	4	4	Political Science
South African Geographical Journal	0.207	4	4	Geography
South African Journal of Business Management	0.146	4	4	Business
		4	–	Management
*South African Journal of Economics**	0.248	4	4	Economics
South African Journal of Economic and Management Sciences	0.082	4	4	Economics
		4	–	Management
South African Journal of Education	0.308	4	3	Education & Educational Research
South African Journal of Human Rights	0.692	3	–	Law
*South African Journal of Psychology**	0.347	4	4	Multidisciplinary Psychology
South African Journal of Psychiatry	0.409	4	4	Psychiatry
Southern African Linguistics and Applied Language Studies	0.066	4	4	Linguistics
*Social Dynamics**	0.237	3	4	Area Studies

**Journals indexed during 2002.*

Table 5: Test for equality of means between pre-existing (Group B) and newly added (Group A) South African journals in Thomson Reuters' Journal Citation Reports® Social Sciences Citation Index

Included observations: 12

Method	d.f.	Value	Probability
t-test	14	0.070527	0.9448

Category Statistics

Variable	Count	Mean	s.d.	s.e.m.
GROUP_A	12	0.312833	0.220612	0.063685
GROUP_B	4	0.304750	0.073848	0.036924
All	16	0.310813	0.191820	0.047955

Table 7 shows the structure of the editorial boards (as they appear in the relevant journals) of the South African journals. The *International Sportmed Journal* and *South African Journal on Human Rights* have more foreign than local academics on their boards. A large number of journals have no foreign academics on their editorial boards. As the structure of the editorial board reveals, at least partially, the international character and the quality of a journal, this situation is a policy concern.

It is interesting to compare the number of South African journals covered by Thomson Reuters with those of some other countries. Table 8 shows the number of journals indexed in the JCR from South Africa and other selected countries. South Africa, with 29 journals in the scientific domain, has more indexed journals than New Zealand, Ireland, Mexico and Israel. In the social sciences, South Africa has even more than countries like Japan and China, which probably is related to language issues. On the African continent, Nigeria follows South Africa with eight and two journals in the sciences and social sciences, respectively.

Analysis of the disciplinary fields covered by the indexed South African journals shows that 13 journals (out of 29) belong in the plant and animal sciences category. Social sciences follows with 7 journals, and education, economics and business, psychology/psychiatry and

Table 6: Eigenfactor® of South African journals in Thomson Reuters' Journal Citation Reports®

Journal	Eigenfactor
SAMJ: South African Medical Journal	0.00418
South African Journal of Botany	0.00302
South African Journal of Science	0.00214
Water SA	0.00176
African Journal of Marine Science	0.00153
South African Journal of Geology	0.00116
African Zoology	0.00097
South African Journal of Wildlife Research	0.00073
AJAR – African Journal of AIDS Research	0.00062
South African Journal of Animal Science	0.00062
Journal of the South African Institute of Mining and Metallurgy	0.0006
Journal of the South African Veterinary Association	0.00059
African Entomology	0.00056
Politikon	0.00056
Quaestiones Mathematicae	0.00055
*South African Journal of Psychology**	0.00052
Onderstepoort Journal of Veterinary Research	0.00051
Bothalia – African Biodiversity and Conservation†	0.00049
Ostrich	0.00047
*South African Journal of Economics**	0.00047
African Invertebrates	0.00044
South African Journal of Enology and Viticulture	0.00044
Southern Forests	0.00038
*Social Dynamics**	0.00036
South African Journal of Chemistry	0.00033
South African Journal of Education	0.00029
International Sportmed Journal	0.00028
South African Journal of Surgery	0.00026
African Journal of Herpetology	0.00025
Southern African Journal of HIV Medicine	0.00025
Anthropology South Africa	0.00019
South African Journal of Psychiatry	0.00018
South African Journal of Economic and Management Sciences	0.00015
Southern African Linguistics and Applied Language Studies	0.00015
South African Journal of Industrial Engineering	0.00014
South African Journal of Business Management	0.0001
Education as Change	0.00008
Journal of the South African Institution of Civil Engineering	0.00007
SAJOG – South African Journal of Obstetrics	0.00004
African Journal of AIDS Research	–
Lexikos	–
*Perspectives in Education**	–
South African Geographical Journal	–
South African Journal of Human Rights	–
South African Journal of Psychiatry	–

**Journals indexed during 2002.*
†Previous title was Bothalia.

engineering with 3 journals each. The dominance of plant and animal journals is the result of the country's wealth in flora and fauna resources.

Discussion

We report the results of an investigation aimed at identifying the performance of South African journals indexed by Thomson Reuters' JCR. Inclusion in the citation indices is of importance internationally as an indicator of journal visibility.

In South Africa, inclusion in the citation indices is of particular interest as publications in the indexed journals automatically qualify the country's universities for government subsidy. Universities in South Africa receive government subsidy according to a funding formula in which one of the components is the number of research publications. Universities currently receive more than ZAR120 000 (approximately USD12 000) for each publication that their members of staff and students publish in qualifying journals.

The increase in the number of indexed South African journals during the recent years undoubtedly increases the country's scientific visibility.

A comparison of the journal's performance during 2002, 2009 and 2010 identified a relative deterioration in terms of the impact factor. During the most recent period, the majority of the South African indexed journals belong to the fourth and third quartile in terms of impact factor. Only three of the scientific journals were in the second quartile. Similarly, all the social sciences journals were in the third and fourth quartiles. Journals in the tail of the Thomson Reuters ranking are at risk of being dropped from the citation indices. Furthermore, as researchers prefer to submit their articles to high-impact journals, the journals in the tail run the danger of not receiving an adequate number of quality articles and hence will either reduce their quality standards or cease to exist.

The identification of the Eigenfactors of the South African journals will provide a valuable benchmark of performance for future investigations as there currently are no historical data of this indicator.

The identification of the structures of the editorial boards emphasises the above findings. The majority of South African journals are dominated by local researchers. As many as 20 journals do not have any foreign researchers or academics on their editorial boards. As international gatekeepers can transmit international standards and practices in the local journals, and because they may increase the prestige of the journal with their presence, the issue should receive attention by the relevant authorities. It should be emphasised that international researchers on editorial boards alleviate the shortcomings of peer review in scientifically small countries like South Africa. It has been argued that in scientifically small countries, a small number of researchers work in the same field, they know each other personally and they are socially tied to each other and to the social community surrounding them. 'When they have to render a verdict on a research proposal or research article these ties impair them from being objective'[3]. While other approaches (such as monitoring comments of peers and increasing the number of members on editorial boards) may be able to alleviate the challenges of biases, the incorporation of international researchers on editorial boards is probably among the most effective approaches.

It is important for the prestige of the country, and of ASSAf, to take appropriate actions to improve the country's journals. Their approach of coupling scientometric assessments with peer reviews can further provide evidence of the validity of the above findings.

The addition of new journals in the indices has implications for the future of science policy and warrants intensive relevant monitoring in all countries like South Africa which monitor their science performance using the Thomson Reuter indices. The addition of journals in the indices increased the coverage of the various countries' scientific articles but created discontinuities in the time series data. Similarly, the differentiated coverage of the various disciplines (e.g. social sciences versus engineering) can create changes in the publication profile of the countries. Science authorities should take action to create compatible time series and relevant country scientific profiles.

Table 7: Structure of editorial boards of selected South African journals

Journal	South African editors	Non-South African editors	Total	% Foreign members
African Entomology	18	0	18	0
African Invertebrates	9	0	9	0
African Journal of Herpetology	19	13	32	41
African Journal of Marine Science	12	0	12	0
African Zoology	10	0	10	0
African Journal of AIDS Research	12	0	12	0
Anthropology Southern Africa	21	2	23	9
Bothalia – African Biodiversity and Conservation	2	3	5	60
Education as Change	9	0	9	0
International Sportmed Journal	3	25	28	89
Journal of the South African Institute of Mining and Metallurgy	12	0	12	0
Journal of the South African Institution of Civil Engineering	19	1	20	5
Journal of the South African Veterinary Association	9	0	9	0
Lexikos	12	0	12	0
Onderstepoort Journal of Veterinary Research	30	1	31	3
Ostrich	5	7	12	58
Perspectives in Education	25	14	39	36
Politikon	22	11	33	33
Quaestiones Mathematicae	0	7	7	100
Southern Forests	11	0	11	0
South African Journal of Economic and Management Sciences	–	–	–	–
South African Geographical Journal	13	6	19	32
South African Journal of Animal Science	12	0	12	0
South African Journal of Botany	12	0	12	0
South African Journal of Business Management	16	9	25	36
South African Journal of Chemistry	8	0	8	0
South African Journal of Economics	–	–	–	–
South African Journal of Education	16	12	28	43
South African Journal of Enology and Viticulture	14	1	15	7
South African Journal of Geology	9	3	12	25
South African Journal of HIV Medicine	1	0	1	0
South African Journal of Human Rights	4	16	20	80
South African Journal of Industrial Engineering	14	6	20	30
South African Journal of Psychology	19	8	27	30
South African Journal of Science	13	0	13	0
South African Journal of Surgery	4	0	4	0
South African Journal of Wildlife Research	10	2	12	17
South African Journal of Obstetrics	2	0	2	0
South African Journal of Psychiatry	26	13	39	33
South African Medical Journal	18	0	18	0
Southern African Linguistics and Applied Language Studies	11	0	11	0
Social Dynamics	23	23	46	50
Water SA	7	11	18	61

Table 8: Number of indexed journals in Journal Citation Reports® (2009): South Africa and selected countries

Country	Science Citation Index	Social Sciences Citation Index
USA	2612	1092
England	1469	548
Netherlands	643	140
Germany	512	90
Japan	200	8
Switzerland	158	25
P.R. China	114	8
Australia	97	61
India	68	4
Brazil	65	10
Singapore	47	4
South Africa	**29**	**16**
New Zealand	26	9
Ireland	22	3
Mexico	22	11
Chile	16	8
Israel	12	1
Argentina	10	4
Nigeria	8	2
Malaysia	6	2

Finally, it should be mentioned that the addition of South African journals in the citation indices has not adversely affected the country's scientific profile. Even though Thomson Reuters[13] stated that 'the importance of the [inclusion of] regional journal is measured in terms of the specificity of its content rather than in its citation impact', our investigation shows that the newly added journals were of the same quality in terms of impact factor as the pre-existing ones.

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Authors' contributions

Both authors contributed equally to this article.

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Preliminary laboratory assessments of a lightweight geocomposite material for embankment fill application

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The cost of retaining structures used for the lateral support of roadside embankments can be significantly reduced through the use of lightly cemented mixtures of expanded polystyrene (EPS) beads and backfill soils as lightweight roadside embankment material. Four grades of residually derived sandy soils were mixed with EPS beads and the geocomposites were stabilised with 3% cement content, compacted and cured. The textural properties and shear strength parameters of dry and soaked specimens of the cemented geocomposites were determined by direct shear tests. The shear parameters and slope stability charts were used to simulate the slope of typical road embankments. The settlement potentials at different applied normal stresses were also determined. Inclusion of EPS reduced the dry density of the residual soils from an average value of 1790 kg/m^3 to 1335 kg/m^3. The maximum friction coefficient, tan α', mobilised by the geocomposite specimens decreased with an increase in the soil fines content (>0.425 mm). The difference in tan α' between the stabilised geocomposites and the natural soil was also dependent on the fines content. For an embankment height of 20 m, slope angles of 38° and 62° were determined for fine sand geocomposites in fully saturated drainage and drained conditions, respectively. Lower slope angles were determined for geocomposites made from silty, coarse and gravelly sands. A limiting embankment height of 50 m was determined for the four geocomposites. Rainfall-induced settlement of geocomposites was dependent on pre-inundation stiffness; for the range of applied stress up to 200 kPa, the settlement exhibited by the fine and silty sand geocomposites was lower than that for the coarse and gravelly sand geocomposites. Fine and silty sands make poor materials for slope embankments because of their poor hydraulic conductivity; however, fine and silty sand geocomposites have a good conductivity and friction angle to support slope embankments.

Introduction

The cost of road construction can be reduced significantly when the backfill materials used for the preparation of the road subgrade, subbase and side embankments are constructed using soil and road materials that exist along the designated roadway. In most parts of the tropical and subtropical regions of the world, residual soils are frequently encountered along most proposed roadways. Because of the mode of formation, residual soils are heterogeneous and may be predominantly granular or very fine depending on the degree of weathering. The texture and mechanical properties of the soil may vary both laterally and vertically. It may be difficult to predict the type of foundation required when a residual soil is encountered.[1,2] Residual soils can be recompacted to high density in situ, and are known to mobilise high shear strength when dried, but can soften significantly when wet or poorly drained. Thus embankments constructed with residual soils often require cement stabilisation and a retaining structure to limit or prevent roadside embankment slope failure, especially upon inundation.

Zeevert[1] noted that the granulometry of residual materials can be very variable and may consist of clay and colloids, silt, sand or gravel. This variability means that the density and cementation of the soil can also vary widely. In the upper part of the soil, compressibility may be high and shear strength very low. Earth works requiring compaction of backfills and road embankments are expensive programmes. Poorly compacted residual soils often exhibit significant collapse settlement as a result of rainfall and low undrained shear strength caused by poor and remoulded drainage profiles.[3] Thus the stability of embankments in residual formations requires detailed parametric analysis.

The use of retaining walls to prevent roadside slope failure can be very expensive and for low-cost roads may not be easily justifiable. The use of lightweight geocomposite materials stabilised with lean cement content may offer a cost-effective option for road embankment construction. Roadside embankment infrastructures like bridge abutments, roadside embankments and retaining wall backfills built up with normal residual backfill may require extra embedment depth and adequate reinforcements to prevent lateral displacement and cracking of the retaining wall. The failure of such infrastructures can be prevented through the use of a lightweight fill as an alternative geometrical for the relief of the overburden mass and lateral load of the conventional, but massive, earth filling materials.

Literature review

Polystyrene is a synthetic material produced from naphtha, a by-product of the refining process of petroleum. Heat-induced expansion of pentene gas infused in polystyrene results in expanded polystyrene (EPS) materials in the form of beads or blocks. Polystyrene is a relatively cheap material and widely available. It is durable in harsh environments and often outlives the life expectancy of conventional construction materials. It is commonly used for pipe insulation, lightweight fill material, sheet wall insulation, concrete moulds and backfill insulation.[4,5] The effect of small polystyrene blocks on the mechanical properties of retaining wall backfill has been investigated.[5] Layers of polystyrene blocks were placed above the granular backfill behind a stretch of a retaining wall.[5] The inclusion of

polystyrene blocks decreased the lateral pressure on the retaining wall to such an extent that it was possible to decrease the quantity of reinforcing required in the retaining wall and effectively save costs. Polystyrene has also been used to reduce the settlement of the backfills and increase their insulation. Polystyrene fill was used for the extension of Highway Bridge in Salt Lake City – an area underlain by alluvium deposits of soft clay and lacustrine silt. Geoforms made up of EPS blocks were applied to mitigate settlement of the bridge approach embankments that were constructed over the compressible soft soils.[6] EPS blocks are not suitable for construction in confined spaces and inaccessible locations because of their shape; the blocks are limited to regular shapes and cannot readily be used in areas with irregular shape.[7]

Extensive investigations have been done on the use of lightweight fill material for the construction of embankments on sandy soils, weak soils and dredged mud. Lightweight materials for embankments were achieved by mixing EPS beads, polystyrene pre-puff beads, soil materials, water and cement. Lightweight fill materials made with polystyrene beads were found to be more expensive when cement was used as extra manpower or machines were often required for cement mixing.[7-10]

Onishi et al.[11] investigated the strength and small strain modulus of cement stabilised sand mixed with EPS beads, which they referred to as cemented sand composite. It was found that the inclusion of the EPS beads degraded the strength and deformation properties of the geomaterial even when cement was used; however, when cement was used in appropriate amounts, the strength and deformation properties of the sand composites were enhanced. As a granular material, the shear behaviour of sand–EPS lightweight fills plays an important role in deformation and stability in practical works, and thus deserves further investigation beyond its general engineering properties. The shear behaviour of the two-phase (sand–EPS) geomaterial composite is more complicated than that of common geomaterials composed of pure soils and rocks. The behaviour is essentially dependent on the mix ratios and mechanical interaction of sands and beads.[12] The reduction of lateral earth forces acting on non-yielding retaining walls by EPS inclusion was also investigated.[13] It was observed that the deformation of the EPS was concentrated in the bottom half of the retaining wall because of higher stresses in that zone. The elastic and plastic deformation phases of EPS-based backfill make the prediction of field settlement a design challenge, as elastic and plastic deformation parameters depended on the external load, loading rate and field drainage paths.

Shear-induced deformation parameters of naturally cemented and lightly cemented soft soils containing EPS were determined in the laboratory from the conventional constant normal stress triaxial or direct shear tests. The test condition in the triaxial apparatus assumes that the external load on the sample remains constant until failure and the shear strength mobilised is associated with shear-induced volume compression or dilation of the material. In reality, for most in-situ loading conditions, the principal stresses rotate during shear and are not constant as in triaxial devices. Furthermore, back analysis of slope failures shows close correlation with shear strength parameters derived from the direct shear tests. The aim of this research was to evaluate the shear parameters of a lightly cemented mixture of EPS and granular soil materials (cemented composites), to determine the relationship between the textural properties of soil backfill materials and the strength properties of the geocomposites, and to estimate the slope angles of typical embankments of the cemented composites for different drainage conditions and the moisture-induced settlement potential of the cemented composites.

Materials and methods

Materials

The EPS investigated (shown in Figure 1) was collected from a textile factory in Johannesburg, at which the beads were further processed and used for the production of picture frames and furniture. The beads were spherical to near spherical superlight polymer products of pre-puffed polymer resins. The material was kept in a dry chamber before use.

Figure 1: (a) Expanded polystyrene beads and (b) a mixture of expanded polystyrene beads and silty sand.

The residual soil used is a common backfilling material derived from the weathering of quartzite. Reddish residual sandy soil was obtained from a road construction site in Auckland Park, Johannesburg. The Brixton Formation is part of the West Rand Group which forms part of the Witwatersrand Supergroup. The Witwatersrand Supergroup is made up of a thick sequence of shales, quartzites and conglomerates.[14] X-ray diffractometer analysis of the mineral constitution revealed the presence of quartz, haematite, muscovite, garronite and chloritoid. Quartz was the greatest constituent of the soil, followed by haematite, muscovite, garronite and chloritoid. The residual soil was dried, mixed and sieved to remove soil fractions with diameters greater than 6.75 mm. The soil was then reconstituted to produce the following four major types of backfills: silty sands (0.075–4.75 mm; 30% <0.075 mm), fine sands (0.075–4.75 mm; 10% <0.075 mm), uniform coarse sands (2.00–4.75 mm) and gravelly sands (0.075–6.75 mm; 70% <4.75 mm). Although the particle size diameter of the EPS is within the range of 2.35–6.75 mm, only the fraction with diameters in the range 2.35–4.75 mm was used. The four backfill materials were compacted in a mould by the application of 55 blows per layer to three layers of each material in a mould 150 mm in diameter and 125 mm in height, in order to determine the maximum dry density and optimum moisture content. Mixtures of backfill materials and 3% cement by mass were made and transferred into a large graduated cylinder. The mixture was blended with 30% by volume of EPS beads and water and also compacted in the mould to determine the effect of EPS proportion on the optimum moisture content and dry density of cement-stabilised backfill materials.

An ordinary Portland cement (CEM II, Afrisam, Johannesburg, South Africa) was used as a binder. The specific gravity of the cement was 3.6 g/cm^3. The compressive strength of the mortar was 22 MPa after 3 days and 30 MPa after 7 days. To provide adequate bonding for the composite material, 3% of the cement by mass of the backfill was used. For the stabilisation of poor road subgrade and the backfill layer below the subbase, the amount of cement used often varies from 1% to 3%, especially for C4 grade roads. This amount of cement is usually adequate to provide strength improvement in residual soils. A value of 3% was adopted after preliminary tests indicated that 2% and 3% cement showed some sensitivity to moisture-induced reduction in strength of residual soil based lightweight geocomposite. In addition, the treatment of roadside embankments with a high percentage of cement would result in a very high total road construction cost, especially for low-cost or low-grade roads in undulating terrain. The optimum moisture content and dry density of the cement-stabilised EPS–backfill specimens were used to prepare the specimens for shear strength tests.

The four composite materials produced were: (1) a cement-stabilised mixture of EPS and silty sand, (2) a cement-stabilised mixture of EPS and fine sand, (3) a cement-stabilised mixture of EPS and uniform sand and (4) a cement-stabilised mixture of EPS and gravelly sand.

Direct shear test

For the direct shear tests, compacted specimens of the natural soils and the geocomposite materials were cut into 100-mm square specimens with a thickness of 50 mm. The direct shear specimens were soaked for 6 days in a curing room at a constant humidity of 80% and temperature of 20 °C to ensure that sufficient water was available for cement hydrolysis. On the seventh day, a set of the soaked specimens was further soaked for 24 days in the shear box and tested. A second set of specimens was dried to the optimum moisture content and tested. The constant normal stress direct shear tests were conducted in a 100-mm square shear box apparatus with a lever arch loading system. The specimens were consolidated with applied normal stresses of 50 kPa, 100 kPa, 200 kPa and 400 kPa. The samples were then sheared at a shear displacement rate of 0.2 mm/min.

Settlement test

There are two widely used laboratory methods for determining the collapse settlement of soils. The first is the double oedometer collapse settlement method in which one of two identical samples is saturated before subjecting both samples to a series of applied stresses. Moisture-induced collapse settlement of the cemented composites was studied by the second method. This method entails increasing the stress on a sample up to a specified value followed by inundation at that specified stress. The advantage of the second method of determining collapse settlement is that field compression stress paths can be directly simulated.

The samples used for these tests were statically compacted into standard oedometer rings 40 mm in height and 150 mm in diameter at an initial moisture content of 20%, and placed in the oedometer pots between air-dried porous stones. The inner surface of the oedometer rings was lubricated with a commonly available spray lubricant (Q10) before sample compaction to reduce the effect of side shear in the sample during compression. All the samples used for the standard settlement tests and moisture-induced collapse settlement tests were left for 24 h for consolidation. Depending on the tests, at a given applied stress, collapse was induced by gradually filling the oedometer pots with distilled water, after removing the plastic bag. The sample was then allowed to stand for 24 h after which time the deflection was noted.

At a given vertical stress, the samples were soaked by gradually filling the oedometer pots with distilled water, thus ensuring that moisture uptake was through suction alone, and the amount of collapse was noted. Moisture-induced settlement was calculated as the ratio of the change in height, $\triangle H$, of a specimen when soaked to the initial height H associated with the soaking pressure, expressed as a percentage. The moisture-induced settlement of a specimen at any applied stress expressed as a percentage was given by Knight[15] as:

$$\frac{\triangle e}{1+e_o} \text{ x100\% ,} \qquad \text{Equation1}$$

where Δ_e is the change in void ratios as a result of saturation and e_o is the void ratio of the sample before inundation. Because of the difficulty in estimating the void ratio of the cemented geocomposite materials, the general form of Equation 1 – that which is applicable to one-dimensional compression and settlement relationships – is used.

$$\frac{\triangle H}{H} = \frac{\triangle e}{1+e_o}, \qquad \text{Equation 2}$$

where ΔH represents the change in height of a specimen as a result of saturation and H is the height of the specimen as a result of the current applied stress before inundation. One-dimensional compression tests were conducted on compacted specimens of homogenously blended EPS beads, residual soils and 3% cement. The mixture was blended with water equal to the optimum moisture content of the soil and was compacted into oedometer rings at maximum dry densities and cured for 7 days. The specimens were consolidated with applied normal stresses of 50 kPa, 100 kPa, 200 kPa and 400 kPa and soaked at selected applied normal stresses. After soaking, the specimens were left for 24 h before dial gauge reading and unloading.

Results and discussion

Textural properties

The textural properties of the backfill soils were determined from the particle size distribution curves shown in Figure 2. The major textural properties of the granular backfill (i.e. the per cent fines; >0.425 mm), the particle sizes that permit 10%, 30%, 50% and 60% of the granular backfill materials, the coefficient of uniformity (C_d) and the coefficient of curvature (C_c) are presented in Table 1. It can be noted that a well-graded soil has a uniformity coefficient of greater than 4 for gravel and 6 for sands, and a coefficient of curvature or gradation between 1 and 3.[16]

Table 1: The textural properties of the backfill soils

Textural properties	Silty sand	Fine sand	Uniform sand	Gravelly sand
D_{10}(mm)	0.007	0.09	0.16	0.28
D_{30}(mm)	0.08	0.4	0.8	1.2
D_{50}(mm)	0.5	1.2	1.4	3
D_{60}(mm)	0.8	1.9	2.4	3.8
C_c	114	21	15	13.5
C_d	1428	52	18	11
% Fines	47	32	2	18

Values outside the stipulated ranges indicate a poorly graded soil. Poorly graded soils are gap graded because of the absence of soils of some particle sizes. The particle size range of the EPS beads is 2.3 mm to 4.74 mm and thus the beads are uniformly graded. The specific gravity and dry density are 0.021 and 21.097 kg/m^3.

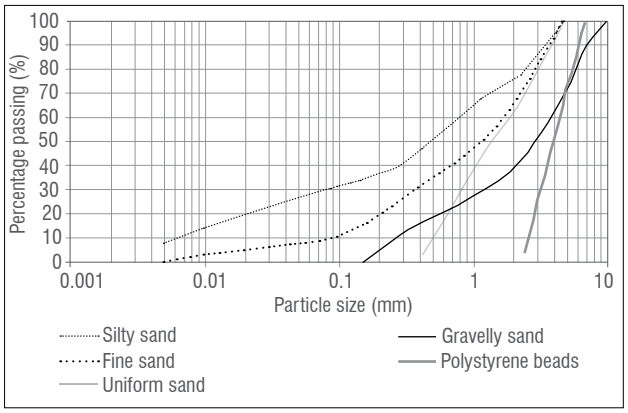

Figure 2: Particle size distribution curves of backfill soils and expanded polystyrene beads.

Compaction

The maximum density of the backfill soils ranged from 1730 kg/m^3 to 1850 kg/m^3 and the optimum moisture content ranged from 9% to 13%. The maximum densities of gravelly sand and silty sand are the maximum and minimum, respectively, and a trend of increasing dry density with an increase in the value of the textural properties was evident. These densities are above the 1650 kg/m^3 benchmark of in-situ residual soils from southern Africa that have a high likelihood of moisture-induced settlement.[14,15]

The effect of the addition of 30% EPS (by volume) resulted in a decrease in the maximum dry density of the cement-stabilised soils (Figure 3a and 3b). The maximum density and optimum moisture content of the blended specimens of soil, EPS and 3% cement varied from 1303 kg/m^3 to 1368kg/m^3 and 9% to 7%, respectively. However, a trend of increasing dry density with the textural properties was not evident in Figure 3b.

Strength and deformation of silty sand geocomposite

The result of direct shear tests on the cement-stabilised mixture of fine sand and EPS is shown in Figure 4a. The specimens were tested after drying. The shear stress curves were presented in terms of stress ratio, i.e. the ratio of mobilised shear stress to the applied normal stress, because the stress ratio presented a better indication of the influence of applied stress on the slope of the stress–displacement curves at small shear displacements. The stress ratio is a good indicator of soil structure. The effect of an applied pressure of 50 kPa on the slope of the stress–displacement curve of the silty sand composite was minimal in comparison to the effect of higher applied stresses (100 kPa to 400 kPa) on the specimen. Thus the stress ratio mobilised by the specimen as a result of an applied stress of 50 kPa was the highest because the specimen structure was least degraded by the applied pressure of 50 kPa. For the range of applied stress used, the specimen exhibited strain-hardening behaviour, i.e. shear stress increased progressively with shear displacement, as a result of the increase in shear-induced volume compression of the specimen. The degree of strain hardening decreased with an increase in the magnitude of applied stress and the elastic, yield and plastic phases were more evident at low normal stress. The slope of the stress displacement curves was highest for a specimen subjected to a normal stress of 50 kPa. The displacements at which the maximum shear strength was mobilised increased with the applied pressure. The shear-induced volume compression also increased with the applied stress. At large imposed shear displacements there was coinciding shear stress and shear-induced volume compression, as both parameters tend to constant values and the shear stresses mobilised at large displacement varied in relation to applied pressure.

The strength envelope of soil and rock materials is the Mohr Coulomb failure criterion given by Equation 3:

$$\tau' = \sigma_n' \tan \varnothing' + c' , \qquad \text{Equation 3}$$

where τ' is the shear strength from drained tests, σ_n' is the effective normal stress, tan $\varnothing'$ is the coefficient of intergranular friction from drained tests and c' is the effective cohesion from drained tests.

The underlying concept of rupture mechanics contends that materials fail because of a critical combination of normal stress and shearing stresses and not from the maximum normal or shear stress alone. Thus the failure plane that defines the functional relationship between normal stress and shear stress is a curved line. For most soil mechanics problems, however, it is sufficient to express the shear stress as a linear function.[16] The stress–deformation curves of soaked specimens are shown in Figure 4b. The specimens showed elastic plastic strain hardening behaviour – i.e. the stress ratio increased as a result of shear-induced compression of the specimens and the yield phase was not evident. The mobilised stress ratio and stiffness decreased with an increase in applied pressure while the magnitude of shear-induced volume compression increased with applied pressure. The percentage of fines (>0.425 mm) in the fine sand is 30%. The low shear strength mobilised by soaked specimens of fine sand as well as the direct shear-induced volume compression indicated in Figure 4c can be associated with the dry density and the percentage of fines.

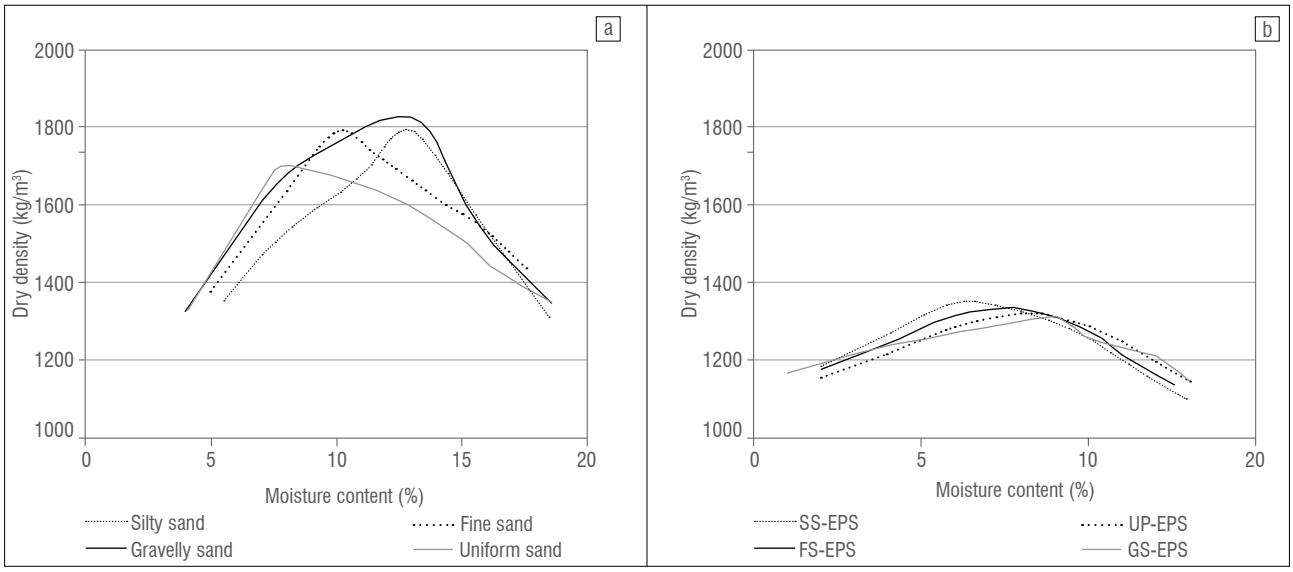

Figure 3: Compaction curves of (a) the backfill soils and (b) mixtures of 3% cement-stabilised soils and expanded polystyrene (EPS) beads.

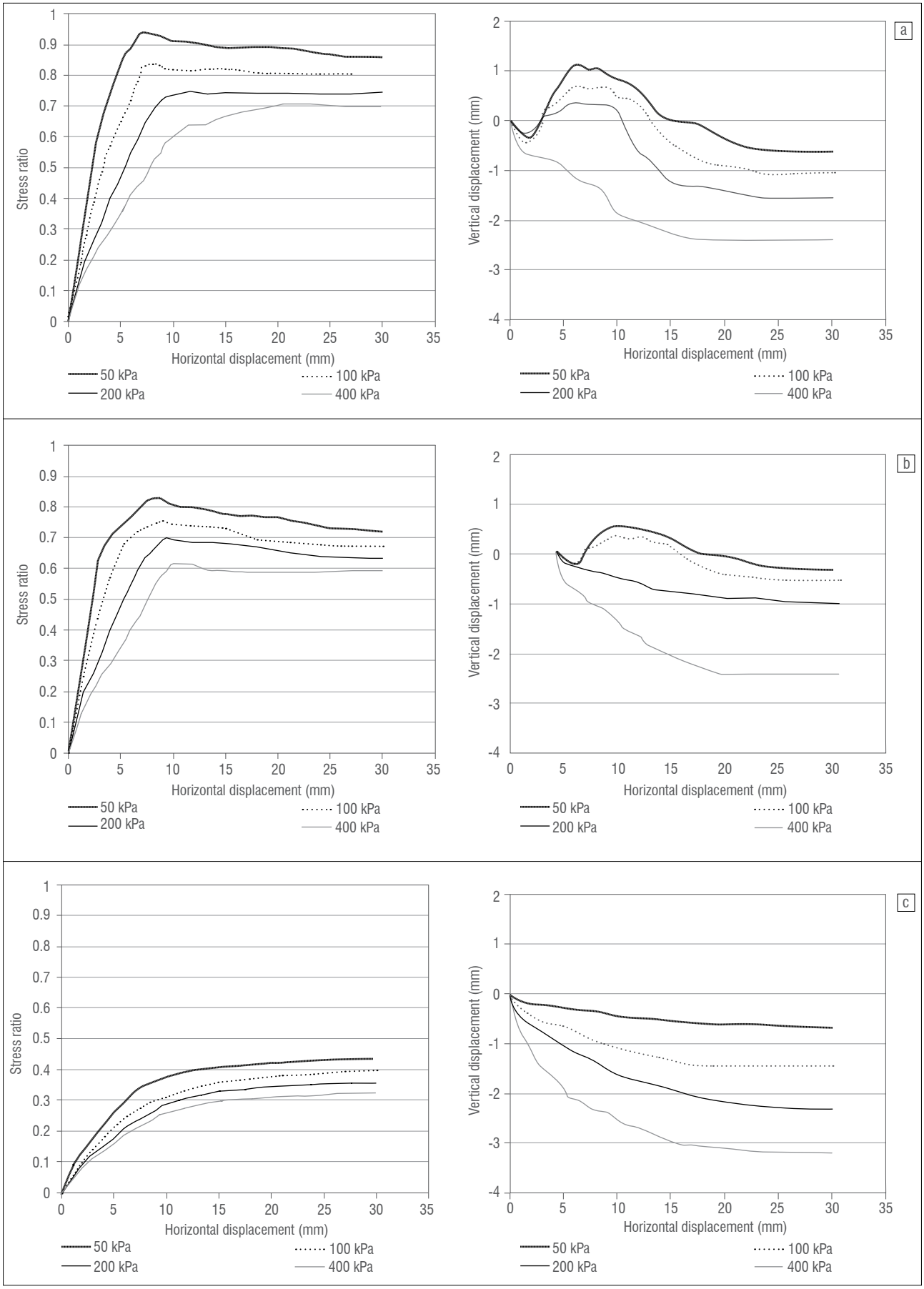

Figure 4: Stress and deformation curves for (a) a dry fine sand and expanded polystyrene composite, (b) a soaked fine sand and expanded polystyrene composite and (c) a soaked fine sand.

Stress and deformation behaviour of cement-stabilised soils and EPS

The direct shear stress and deformation behaviour of dry and soaked specimens of cement-stabilised geocomposites made from fine sand, uniform coarse sand and gravelly soils and EPS are similar to the behaviour presented in Figure 4a and 4b. The dry specimens showed mild strain-hardening behaviour at low values of applied pressures and mild strain-hardening behaviour at large applied pressures. The transition from strain-hardening to strain-softening behaviour was associated with minimum shear-induced volume compression and higher stiffness of the specimen caused by low applied pressure and significant specimen compression at large applied pressure. Specimens subjected to low pressures also exhibited dilatancy at small displacement and compression at large imposed shear displacement. The dry specimens exhibited mild strain-softening behaviour characterised by elastic, yield and plastic phases of deformations at applied normal stress of 50 kPa and 100 kPa and elastic perfect plastic behaviour for applied normal stresses of 200 kPa and 400 kPa. At large imposed shear displacement, the mobilised shear stress and stress ratio decreased with an increase in applied normal stress. The weak cement bond was not broken down by the application of normal stresses of 50 kPa and 100 kPa and thus mobilised a high shear stress ratio at small displacement. At larger imposed displacement, the cement bond was gradually broken and plastic flow behaviour was exhibited. The application of normal stresses of 200 kPa and 400 kPa resulted in the breakdown of the cement bond and thus subsequent imposition of shear displacement resulted in elastic plastic behaviour and shear-induced volume compression. The displacements at which the maximum shear strength was mobilised varied and increased with the applied normal stress. The shear induced-volume compression also increased with the applied stress. The stress ratio curves of the soaked specimens were characterised by elastic plastic strain-hardening behaviour at applied pressures of 200 kPa and 400 kPa and strain-softening behaviour at applied pressures of 50 kPa and 100 kPa. The transition from strain softening to strain hardening was related to the influence of applied normal stress on specimen stiffness.

Strength envelopes of lightweight backfill materials

The strength envelopes for specimens of dry and soaked silty sand and specimens of a cement-stabilised mixture of silty sand and EPS are shown in Figure 5. The direct shear strength envelopes of the cemented geocomposites are also presented in Table 2. The shear strength of the cement-stabilised silty sand composite in the dry state was lower than that in the wet state for applied normal stress because of the effect of increased shear-induced compression in the soaked state on strain hardening, especially at large shear displacement. As the applied stress increases, the strength in the dry state approached the strength in the wet state because of an increase in intergranular friction. For the gravelly sand geocomposite, while the friction coefficient decreased by 50% as a result of inundation, the cohesion was only marginally affected by soaking. Figure 5 shows that the reduction in the mobilised friction coefficient from soaking increased with applied stress because of the combined effect of moisture-induced softening and reduction in stiffness and breakdown of the cement bond. The coupled effect of reduction in stiffness and breakdown of natural cement bonds is common in weathered residual rocks.[17] There is no difference in the cohesion of dry silty sand and silty sand geocomposite; the difference in friction coefficient was due to the effect of increased normal stress on the structure of the natural soil and the stabilised geocomposite. The strengths of the residual silty sand specimens are very sensitive to changes in moisture content. The addition of cement reduced moisture sensitivity in the stabilised geocomposite.

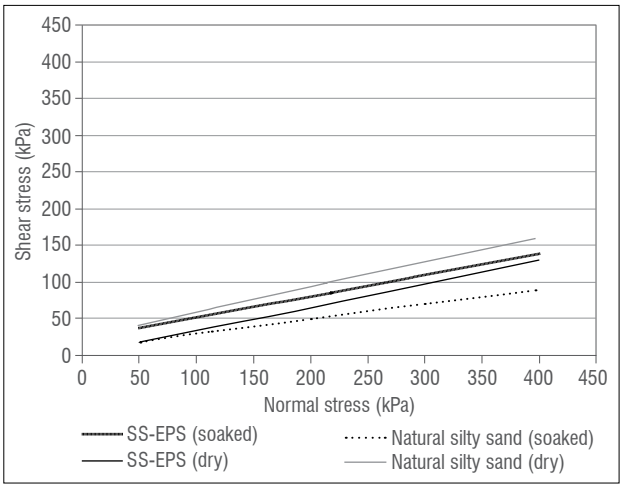

Figure 5: Strength envelopes of a silty sand and expanded polystyrene composite (SS-EPS) and silty sand when dry and soaked.

Table 2: Strength envelopes for cemented soil composites

Specimen	Envelopes	R^2
SS–EPS (soaked specimen)	$\tau = 0.29\ \sigma' + 22.34$	0.9871
SS–EPS (dry specimen)	$\tau = 0.32\ \sigma' + 1.8$	0.9971
FS–EPS (soaked specimen)	$\tau = 0.34\ \sigma' + 8.7$	0.9854
FS–EPS (dry specimen)	$\tau = 0.37\ \sigma' + 29.34$	0.9723
US–EPS (soaked specimen)	$\tau = 0.40\ \sigma' + 13$	0.9487
US–EPS (dry specimen)	$\tau = 0.50\ \sigma' + 18$	0.9532
GS–EPS (soaked specimen)	$\tau = 0.43\ \sigma' + 8.9$	0.9952
GS–EPS (dry specimen)	$\tau = 0.52\ \sigma' + 14$	0.9624

EPS, expanded polystyrene; SS, silty sand; FS, fine sand; US, uniform coarse sand; GS, gravelly sand.

The effect of fines content of the backfill soils on the friction coefficient of the dry and soaked cemented soil composites is shown in Figure 6. The limiting fine content beyond which reduction of friction ceofficient sets in is approximately 20% and increasing the fines content to greater than 20% results in significant reduction in the friction coefficent of both the natural residual soils and the cement-stabilised geocomposites. The soils used for this investigation were low plasticity weathered quartzites and thus the fines specification also applied with the provision that the soils must be of low plasticity. The reduction in the friction coefficient of the cemented composites also decreased with increasing fines content and the relationship between moisture-induced percentage reduction in friction coefficient and fines content is exponential. Figure 6 also revealed that for the production of lightweight cemented soil and EPS, the backfill soils with intermediate fine content of 20% ensured that the composite material mobilised maximum friction coefficient and marginal reduction of friction coefficient upon inundation. In comparison with the natural soils, the mobilised friction coefficients of the geocomposites were lower, especially for fines contents lower than 20%; however, the dry densities of the geocomposites were lower by an average of 20%.

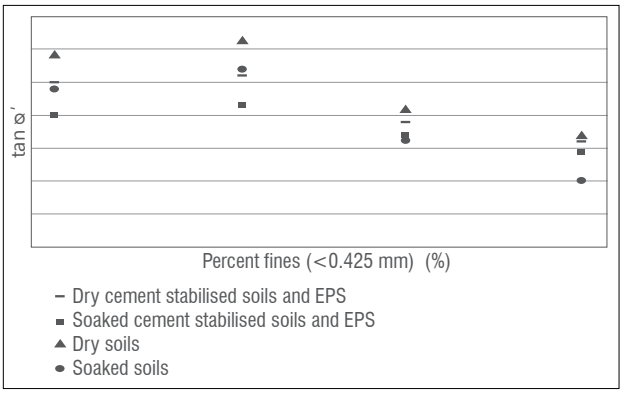

Figure 6: Friction coefficient of cemented soil composites versus per cent fines of the backfill soils.

Simulated slope stability analysis

Taylor's stability charts derived from the friction circle method have been used for the stability analysis of clay pit slopes, projected open pit slopes for crushed waste rock mass, mining and construction waste dumps, and highly altered and weathered rocks based on limit equilibrium conditions. For such materials, failure may occur along a surface which approaches a circular shape. The general structure of lightly cemented soils and EPS beads falls under this category. Hoek and Bray[17] modified the Taylor stability charts for cases of different drainage conditions. The general formulations are based on the shear strength parameters and factor of safety. Simulated limit equilibrium stability analysis was used to evaluate the stability of a typical embankment.

The factor of safety against failure (F) of a drained slope embankment of density (γ), with slope angle (ψ) and slope height (H), was expressed by Hoek and Bray[17] as:

$$F = \frac{\tan \varnothing'}{\tan \psi} + \frac{c'}{\gamma H \cos^2 \psi \tan \psi}. \qquad \text{Equation 4}$$

F is generally defined as the ratio of the shear strength for sliding resistance to shear strength mobilised by the material along the failure surface.

For an embankment constructed with granular backfill soil without cohesion, F is equal to [(tan ⍵′)/(tan ψ)], i.e. F is independent of the height of the embankment and the slope of the embankment is stable as long as $\psi < \varnothing'$. If the shear strength of the backfill soil is based on both cohesion and frictional resistance, i.e. a cemented composite, the depth of the plane that is subject to critical equilibrium (or impending failure, F=1) is expresed by Equation 5:

$$H = \frac{c'}{\gamma \cos^2 \psi \, (\tan \psi - \tan \varnothing')}. \qquad \text{Equation 5}$$

For the condition of steady-stage seepage, i.e. the occurrence of seepage through the embankment material and when the groundwater level coincides with the slope surface:

$$F = \frac{\gamma' \tan \varnothing'}{\gamma_{sat} \tan \psi} + \frac{c'}{\gamma_{sat} H \cos^2 \psi \tan \psi}. \qquad \text{Equation 6}$$

Hoek and Bray[17] also reformulated Equations 4–6 into charts with dimensionless stability factors:

$$\frac{\tan \varnothing}{F}, \frac{c}{H\gamma \tan \varnothing} \text{ and } \frac{c}{\gamma H F}$$

as the three axes of the charts. The charts were developed for different drainage conditions. The strength parameters presented in Table 2 were used to determine the stability factors. These charts were used to simulate the slope angles for selected embankment heights (0–100 m) for the different cemented composite specimens based on a factor of safety (F) of 1. The two groundwater conditions considered were: (1) a fully drained slope profile and (2) a saturated slope subject to heavy surface recharge (flooding). For a typical embankment of the geocomposites, the relationship between the slope angle (ψ) and slope height (H) was estimated from charts corresponding to the dry slope profile and a slope with a shallow water table. The slope height versus slope angle relationships which were based on the shear strength parameters of the lightweight fine sand composites in fully drained and fully saturated conditions are shown in Figure 7.

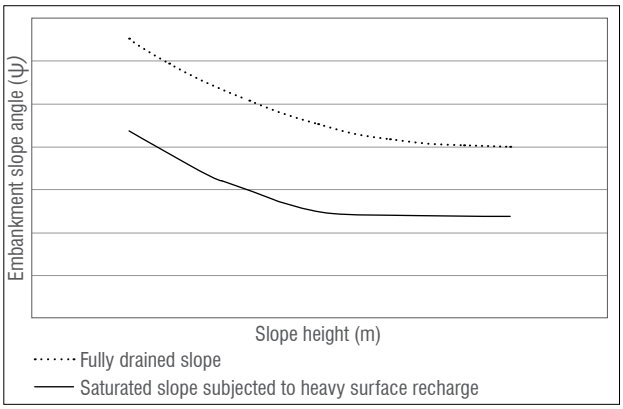

Figure 7: Slope angles and slope height of a fine sand and expanded polystyrene composite.

The slope stability charts were not sensitive to slope heights greater than 50 m, thus the limiting or critical slope of a lightweight embankment constructed with cement-stabilised soils and EPS is 50 m. For slope heights from 0 m to 50 m, the most suitable soils for the construction of an embankment slope are uniform coarse sands while the gravelly sand is the least stable material. Thus although the shear strength of the cemented gravelly sand geocomposites for the range of applied normal stresses was the highest, the simulated stability analysis of lightweight embankments constructed with the different soils revealed that for a typical slope height of 20 m, embankments built with fine sands geocomposite sustained slope angles of 65° and 44° in fully drained and saturated drainage conditions, respectively. For the same slope height, silty sand, uniform sand and gravelly sand geocomposites, respectively, sustained slopes of 58° and 40°, 62° and 41°, and 60° and 38° in fully drained and fully saturated conditions, respectively. The percentage reduction in slope angles as a result of the change in drainage conditions from drained to saturated conditions of the four geocomposites also increased with the embankment slope heights. The soil type that resulted in the least or maximum reduction in the slope angle of the composites was not clearly evident.

Moisture-induced settlement of cemented lightweight composites

Different mechanisms of moisture-induced collapse of soil deposits and compacted backfills have been postulated on the basis of soil structural matrix, initial stress state and parametric stress variables. It was postulated that the collapse of a soil structure is a result of a moisture-induced reduction in the strength of clay bridges existing between unweathered discrete grains in an open soil structure below existing applied stress.[15] The reduction in strength is strongly related to the relative abundance of the different pore sizes within a soil matrix.[18-20] Moisture-induced soil settlement potential criteria established for southern African formations recommended that about 80% of aeolian sands with dry densities greater than 1670 kg/m^3 and mixed origin soils with dry densities greater than 1650 kg/m^3 are generally not collapsible.[21,22] While failure of roads, embankments and slopes that can be directly linked to rainfall-induced soil collapse are widespread in semi-arid regions of southern African and arid regions of the world, as noted by Paige Green and Gerryt (1998), the collapse of lightweight geocomposites consisting of

lightly cemented soil and EPS are not widely documented. The collapse potential of specimens of cemented soils and EPS was evaluated using the severity of soil collapse proposed by Fookes[23]. The criteria related the percentage moisture-induced settlement of soil profile to the severity of the problem within the overlying infrastructure as follows: 0–1% (no problem), 1–5% (moderate trouble), 5–10% (severe trouble), 10–20% (severe to very severe trouble) and <20% (very severe trouble). Ratings from 10% and above can result in failure of the overlying infrastructure while ratings from 1% to 10% can result in tensile cracks induced by differential settlement of the foundation of the infrastructure as a result of moisture-induced collapse of the underlying soil.

Figure 8a and 8b show the effect of applied stress on the vertical strain of a silty sand geocomposite and the settlement potential curves of specimens of cemented silty sand and cemented gravelly sand composites. The magnitude of moisture-induced settlement of specimens of cemented silty and fine sand composites increased with the applied stress while the settlement of specimens of coarse and gravelly sand composites approached maximum values of settlement for an applied stress of 200 kPa and decreased at higher applied stress.

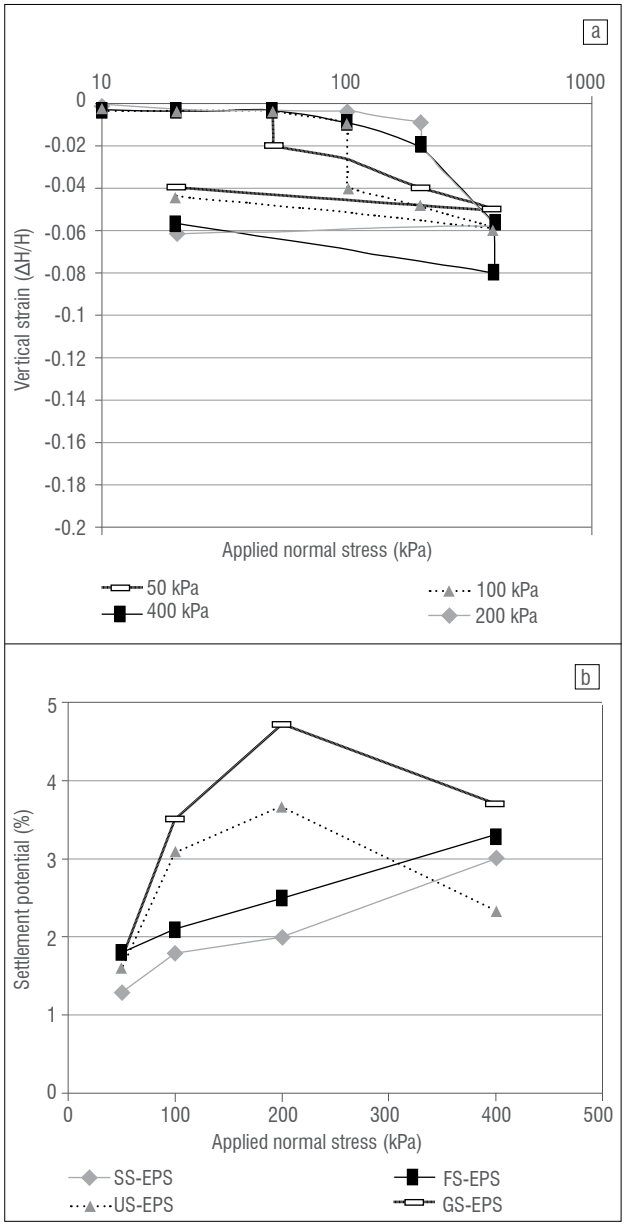

Figure 8: (a) Stress–strain curves of a silty sand and expanded polystyrene composite (SS-EPS) and (b) settlement potential curves of all cemented soil composites.

The moisture-induced settlement potential was dependent on the effect of applied normal pressure on the pre-inundation specimen stiffness. The specimen pre-inundation stiffness, also known as constrained modulus, is the ratio of the applied normal stress to the induced vertical strain before inundation. The pre-inundation stiffness of cemented silty sand and fine sand composites decreased marginally from 8200 kPa to 5300 kPa with an increase in applied pressure from 50 kPa to 400 kPa. The pre-inundation stiffness of cemented gravelly and coarse uniform sand decreased significantly from 21 050 kPa to 8300 kPa due to an increase in applied pressure from 50 kPa to 400 kPa, which resulted in significant pre-inundation softening of the specimen and thus significant collapse settlement, especially at an applied pressure range of 50–200 kPa. The magnitudes of settlement at an applied stress of 400 kPa of the four geocomposites tended towards the same value, indicating that significant destructuration and debonding of the specimens occurred, irrespective of the soil type, as shown in Figure 8b for the silty sand geocomposite.

However, based on the severity of collapse criteria,[23] the maximum settlement exhibited by the specimens can be classified as moderate trouble, i.e. the collapse settlement of infrastructures founded on the lightweight material induced by an applied pressure of 200 kPa – which is the average pressure imposed by typical two-storey buildings or cottage industries which are likely to encroach on low-cost road embankments – is likely to result in cracks but not failure of such infrastructure.

Conclusions

The relationship between the textural properties of four residual granular backfill soils and the direct shear parameters of a lightly cemented mixture of EPS and backfill soils was evaluated.

The stress–strain behaviour of the four cemented geocomposites showed defined elastic, yield and plastic zones due to shear-induced contraction of the specimens at large shear displacement. The degree of contraction decreased with an increase in the soil fines (<0.425 mm).

Percentage decrease in tan ⍉′ due to soaking also decreased exponentially with an increase in soil fines. The inclusion of EPS and 3% cement resulted in a 20% reduction in dry density and marginal reduction in shear strength when soils with less than 20% fines were used for the production of the geocomposites.

Limit equilibrium stability analysis of embankments constructed with the cemented geocomposites indicated a critical embankment height of 50 m, i.e. the strength parameters are not sensitive to an embankment height greater than 50 m. The stability analysis indicated that embankments constructed with fine sand and coarse sand composites are the most stable in both drained and fully saturated drainage conditions. The percentage reduction in critical slope angles as a result of a change in drainage conditions increased with the slope height; however, specimens with the most soil fines experienced the highest reduction in critical slope angles.

The collapse potential was dependent on the effect of applied normal pressure on the specimen stiffness before inundation. For an applied stress range of 0–200 kPa, both the collapse potential and the change in stiffness of silty and fine sand geocomposites were minimal.

For the construction of a lightweight embankment with a lean cement-stabilised mixture of soils and EPS, the limiting or critical slope height is 50 m, and, to ensure minimal rainfall-induced collapse settlement, a maximum fines content of the backfill soil is limited to 18%.

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Use of wood anatomy to identify poisonous plants: Charcoal of *Spirostachys africana*

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Spirostachys africana Sond. (tamboti/tambotie) is a woodland tree that is often found near water. It has a poisonous and purgative latex. The archaeological site of Sibudu, a rock shelter in KwaZulu-Natal, has evidence, from well-preserved charcoal and seeds, of past environments and wood use from approximately 77–38 thousand years ago (ka). As their uses and environmental indicators are different, it is critical to confidently distinguish among the three anatomically similar woods of the Euphorbiaceae: *Spirostachys africana*, *Sclerocroton integerrimus* and *Shirakiopsis elliptica*. A detailed anatomical study of reference and archaeological charcoal shows that xylem vessel width increases proportionally as vessel frequency decreases, from *Spirostachys africana*, *Sclerocroton integerrimus* to *Shirakiopsis elliptica*. Crystals of calcium oxalate are present in ray cells of *Spirostachys africana*, whereas silica bodies are present in ray cells of *Sclerocroton integerrimus* and *Shirakiopsis elliptica*. Using these features, the presence of *Spirostachys africana* was confirmed amongst hearth charcoal of the Spotty Camel layer, with an age of approximately 58 ka and of the Mottled Deposit occupational layer, with an age of approximately 49 ka. The presence of this charcoal, collected from ancient fireplaces or sieved from surrounding sediments, implies that people at Sibudu understood and used this poisonous tree to their advantage. We are encouraged in this view by the presence of many *Cryptocarya woodii* leaves found on the surface of 77-ka sedge bedding at Sibudu (Wadley L et al., Science. 2011;334:1388–1391). *Cryptocarya woodii* has insecticidal and larvacidal properties and members of the Laurel family are well known for their medicinal properties.

Introduction

General introduction

Three indigenous woods – *Spirostachys africana* (tamboti), *Sclerocroton integerrimus* (duiker-berry) and *Shirakiopsis elliptica* (jumping-seed tree) – were tentatively identified from charcoal recovered from archaeological deposits at the rock shelter Sibudu. The anatomy of charcoal reference material was compared with that of the recovered charcoal in order to confidently identify these taxa in the archaeological charcoal. The identification of these woods in the Middle Stone Age at Sibudu is significant because *Spirostachys africana* is particularly poisonous. *Spirostachys africana* Sond., *Sclerocroton integerrimus* Hochst. (=*Sapium integerrimum* (Hochst.) J.Léonard) and *Shirakiopsis elliptica* (Hochst.) Esser (=*Sapium ellipticum* (Hochst.) Pax) are members of the family Euphorbiaceae, subfamily Euphorbioideae, tribe Hippomaneae A.Juss. ex Bartl. and subtribe Hippomaninae.[1]

Sibudu

Sibudu is situated on the uThongathi River, KwaZulu-Natal. It has a sequence of archaeological layers from the Middle Stone Age, dated by single-grain optically stimulated luminescence to approximately 77–38 ka.[2-6] Some of the evidence for the behaviour of the anatomically modern people who visited and lived at Sibudu includes stone tools, ochre, bone, perforated seashells and hearths[7-15], as well as evidence for the making and use of compound adhesives[16], and circumstantial evidence for snares[17] and bows and arrows[18]. There is evidence of the use of plant resources from pollen, phytoliths, seeds, nutlets, stems, charcoal and leaves excavated at Sibudu.[2,19-27]

The relevance of identifying *Spirostachys africana*

The presence of charcoal at Sibudu implies that people who visited and occupied the site burned wood.[2,4,5]

Spirostachys africana charcoal was tentatively identified from Sibudu in a previous study.[20,21] Nowadays, the wood from this tree is not used as fuel for cooking because the smoke and fumes are poisonous.[28] People who live in a particular environment for long periods develop knowledge about local resources[2,14,25,29] and the *Spirostachys africana* wood was almost certainly recognised for its toxic properties and utilised by ancient hunter–gatherers[14]. Therefore a secure identification of the archaeological charcoal is necessary in order to interpret behavioural strategies in the past.

Sclerocroton integerrimus wood anatomy is similar to that of *Spirostachys africana*.[1,20,30] Both were recorded as *Spirostachys*/*Sapium* in the scanning electron microscopy (SEM) study of charcoal from Sibudu,[20,21] so it is important to try to distinguish between the two taxa. *Shirakiopsis elliptica* wood anatomy is also similar.[1,31] As it was not in the original charcoal reference collection for Sibudu,[20] new fresh material was gathered, charred and studied.

Anthracology

Archaeological charcoal is identified by means of wood anatomy[32-35] to describe palaeoenvironments and palaeoclimate and to develop an understanding of past wood use[36-38]. Anatomical features of living or fresh woods, listed by the International Association of Wood Anatomists, accessed on InsideWood, an online database[39], can

assist with charcoal identification[34,35,40] but charred reference material is more useful[41-43]. Woody taxa have been identified from charcoal assemblages from many sites elsewhere in southern Africa; a few examples are Diepkloof Rock Shelter[44] and Elands Bay Cave in the Western Cape[45] and from sites in Lesotho[46,47].

Habits, habitats and uses of the three woods

Spirostachys africana is a medium-sized, hardwood, deciduous tree, 10–18 m tall, and grows in woodland and valley bushveld. Often found in dense stands; in warm, dry areas along rivers and drainage lines; in poorly drained brackish and clay soils; or near underground water, tambotie is distributed from KwaZulu-Natal to Tanzania.[48] *Sclerocroton integerrimus* is a small- to medium-sized, hardwood, deciduous tree, 2–10 m tall, and grows in coastal thicket, on forest margins and in wooded grassland.[48] *Shirakiopsis elliptica* is a medium to tall, softwood, deciduous tree, 12–20 m tall. It grows in wooded ravines and is common at the canopy edge of evergreen forests and as a canopy tree in swamp forests.[48] The timber of the three trees is similar.[49]

The bark, wood, stems and leaves of *Spirostachys africana* contain poisonous milky latex[28] which is used as a purgative in small doses[50]. This fish and arrow poison causes conjunctivitis when in contact with the eyes[28] and urticaria and blistering when in contact with the skin[28]. A triterpenoid (C_{30}) isolated from the bark showed significant inhibition of the bacteria *Staphylococcus aureus, Salmonella typhi, Vibrio cholera, Escherichia coli* and *Shigella dysenteriae*, explaining the traditional use in several African countries against diarrhoea and dysentery.[50-55] Cytotoxic and genotoxic activities have been reported.[28,52]

The cytotoxins in latex are phorbol esters, which are terpenoids.[28,54] *Spirostachys africana* is classified as an extremely hazardous Class IA cellular poison according to the four toxicity classes recognised by the World Health Organization. This measure of poisoning is based on an LD_{50} determination in rats, that is, less than 5 mg of plant material ingested per kilogram body mass killed 50% of the population.[28] (Poisons kill in minute amounts, toxins are less toxic than poisons and toxicants are toxic in high concentrations only.[50]) Phorbol esters affect mucous membranes in the skin and the alimentary tract.[28] The latex and bark have antimicrobial, anthelminthic and larvacidal properties and are effective against ailments of the digestive tract, skin, reproductive system and respiratory tract.[50-55]

Spirostachys africana wood is hard and heavy with a beautiful close grain coppery brown colour, impervious to insect attack and weathering.[48] When burned, the wood gives off a sweet odour, which can cause headaches, nausea and diarrhoea.[28,55] The Venda use *Spirostachys africana* smoke to fumigate their huts against wood-boring and other insects (Anonymous reviewer, 2014, written communication of personal observation, July 03).

Sclerocroton integerrimus has clear latex which is suspected of being poisonous and is used as a mouthwash to relieve toothache and coughs.[56] Fruit is used to make ink and as a source of tannin. Fallen fruit and leaves are eaten by antelope and stock animals.[48]

Shirakiopsis elliptica is considered very poisonous and is used as a drastic purgative in West Africa.[57] The rough bark has sparse, scattered depressions and clear latex. Bark latex is added to arrow poison, *ouabain*, from the East African *Acokanthera schimperi* and is used as bird lime and for body markings.[57] *Acokanthera oppositifolia* (Bushman's poison), distributed along eastern and northern parts of South Africa, is amongst the *Acokanthera* species which are known to be sources of extremely toxic arrow poisons.[28] Various parts of the *Shirakiopsis elliptica* tree are used in folk medicine in Africa, in dermatology and gastroenterology, particularly as an anthelminthic.[57]

Wood anatomy

A detailed study of the wood anatomy of *Spirostachys africana*, *Sclerocroton integerrimus* and *Shirakiopsis elliptica* has been done to distinguish among these taxa and to clearly identify *Spirostachys africana* in charcoal from Sibudu. Modern reference material was collected specifically for this project, charred in a furnace and supplemented with data from InsideWood and the literature. As outlined below, the three woods share similar features but there are several useful distinguishing characteristics.

Methods

Material

Comparative reference collection

A wood sample of *Spirostachys africana* from a Southern African Forestry Department woodblock stored in the Department of Archaeology, University of the Witwatersrand, was carbonised and studied as a reference of anatomical features (SJL 103; Table 1, Figure 1a–c). Inferred archaeological *Spirostachys africana* charcoal from Ndondondwane Iron Age site[58] in KwaZulu-Natal was used as intermediate reference material (NDO; Table 1, Figure 1d). Reference wood samples and voucher herbarium specimens of *Sclerocroton integerrimus* (SJL 88, Figure 1e) and *Shirakiopsis elliptica* (SJL 67, Figure 1f) were identified by local botanists and were collected *ex hort* in Durban and on a farm near Port Edward, KwaZulu-Natal (coordinates 31.04615°S, 30.16886°E) for a study of anatomical features (Table 1).

Archaeological specimens

Sibudu archaeological charcoal was examined from squares of occupational layer Spotty Camel (SPCA), which has not been dated but lies between layers with ages of 61.3 ± 2.0 ka and 56.2 ±1.9 ka, and from Mottled Deposit (MOD) at approximately 49.7 ± 1.8 ka.[1,3-6] These layers were chosen because *Spirostachys*/*Sapium* charcoal was previously recorded from them by Allott[20,21].

Methods

Reference woodblocks were charred in a LENTON 0861 muffle furnace (Lenton, Hope, UK) for 3.5 h at 350 °C at the Palaeosciences Centre, University of the Witwatersrand. Archaeological charcoal was identified by comparing it with reference material, using standard techniques.[20,21,41-43] Charcoal blocks were viewed from three planes by means of stereomicroscopy (Olympus SZX16, Münster, Germany) and reflective and polarised light microscopy (Olympus BX51) at magnifications of 100x, 200x and 500x. Characteristic anatomy was digitally photographed using Olympus Stream Essentials® image analysis software with extended focal image capability. Anatomical features according to the International Association of Wood Anatomists' list[35,39] were recorded for the comparative reference material and archaeological specimens. Identifications were also confirmed against published reference material.[1,32,33,39,49]

Useful distinguishing features

Prismatic crystals occur in *Spirostachys africana* ray and parenchyma cells, whereas silica bodies are absent in this species.[1,30,59] Silica bodies occur in *Sclerocroton integerrimus*[2,60] and *Shirakiopsis elliptica*[1,31] ray cells, whereas crystals are absent from ray cells[40]. Crystals are occasionally visible in the parenchyma cells of *Sclerocroton* and *Shirakiopsis*.[2]

Prismatic crystals are not common in wood anatomy and their occurrence may be sporadic.[35] Features such as crystals and silica bodies are therefore useful attributes and are listed as an anatomical feature when commonly observed. Prismatic crystals are solitary, rhombohedral or octahedral crystals of calcium oxalate which are birefringent (produce a rainbow effect) under polarised light[35] and appear shiny in charcoal specimens.

Silica bodies are spheroidal or irregularly shaped particles of silicon dioxide which are non-birefringent (do not produce a rainbow effect) under polarised light[35] and appear opaque. Silica is present in ray cells in African *Sapium* species in aggregates, which often fill the entire cell lumen, or as grains or small dark dots in Asian *Sapium* species such as

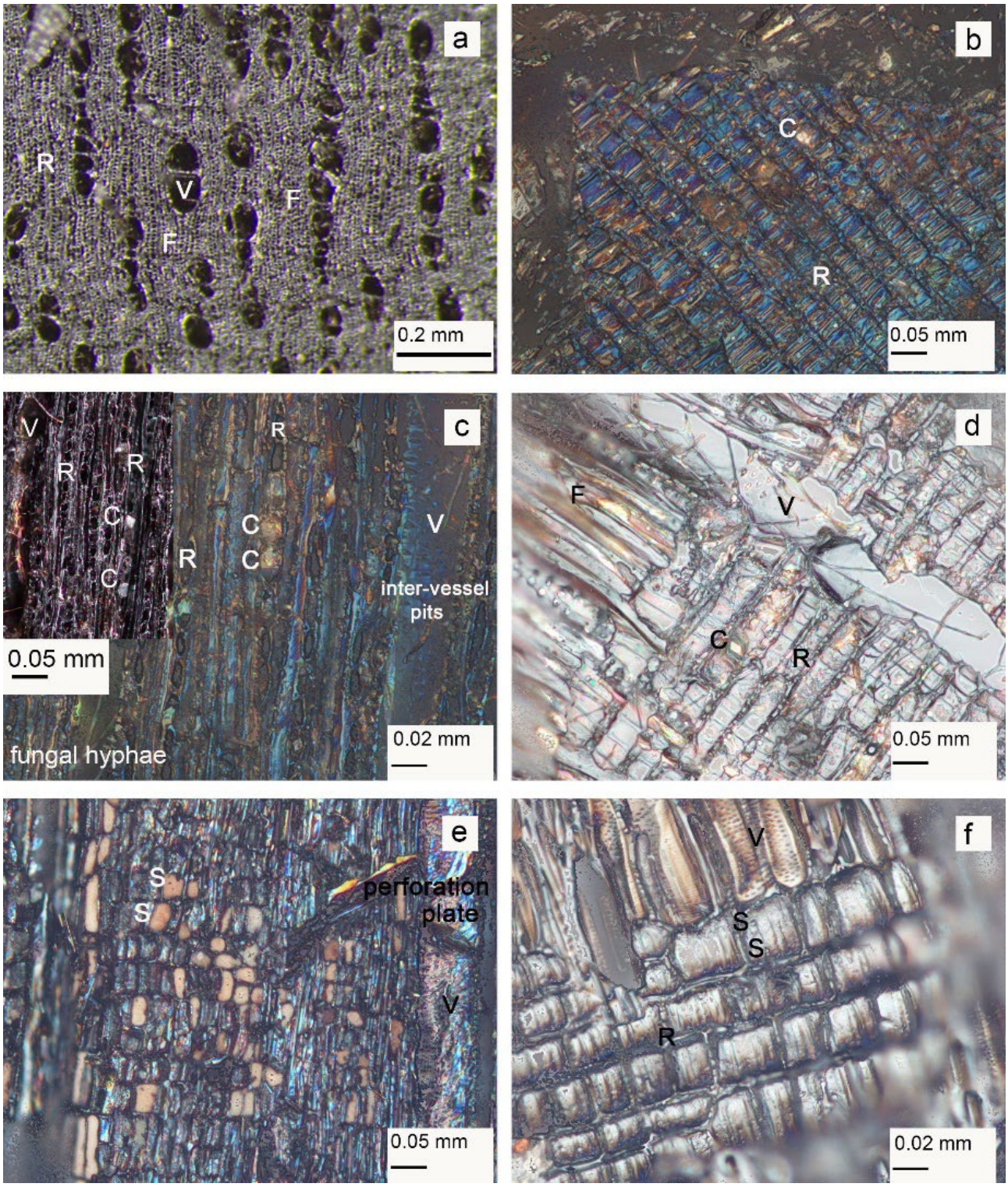

Figure 1: Diagnostic characteristics of charcoal reference material: (a–c) *Spirostachys africana* (SJL 103), (d) *Spirostachys africana* (NDO), (e) S*clerocroton integerrimus* (SJL 88) and (f) *Shirakiopsis elliptica* (SJL 67). (a) In transverse section, *Spirostachys africana* has many small vessels (V) in long lines. Vessels are occasionally in pairs. The shiny cell contents may be resin[2] or gum[30]. These fibres (F) are thin-walled and regular. (b) The radial longitudinal section has crystals labelled (C) in the ray cells, which shine under polarised light. Ray cells (R) are mixed; the procumbent cells are as high as the square cells and occasionally there are upright cells in the margins. The rays are low. (c) The tangential longitudinal section has frequent, uniseriate rays. The prismatic crystals of calcium oxalate in ray cells which distinguish *Spirostachys* shine under polarised light. Vessels with alternate inter-vessel pits occur and the vessel walls are birefringent under polarised light. The insert shows these ray crystals at a lower magnification. (d) Inferred *Spirostachys africana* reference material from Ndondondwane, KwaZulu-Natal (NDO) has prismatic, rhombic, crystals in the ray cells which shine under non-polarised light, in radial longitudinal section. (e) In S*clerocroton integerrimus* reference material, SJL 88, there are silica bodies labelled (S) in the ray cells. These are spheroidal or irregularly shaped particles which are opaque under polarised light. The ray cells are heterocellular, mixed procumbent, square and upright in radial longitudinal section. The cell walls of the vessels, rays and fibres are birefringent in polarised light. (f) In *Shirakiopsis elliptica* reference material, SJL 67, the silica bodies (S) in ray cells are granular, dark spots. Rays are heterocellular with upright and square cells seen in radial longitudinal section. These inter-vessel pits are alternate.

Sapium luzonicum.[40] The arrangement (aggregated, irregularly shaped or globular) or surface (smooth or verrucose) may be diagnostic in certain groups and needs to be recorded in a description.[35]

Results and discussion

Figure 1 illustrates reference charcoal of the three taxa. Figure 1d, *Spirostachys africana* (NDO), is of archaeological charcoal and is therefore an interpreted identification. Figure 2 illustrates the identified archaeological charcoal from Sibudu. Table 1 summarises the charcoal anatomy of the modern reference and archaeological material. Table 2 lists the most useful diagnostic features for identifying the three species, the environmental conditions required by the trees and the medicinal and other uses for their wood.

Table 1: The anatomical features of modern and archaeological charcoal specimens of *Spirostachys africana, Sclerocroton integerrimus* and *Shirakiopsis elliptica*

Plant species	Charcoal specimen	Vessel radials	Vessel diameter	Vessel frequency	Ray width in cells	Heterocellular ray body cells	Ray marginal cells	Parenchyma	Ray crystals or silica bodies
Spirostachys africana	SJL 103	l	s	a	1	p,s,u	–	da	c
	NDO	l	s	a	1	p,s,u	–	da	c
	MOD C6a 39	l	s	a	1	p,s,u	(s)	d	c
	SPCA D5c 51	l	s	a	1	p,s,u	(s)	d	c
	SPCA B4b 62	l	s	m	1	p,s,u	–	d	c
	SPCA B4b 67	l	s	m	1	p,s,u	–	d	c
Sclerocroton integerrimus	SJL 88	s	m	m	1	p,s,u	–	da	s
	MOD E3d 08	s	m	m	1	p,s	(u)	d	s
	SPCA B4b 65	l	m	m	1	p,s	–	d	s
	SPCA B4b 66	l	m	m	1	p,s,u	–	d	s
	SPCA B4c 07	l	m	m	1	s,u	–	d	s
	SPCA B4c 14	l	m	m	1(–2)	s,u	–	d	s
	SPCA D5a 27	l	m	m	1	s,u	–	d	s
Shirakiopsis elliptica	SJL 67	s	l	f	1(–2)	s,u	–	d	s
	MOD C6a 46	s	m	m	1(–2)	p,s	u	dc	s
	SPCA B4c 45	s	m	m	1(–2)	p,s	u	d	s

Notes:

Vessel radials: short (s), 1–3 vessels; or long (l), >4 vessels

Vessel diameter: small (s), <50 μm; medium (m), 50–100 μm; large (l), 100–200 μm

Vessel frequency: few (f), 5–20 per mm²; medium (m), 20–40 per mm²; abundant (a), 40–100 per mm²

Heterocellular ray body cells: procumbent (p); square (s); upright (u)

Ray marginal cells: square (s); upright (u); (bracketed = occasional)

Parenchyma: diffuse (d) or diffuse-in-aggregate (da); crystals (c)

Ray crystals (c) or silica bodies (s)

Attributes common to Spirostachys, Sclerocroton *and* Shirakiopsis

Vessels are commonly arranged in long, radial multiples ($\geq$4). Perforation plates are simple. Inter-vessel pits are alternate and polygonal; medium (8–10 μm) in *Spirostachys africana* [1,30,49], medium to large (8–10 μm to 11–16 μm) in *Sclerocroton integerrimus*[60] and large (11–16 μm) in *Shirakiopsis elliptica*[31]. Vessel-ray pits are bordered and similar to inter-vessel pits in size and shape in *Spirostachys africana* and *Shirakiopsis elliptica;* rounded or angular, with much reduced borders, in *Sclerocroton integerrimus*. Fibres are non-septate, with simple to minutely bordered pits. Fibres are short in *Spirostachys africana*; in *Sclerocroton integerrimus,* they are medium length and regularly arranged. *Shirakiopsis elliptica* fibre length varies from short to long (Figure 1).

Diffuse parenchyma occurs in *Spirostachys africana.* Parenchyma which is diffuse-in-aggregate (SJL 103, Figure 1a), or in narrow bands or lines which are up to three cells wide, may be observed as a variation.[1,30,49] Parenchyma which is diffuse or diffuse-in-aggregate is difficult to see. In *Sclerocroton integerrimus* parenchyma is diffuse-in-aggregate and/or there are narrow bands or lines up to three cells wide.[60] *Shirakiopsis elliptica* parenchyma is diffuse and/or diffuse-in-aggregate, with the variation of occasionally occurring in narrow bands or lines up to three cells wide.[31] Axial parenchyma strand length is either 4 or 8 cells per parenchyma strand in all three woody taxa.

Rays are exclusively uniseriate, commonly heterocellular, with procumbent, square and upright cells mixed throughout the ray (SJL88, Figure 1e), although this pattern varies within and between the three woody taxa (Table 1; SJL 103, Figures 1a–c; NDO, Figure 1d). *Shirakiopsis elliptica* reference charcoal ray cells are upright and square (SJL 67, Figure 1f). Very long rays occasionally occur in *Shirakiopsis elliptica* where two rays meet end to end, and are visible in both reference material (SJL 67) and archaeological material (SPCA B4c 45).[1,31,40]

Rays are frequent, with up to 12 observed per millimetre. Laticifers – thin, radial tubes carrying latex which occasionally occur in Euphorbiaceae wood – were absent from the charcoal examined.[1,35]

Distinguishing attributes of reference material

The charcoal of the three species differs in vessel size and frequency as well as in the presence or absence of crystals or silica bodies in ray cells. The differences in vessel size and pattern among the wood of the three species are recorded in a photographic study of endgrain woodblocks of Euphorbiaceae.[49]

Spirostachys africana has several to many, small to medium vessels in long radial lines.[1,30,49] Charcoal reference, SJL 103, (Figure 1) and interpreted reference material, NDO, vessels are narrow (30–50 μm), at a frequency of between 40–100 vessels per mm² (an average of 80/mm²) and vessels are arranged in long radial lines (radial multiples $\geq$ 4). The prismatic crystals in ray cells are birefringent, appearing shiny under reflected polarised light. Shape may vary in different material, from clearly rhombic in the archaeological specimen – which is an interpreted reference for *Spirostachys africana* (NDO in Figure 1d) – to irregular but shiny in the modern wood forestry block reference material (SJL 103 in Figure 1b and 1c). Crystals are visible in the SEM images recorded by Allott[20]. Silica bodies are absent from ray cells. The vessel inclusions are either resin[1] or gum[30]. Resin occurs in the heartwood.[1] Similar comparative images of *Spirostachys africana* have been recorded by Allott[20], Ilic[32] and Kromhout[33].

Sclerocroton integerrimus has few, medium to large vessels in radial lines.[1,60] Charcoal reference material, SJL 88, vessels are narrower than 100 μm, at a frequency of 20–40 vessels per mm², and are arranged in short radial lines of two to four vessels. The silica bodies are non-birefringent and opaque under polarised light (SJL 88, Figure 1e).[35] The silica bodies present in ray cells are spheroidal, irregularly shaped particles[35] arranged in aggregates which often fill the entire cell lumen[40]. These silica bodies are visible in the SEM images recorded by Allott[20]. Prismatic crystals are absent from ray cells.

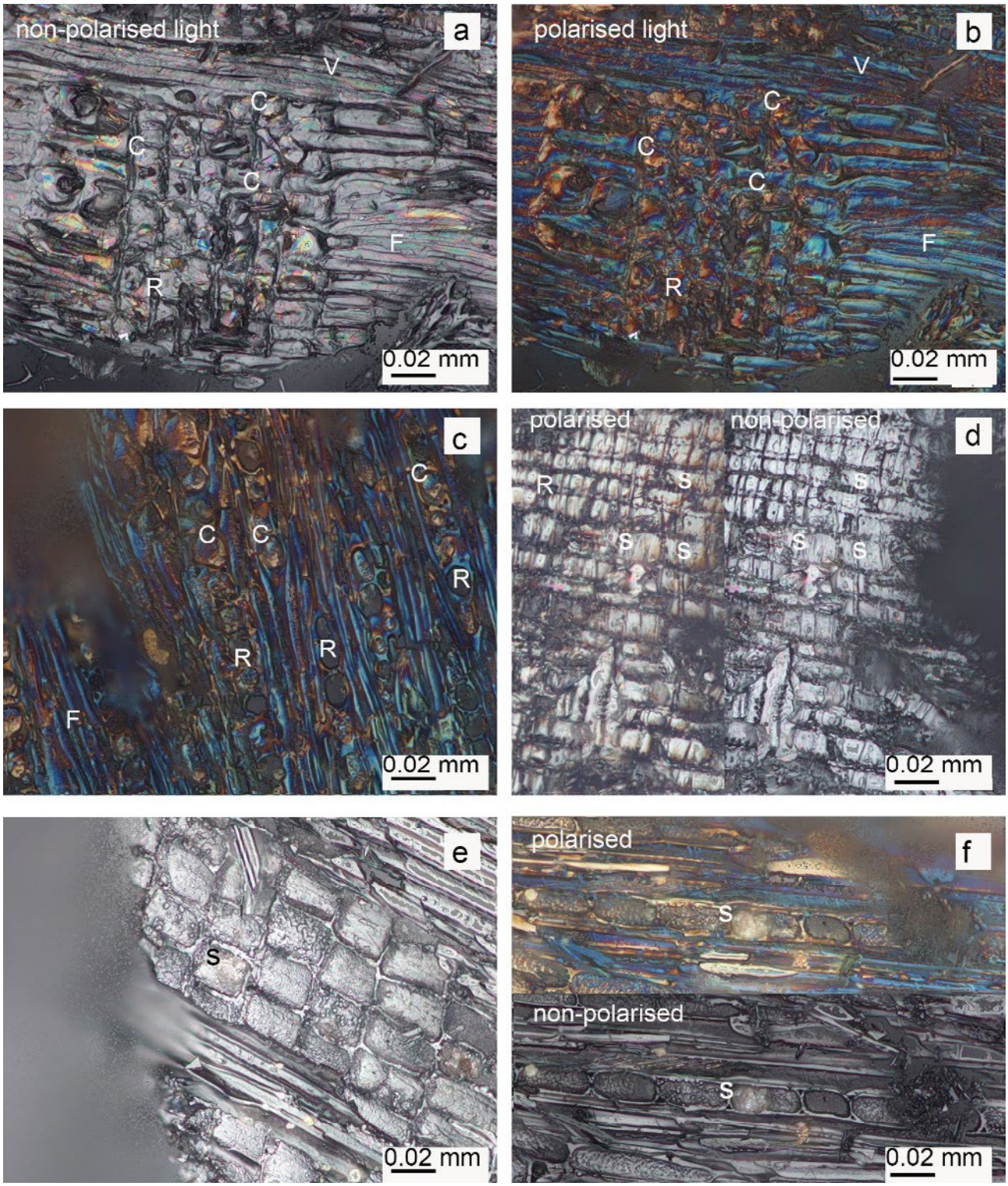

Figure 2: Diagnostic characteristics of archaeological charcoal: (a–c) *Spirostachys africana,* (d) *Shirakiopsis elliptica* and (e,f) *Sclerocroton integerrimus.* (a) In *Spirostachys africana*, SPCA B4b 62, there are prismatic crystals (C) in the procumbent ray cells (R), under non-polarised light. (b) These appear shiny under polarised light in radial longitudinal section, matching those of the *Spirostachys africana* SJL 103 reference material. The vessel (V), fibre (F) and ray cell (R) walls are also birefringent under polarised light. (c) In *Spirostachys africana,* SPCA D5c 51, tangential longitudinal section, the ray cell walls are cut away and the crystals underneath are present and shiny, matching those of the *Spirostachys africana* SJL 103 reference material when magnified 500x. (d) In *Shirakiopsis elliptica* archaeological material, MOD C6a 46, silica bodies (S) are present as grains and dots in ray cells and appear opaque under both polarised and non-polarised light. Rays are heterocellular, with mixed upright, square and procumbent cells, in radial longitudinal section. (e) In *Sclerocroton integerrimus* archaeological charcoal, SPCA B4b 66, the silica bodies in the ray cells are spheroidal or irregularly shaped and opaque in non-polarised light in radial longitudinal section and in both polarised (f) and non-polarised light in tangential longitudinal section.

Shirakiopsis elliptica has very few, large to very large vessels in radial lines.[1,31] Charcoal reference material, SJL 67, (Figure 1f) vessels are wider than 100 μm, at a frequency of fewer than 10 vessels per mm^2, and are arranged in short radial lines. Silica bodies occur as grains or small dark dots in Asian *Sapium* species.[41] In our reference material, the silica bodies are inconspicuous, prismatic crystals are absent from ray cells with occasional crystals observed in the parenchyma and tyloses commonly occurring in vessels.[1,31]

Spirostachys *and* Sclerocroton *archaeological charcoal*

Spirostachys africana was identified in charcoal from Sibudu from MOD square C6a and from SPCA squares B4b and D5c. Specimens MOD C6a 39 and SPCA 62 have as many as 110 vessels per mm^2, small (20–30 μm) to medium (50–100 μm) in size and arranged in radial multiples $\geq$4 (long radial lines); rays are uniseriate, frequent and heterocellular, with mixed procumbent, square, upright cells. Prismatic crystals occur in ray cells and shine under polarised light (Figure 2a–c).

Sclerocroton integerrimus charcoal was identified from MOD square E3d and from SPCA squares B4b, B4c and D5a. Few (30–50 vessels per mm^2), medium-sized (50–100 μm) vessels occur in radial multiples $\geq$4. Silica bodies occur as aggregates which partially fill the ray cell lumen and are opaque under both non-polarised as well as polarised light (SPCA B4b 66; Figure 2e). Variation was observed in vessel arrangement and ray cell pattern (Table 1).[1,60]

Shirakiopsis elliptica charcoal was identified from MOD square C6a. Specimen MOD C6a 46 has many (40 vessels per mm^2), medium ($\pm$50 μm) vessels in radial lines. Specimen SPCA B4c 45 has as many as 50 large (100-μm) vessels per mm^2. Occasionally two uniseriate rays meet, forming rays which are jointly longer than 1 mm. Silica bodies in ray cells appear as inconspicuous grains or small, dark dots (MOD C6a 46; Figure 2). The diffuse parenchyma occasionally contains crystals.[1]

Summary of the characteristic diagnostic features of each species

The detailed anatomical study of reference material enables the identification of these taxa based on the occurrence of crystals in *Spirostachys africana* and silica bodies in *Sclerocroton integerrimus* and *Shirakiopsis elliptica* ray cells[1] as well as on vessel size classes and frequency of vessels. These diagnostic characteristics are compared in Table 2.

The vessel size of *Spirostachys, Sclerocroton* and *Shirakiopsis* increases proportionally as vessel frequency decreases, from *Spirostachys africana*, with the smallest and most numerous vessels, to *Sclerocroton integerrimus*, then to *Shirakiopsis elliptica* with the largest and fewest vessels.

A comparison of anatomical features

No clear differentiation in anatomical features among these three taxa under investigation could be found, thus necessitating this study. There is some variation in vessel width and frequency, ray cell type, the absence or presence of tyloses in vessels, of laticifers in rays and of gum or resin deposits in vessels among different published accounts.[1,30,31,33,49,59]

Relative abundance of crystals may vary. As wood is inherently variable, some features are well defined in some samples, but poorly defined or absent in other samples of the same species.[35] There are no quantitative criteria for 'common' in the list of the International Association of Wood Anatomists. Comments on relative frequency are therefore added to descriptions.[35]

The crystals of calcium oxalate are birefringent under polarised light; however, some cell walls, especially lignified cell walls, are also birefringent (Anonymous reviewer, 2014, personal observation, written communication, July 03). Structures such as xylem vessels with birefringent cell walls have a rainbow sheen in the reference material (SJL 103) and in the inferred reference material (NDO). Birefringent crystals are visible in *Spirostachys africana* reference material in the

Table 2: Comparing the wood anatomy, environment and uses of *Spirostachys, Sclerocroton and Shirakiopsis* (Euphorbiaceae)

	***Spirostachys africana*[2,30,59]**	***Sclerocroton integerrimus*[2,60]**	***Shirakiopsis elliptica*[2,31]**
Wood anatomy: vessel size and frequency, cell inclusions	Small to medium vessels, 50–100 μm wide Several (20–40/mm^2) to many (40–100/mm^2) vessels	Medium (50–100 μm wide) to large (100–200 μm wide) vessels Few vessels, 5–20/mm^2	Large (100–200 μm wide) to very large ($\geq$200 μm wide) vessels Very few vessels, <5/mm^2
	Prismatic crystals are present in ray cells. Parenchyma may contain prismatic crystals.	Silica bodies are present in ray cells. Parenchyma may contain prismatic crystals.	Silica bodies are present in ray cells. Parenchyma may contain prismatic crystals.
Timber	The hard, heavy wood has contrasting light sap wood and dark heartwood, with an attractive lustre when polished and has therefore been used as a replacement for sandalwood. It is used in furniture, for staves, beads and bangles and in construction as rafters. The sawdust is poisonous, as is the wood if burnt for fuel, causing conjunctivitis, nausea and food poisoning.[28,55]	The hard, durable wood is used as timber for general purposes, in construction and for furniture.[56]	The tough, soft, light, white wood is used to make instruments, burnt as firewood and charcoal, but not used as rafters when used in construction as it is susceptible to insects.[57]
Phytochemistry and uses	Phorbol esters (terpenoids) classify latex in bark, wood, stems and leaves as an extremely hazardous, Class 1a, cellular poison (LD_{50} =5 mg/kg).[28,50,61] Isolated terpenoids have antibacterial properties.[28] A very drastic purgative, the bark and milky latex are used to treat alimentary tract infections. Latex is used to treat tooth decay and eye infections. Used as fish and arrow poison, latex causes conjunctivitis, or a severe contact dermatitis. Bark is used for skin ailments, and headaches. The fragrant woodblocks are an insect repellent.[62] Smoke is inhaled for treatment of respiratory infections.[28,55]	Toxic tetracyclic triterpenic cucurbitacins have been extracted from root bark of *Sclerocroton cornutus* from West and Central Africa.[56] Suspected of being poisonous, the clear latex is used as an antiseptic against toothache and coughs. The fruits were formerly used to make a black ink and are used for tanning.[56]	Tannins and alkaloids have been extracted from the whole plant. Bark extracts have moderate antimicrobial activity against *Campylobacter jejuni* which causes food poisoning.[57] Considered very poisonous and a very drastic purgative, the clear latex is added to arrow poison and used as bird lime.[57]

tangential longitudinal section in which the cell walls are cut away. The outline of these crystals is visible, differentiating these crystals from ray cell walls in the radial longitudinal section. Under non-polarised light, the crystals in the inferred reference material match those seen in SJL 103 and those usually seen in wood[35] and charcoal[44]. The crystals seen in archaeological specimens of *Spirostachys africana* match those found in reference material SJL 103 ray cells observed in radial and tangential longitudinal sections at high magnification.

The *Spirostachys africana* crystals are magnified to 500x the original size and they are clearly visible. In SEM studies of charcoal, energy dispersive x-ray spectrometry analysis capabilities may be used to distinguish between crystals of calcium oxalate and silica, such as the crystals found in *Searsia undulata* (Namaqua kuni-bush), *Cassine peragua* (spoon-wood) and *Gymnosporia buxifolia* (spike-thorn) from archaeological charcoal at Diepkloof Rock Shelter.[44]

The variation in anatomical features between the charcoal and fresh wood or between charcoal made from modern wood and archaeological charcoal are because of the natural variation occurring in biological material affected by the sample origin (twig or trunk) or habitat.[49] Quantitative variation may be a result of the shrinkage and distortion which occurs during the formation of charcoal.[36,38]

We have supplemented the charcoal wood anatomy descriptions with those from fresh woods from the InsideWood database as more detail usually is visible in fresh wood. Comparative sizes rather than measurements are used in anthracology because the anatomy may be distorted by shrinkage, vitrification, diagenesis, and fragmentation and powdering.[36,38,41]

Conclusion

The charcoal anatomy of *Spirostachys africana, Sclerocroton integerrimus* and *Shirakiopsis elliptica* enables these species to be distinguished by vessel arrangement, size and frequency, as well as by the presence or absence of crystals or silica bodies in ray cells.

Spirostachys africana has narrow, frequent vessels; prismatic crystals are present in ray cells. *Sclerocroton integerrimus* has wider, less frequent vessels. Of the three species under comparison, *Shirakiopsis elliptica* has the widest and least frequent vessels. Silica bodies are present in ray cells of *Sclerocroton integerrimus* and in *Shirakiopsis elliptica* as small grains and dots while prismatic crystals are absent from ray cells. The silica bodies of *Sclerocroton integerrimus* are aggregates of irregularly shaped silicon dioxide particles which often fill the entire cell lumen and appear opaque under polarised light. The silica bodies of *Shirakiopsis elliptica* appear as grains or small, dark dots.

Spirostachys africana was identified amongst hearth charcoal of the SPCA layer in squares B4b and D5c, with an age of approximately 58 ka; and in charcoal of the MOD layer in square C6a, with an age of approximately 49 ka. This find confirmed the use of *Spirostachys africana* wood at Sibudu rock shelter. *Sclerocroton integerrimus* charcoal occurred in SPCA in squares B4b, B4c and D5a and in MOD in square E3d. *Shirakiopsis elliptica* charcoal was found in SPCA B4c and in MOD in square C6a.

Sclerocroton integerrimus, Shirakiopsis elliptica and poisonous *Spirostachys africana* wood was deliberately burned by people at Sibudu who utilised natural resources. *Sclerocroton integerrimus* timber is a hard, heavy, durable wood. *Shirakiopsis elliptica* timber is soft, light, and suitable for making implements. *Spirostachys africana* wood is a hard, durable wood, with poisonous properties.

Many of the present day uses of these woods were not applicable during the Middle Stone Age, but these species may have been selected for making wooden implements and for firewood. *Spirostachys africana* wood is a skin irritant and it seems unlikely that this wood would have been worked by hand to make implements. Nor does it seem likely that the poisonous wood was used for domestic fires to cook food. It seems more likely that *Spirostachys* was deliberately selected for its toxic or insecticidal properties, perhaps so that its smoke would fumigate insects from the camp in Sibudu.

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Authors' contributions

S.J.L. was responsible for the experimental work and wrote the manuscript; M.K.B. supervised the research, helped with charcoal identification and assisted with writing the manuscript.

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Distribution and severity of bacterial brown spot on dry beans in South Africa: An update

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Bacterial brown spot (BBS) of common bean (*Phaseolus vulgaris*) is a seed-borne bacterial disease caused by *Pseudomonas syringae* pv. *syringae* (*Pss*). Dry bean is an important field crop in South Africa and all commercially available South African dry bean cultivars are susceptible to BBS. The aim of this study was to determine the current distribution and severity of BBS in the dry bean production areas of South Africa. We surveyed 31 locations in five provinces. Disease severity was evaluated on selected plots on a 0–9 scale in four different farming systems: commercial and subsistence farms and strip and national cultivar trials. Leaves with typical BBS symptoms were harvested and transferred to the laboratory. Bacteria were isolated following standard procedure using King's B medium. Identification of pure isolates was done using physiological and biochemical techniques. Incidence and severity values were used to calculate a disease index. BBS was observed in 88% of locations. BBS incidence was recorded in 54% to 100% of all the farming systems surveyed during the 2008/2009 and 2010/2011 seasons combined. BBS was more severe in the strip and national cultivar trials than on subsistence and commercial farms during the 2008/2009 season and more severe on the commercial farm and in national cultivar trials than on subsistence farms and strip trials during the 2010/2011 season. Findings of this study signal the importance of developing BBS-resistant dry bean cultivars for South Africa.

Introduction

Bacterial brown spot (BBS), caused by *Pseudomonas syringae* pv. *syringae* (*Pss*), Van Hall, is an important bacterial disease of common bean (*Phaseolus vulgaris* L.) globally, including in South Africa.[1-3] The disease is seed-borne and mainly infects foliage and to a lesser extent pods. It is prevalent where dry bean monocropping is practised and spreads through seed transmission, wind and human movement from infected to uninfected areas.[4] *Pss* has a wide host range, infecting more than 180 host plant species including woody plants and weeds.[5-7]

On common bean leaves, BBS symptoms may first appear as water-soaked spots, which gradually enlarge and dry up, and are often surrounded by a narrow yellow or light green zone. Lesions may coalesce and occasionally abscise, subsequently giving the foliage a tattered appearance.[6] Water-soaked spots may also appear on infected pods as circular and initially water-soaked spots, later becoming darker green and sunken brown and necrotic, and causing the infected area to bend as a result of cessation of growth on young pods at the point of infection.[6] Occasionally, ring spots of lesions occur around a central lesion.[8] Infected seeds initially have water-soaked spots and later become brown and shrivelled when infection is severe.[9] Stem lesions appear when the pathogen develops systemically.[8] Sources of inoculum include seed and infected volunteer beans[10], weed hosts and plant debris[11,12].

Pss has been widely reported in the USA, Brazil and Canada.[1,11-13] The pathogen has also been reported in Algeria, Asia, Australia, Egypt, Europe, Ethiopia, Kenya, Lesotho, Malawi, Mauritius, Morocco, New Zealand, Tanzania, Tunisia, Uganda and Zimbabwe.[14,15] Although Melis[16] reported the incidence of BBS as being 'only occasional' in South Africa, the disease was first described in 1994[17] when 100% incidence on the cultivar Bonus was recorded. Subsequent reports indicated BBS incidences as high as 93% in seed production fields and 100% in commercial fields, although severities were generally low ($\leq$ 2 on a 1–9 scale).[2] The disease is more prevalent during the reproduction stage, gradually lessening as plants reach physiological maturity.

BBS epidemics are favoured by warm humid conditions (>95% RH, 28–32 °C) as well as thunderstorms and hail.[6,10] These conditions characterise the South African climate, especially in the central and eastern parts of the country, where dry beans are largely planted on commercial scale.

BBS management methods include the use of disease-free seed, application of copper-based fungicides, crop rotation, sanitation and avoiding working the field when wet.[6] Copper-based fungicides only serve as a preventative measure and some *Pss* populations are resistant to copper sprays.[18,19]

Yield losses of up to 55% associated with BBS have previously been reported in South Africa.[17] This loss remains a concern, mainly in commercial farming, because the crop has been reported as an important field crop on account of its nutritional composition[20] and it is a staple food in the eastern parts of the country. Commercial annual dry bean production averages 65 000 tonnes on approximately 50 000 hectares.[21] Crops are composed mainly of red speckled sugar (65–75%), small white canning (10–20%) and large white kidney beans (5–10%), and to a lesser extent of alubia (1–5%) and carioca beans (3–5%).[22] Red speckled sugar beans also dominate the composition of beans grown by subsistence farmers. Although previous surveys were conducted in 2002,[2] recent documentation on the incidence of BBS on dry bean production farms and in research trials of South Africa is not available. The objective of this study was to quantify the distribution and severity of BBS on commercial and subsistence farms, as well as in strip and national cultivar trials of South Africa. These trials are planted annually to determine the performances of cultivars in the main bean producing areas. The information obtained from this survey is required to justify the necessity to embark on a BBS-resistance breeding programme and the deployment of effective means of BBS control in dry bean fields.

Materials and methods

Disease surveys in commercial fields

Bacterial brown spot was surveyed in commercial dry bean fields from February to April during the 2008/2009 and 2010/2011 growing seasons to determine incidence and severity. A total of 32 fields at 20 localities (Table 1) was surveyed during flowering, early- and advanced-pod stages. The incidence of plants showing typical BBS symptoms was assessed in 10 randomly selected groups of 10 consecutive plants amounting to 100 plants/field. Incidence and severity values were used to calculate a disease index (D_I) using the model:

$$D_I = (I \times S)/M$$

where *I* is the incidence of diseased plants (%), *S* is the mean severity of foliar symptoms and *M* is the maximum severity value (i.e. 9).[23]

Disease surveys in strip trials

Three strip trials were surveyed in March during the 2008/2009 and 2010/2011 dry bean growing seasons to determine BBS incidence and severity (Table 2). For each cultivar, 10 randomly selected plants were assessed for incidence and severity and D_I was calculated as described above.

Disease surveys in the national cultivar trials

A total of 22 cultivar trials was surveyed for the incidence and severity of BBS at 12 localities during the 2008/2009 and 2010/2011 dry bean growing seasons (Table 3). The plants were evaluated as described above. Samples were collected from only severely infected plants.

Disease surveys on subsistence farms and home gardens

Bacterial brown spot surveys on subsistence farms and in home gardens were done at eight localities during the 2008/2009 and 2010/2011 seasons (Table 4). Incidence of plants showing typical BBS symptoms

Table 1: Occurrence of bacterial brown spot in dry bean commercial fields of South Africa

Location	Altitude† (m)	Season					
		2008/2009			2010/2011		
		I (%)	*S* (%)	D_I (%)	*I* (%)	*S* (%)	D_I (%)
KwaZulu-Natal							
Vryheid	1190	10	1	5.0	–	–	–
Free State							
Warden	1375	8	3	6.0	5	3	5.0
Estcort	1181	3	3	3.0	–	–	–
PetrusSteyn	–	3	2	3.0	4	2	2.7
Sterkfontein	1629	–	–	–	9	3	9.0
Reitz	1615	6	1	3.0	–	–	–
Mpumalanga							
Delmas	1571	5	1	2.5	9	1	4.5
Ermelo	1735	15	1	7.5	–	–	–
Ermelo West	1735	8	1	4.0	9	1	4.5
Middelburg	1447	9	1	4.5	5	1	5.0
Kriel	–	7	1	2.3	–	–	–
Arnot	–	5	2	3.3	–	–	–
Limpopo							
Levubu	961	4	1	4.0	–	–	–
North West							
Lichtenburg	1480	4	1	4.0	7	1	3.5
Ventersdorp	1450	–	–	–	7	1	3.5
Grootpan	1350	0	0	0	6	1	3.0
Rysmierbult	1350	7	1	7.0	–	–	–

†*Sources: altitude*[33-37]

–, location not surveyed for that season; D_I*, disease index (expressed as % infected leaves);* I*, incidence of diseased plants (expressed as % infected plants);* S*, mean severity of foliar symptoms (expressed as % infected leaf area).*

Disease severity was evaluated on a 1–9 scale, where 1=0% foliage affected, 3=2% foliage affected, 5=5% foliage affected, 7=10% foliage affected and 9=25% foliage affected.[24]

Table 2: Occurrence of bacterial brown spot in dry bean strip trials of South Africa

Location	Altitude† (m)	Season					
		2008/2009			2010/2011		
		I (%)	*S* (%)	D_I (%)	*I* (%)	*S* (%)	D_I (%)
KwaZulu-Natal							
Vryheid	1190	22	3	16.5	–	–	–
Mpumalanga							
Middelburg	1447	–	–	–	7	2	7.0
North West							
Grootpan	1350	–	–	–	0	0	0

†Sources: altitude[33-37]

–, location not surveyed for that season; D_I*, disease index (expressed as % infected leaves);* I*, incidence of diseased plants (expressed as % infected plants);* S*, mean severity of foliar symptoms (expressed as % infected leaf area).*

Disease severity was evaluated on a 1–9 scale, where 1=0% foliage affected, 3=2% foliage affected, 5=5% foliage affected, 7=10% foliage affected and 9=25% foliage affected.[24]

Table 3: Occurrence of bacterial brown spot in dry bean national cultivar trials of South Africa

Location	Altitude† (m)	Season					
		2008/2009			2010/2011		
		I (%)	*S* (%)	D_I (%)	*I* (%)	*S* (%)	D_I (%)
KwaZulu-Natal							
Cedara	1052	8	3	6.0	11	3	8.3
Free State							
Warden	1375	25	4	20.0	–	–	–
Fouriesburg	–	19	4	19.0	–	–	–
Sterkfontein	1629	–	–	–	15	3	11.3
Clocolan	1600	5	2	3.3	–	–	–
Ficksburg	1585	14	3	10.5	–	–	–
Mpumalanga							
Delmas	1571	16	3	12.0	14	3	14.0
Ermelo	1735	22	3	16.5	15	2	10.0
Ermelo West	1735	6	1	3	–	–	–
Bethal	1590	21	3	15.8	22	3	22.0
Middelburg	1447	–	–	–	12	2	8.0
North West							
Lichtenburg	1480	11	2	7.3	8	1	4.0
Ventersdorp	1450	–	–	–	7	2	4.7
Grootpan	1350	1	2	8.0	9	2	6.0
Rysmierbult	1350	15	1	7.5	–	–	–

†Sources: altitude[33-37]

–, location not surveyed for that season; D_I*, disease index (expressed as % infected leaves);* I*, incidence of diseased plants (expressed as % infected plants);* S*, mean severity of foliar symptoms (expressed as % infected leaf area).*

Disease severity was evaluated on a 1–9 scale, where 1=0% foliage affected, 3=2% foliage affected, 5=5% foliage affected, 7=10% foliage affected and 9=25% foliage affected.[24]

was assessed in 10 randomly selected plants in home gardens and per row in subsistence farming systems. Disease incidence and severity were evaluated as described above and the disease index was calculated.

Disease severity rating

Disease severity was evaluated on each plant using a modified 1 to 9 International Center for Tropical Agriculture scale, where 1=0% foliage affected, 3=2% foliage affected, 5=5% foliage affected, 7=10% foliage affected and 9=25% foliage affected.[24]

Isolation and identification of bacterial brown spot pathogen

A total of 378 diseased leaf samples were collected and used to isolate the BBS pathogen, *Pss*. Leaves were rinsed under running tap water for approximately 10 min, surface sterilised for 3 min in 3.5% sodium hypochlorite and rinsed twice in sterile water for 1 min at a time. Leaves were macerated in a droplet of sterile water and the macerate was streaked onto King's B agar.[25] Plates were incubated for 48–72 h at 25 °C.

Fluorescent colonies typical of *Pseudomonas* spp. were selected under UV light and incubated for 48 h on King's B medium for purification. Isolates were tested for oxidase (-) and levan production (+).[26] Carbon source utilisation of sucrose, mannitol, sorbitol and inositol was used to distinguish *Pss* from *P. syringae* pv. *phaseolicola* (*Psp*) isolates.[27] Isolates were subjected to the LOPAT test,[28] the analytical profile index 20E (bioMerieux, Marcy l'Etoile, France) and Biolog GN Microplate (Biolog, Hayward, CA, USA) analyses. Agglutination of *Pss*-specific antiserum antibody (Express Kit, NEOGEN Europe Ltd., Scotland, UK) confirmed the identity of isolates.

Results

Commercial fields

Results from surveys conducted in commercial fields are given in Table 1. The BBS incidence, severity and disease index on commercial farms ranged from 0% to 15%, 0% to 3%, and 0% to 7.5%, respectively, during the 2008/2009 dry bean growing season (Table 1). During the 2010/2011 dry bean growing season, BBS incidence, severity and index ranged from 4% to 9%, 1% to 3%, and 2.7% to 9%, respectively. The disease was most severe at Warden (3%) and Estcourt (3%) during the 2008/2009 season and at Warden (3%) and Sterkfontein (3%) during the 2010/2011 dry bean growing season. Generally, BBS occurred on 96% of commercial farms during the two seasons.

Strip trials

Results from surveys conducted in strip trials are given in Table 2. During the 2008/2009 dry bean growing season, one strip trial was surveyed, in which BBS incidence was 22%, severity 3% and the disease index was 16.5%. Two strip trials in two localities were surveyed during the 2010/2011 dry bean growing season in which BBS incidence ranged from 0% to 7%, severity from 0% to 2% and the index from 0% to 7%. Of the two seasons surveyed, the disease was most severe at Vryheid (3%) during the 2008/2009 season. BBS was not recorded in the strip trial surveyed in Grootpan. BBS occurred in 67% of strip trials during the two seasons.

National cultivar trials

Results from surveys conducted in national cultivar trials are given in Table 3. BBS incidence ranged from 1% to 25%, severity from 1% to 4%, and index from 3% to 20% during the 2008/2009 dry bean growing season in the national cultivar trials (Table 3). BBS incidence ranging from 7% to 22%, severity from 1% to 3% and index from 4% to 22% were recorded during the 2010/2011 dry bean growing season. BBS occurred in all the national cultivar trials surveyed over the two seasons. Disease severity was highest at Warden (4%) and Fouriesburg (4%) (2008/2009), followed by Cedara (3%), Sterkfontein (3%), Delmas (3%) and Bethal (3%) (2010/2011). BBS occurred in 100% of national cultivar trials during the two seasons.

Subsistence farms

Results from surveys conducted on subsistence farms are given in Table 4. BBS incidence, severity and index ranged from 0% to 7%, 0% to 2%, and 0% to 7%, respectively, during the 2008/2009 dry bean growing season. BBS incidence, severity and index ranged from 0% to 8%, 0% to 2%, and 0% to 8% during the 2010/2011 dry bean growing season. BBS was observed in up to 46% of subsistence farms. Ohrigstad (2%) and Mgwagwa (2%), respectively, had the highest disease severity during the

Table 4: Occurrence of bacterial brown spot in dry bean subsistence farms of South Africa

Location	Altitude† (m)	Season					
		2008/2009			2010/2011		
		I (%)	*S* (%)	D_I (%)	*I* (%)	*S* (%)	D_I (%)
KwaZulu-Natal							
Mpande	–	0	0	0	3	1	1.5
Ohrigstad	–	7	2	7.0	–	–	–
Mgwagwa	–	–	–	–	8	2	8.0
Limpopo							
Rabali	961	3	1	3.0	3	1	3.0
Matanda	961	0	0	0	0	0	0
Tshiombo	600	–	–	–	0	0	0
Sekororo	880	4	1	4.0	3	1	3.0
Vertilis	880	–	–	–	0	0	0
Maraxwe	600	0	0	0	–	–	–

†*Sources: altitude*[33-37]

–, location not surveyed for that season; D_I*, disease index (expressed as % infected leaves);* I*, incidence of diseased plants (expressed as % infected plants);* S*, mean severity of foliar symptoms (expressed as % infected leaf area).*

Disease severity was evaluated on a 1–9 scale, where 1=0% foliage affected, 3=2% foliage affected, 5=5% foliage affected, 7=10% foliage affected and 9=25% foliage affected.[24]

2008/2009 and 2010/2011 dry bean growing seasons. BBS occurred in 54% of subsistence farms during the two seasons.

Isolation and identification of bacterial brown spot pathogen

Pss was positively identified in 82% of the 378 leaf samples from the 2008/2009 and 2010/2011 seasons combined that were subjected to the pathogen isolation procedure. Isolates were stored at -70 °C following standard procedure and kept for the pathogen characterisation study.

Discussion

Bacterial brown spot incidences and severities varied over seasons at the same locations and over different locations in the same seasons. BBS was observed in 88% of all the locations surveyed. BBS was observed in up to 96% of commercial farms (Table 1), 67% of strip trials (Table 2), 100% of national cultivar trials (Table 3) and 46% of subsistence farms (Table 4). Although BBS severities were low, incidences were high (0% to 25%) in the majority of the locations surveyed. This study confirms that BBS is widely distributed in the dry bean production areas of South Africa, which corresponds with previous reports.[2,17]

Almost all of South Africa's dry bean production takes place in the provinces in which the surveys were conducted. The high incidence of the disease in these areas may have an effect on dry bean quantity and quality. It is possible that the majority of infections was a result of seed infections as it has been previously reported that BBS poses a particularly serious threat in the disease-free seed scheme[29], from which seed is obtained.

Higher BBS incidences and severities, respectively, were recorded in KwaZulu-Natal (22% and 3%), the Free State (25% and 4%) and Mpumalanga (22% and 3%) compared with those of other provinces. The Free State and Mpumalanga Provinces are the largest dry bean producing provinces of South Africa (Figure 1). BBS incidences and subsequent severities were consistently and continuously observed in dry bean production and experimental fields of South Africa.[2,16,17] BBS occurred in 100% of commercial fields with a disease incidence of up to 100% while severity was generally low (1–2).[2] The annual average rainfall is highest in KwaZulu-Natal (845 mm), Mpumalanga (736 mm) and the Free State (532 mm), compared with other provinces surveyed (Table 5). The high rainfall and subsequent humidity in these areas could have favoured BBS occurrence and severity as suggested by Hagedorn and Inglis[6]. Population increases of *Pss* of almost 100-fold from 34–35 days after planting after 26 mm rainfall have been reported.[30] The converse of this notion is supported by the lower BBS incidences in Limpopo and the North West Provinces, which are among the most arid provinces of South Africa with average annual rainfalls of 527 mm and 481 mm, respectively (Table 5). Low BBS incidences (0–7%) on the majority of the subsistence farms (Table 4) could be explained by the lower humidity that characterises these areas.

Table 5: Average weather data and approximate latitudes and longitudes of dry bean producing areas surveyed in South Africa

Location	Average annual rainfall (mm)	Average annual temperature (°C)	Approximate latitude and longitude
KwaZulu-Natal	845	15.8	29°00'S 31°00'E
Free State	532	15.8	28°30'S 27°00'E
Mpumalanga	736	17.1	26°00'S 30°00'E
Limpopo	527	20.0	24°00'S 29°00'E
North West	481	18.3	27°00'S 26°00'E

Sources: average annual rainfall and temperature[38]; approximate latitude and longitude[33-37]

With the exception of the Free State Province, the Limpopo and North West Provinces generally had lower BBS incidences and severities, and are characterised by average annual temperatures (Table 5) of at least 18.3 °C. This observation could therefore imply that very high temperatures might contribute to lower BBS incidences and severities.

Pss is one of the few bacterial species with the ability to inhabit the host leaf surface without causing disease.[31] However, frost injury can occur because *Pss* has the ability to catalyse ice formation at temperatures above -5 °C.[32] The results discussed here do not take into account epiphytic cells that could have been present on the leaf surfaces, even on leaves appearing healthy.

Low disease severities could also be attributed to the fact that many commercial farmers plant disease-free seed. As *Pss* is seed-borne, it continues to be a threat because a number of producers, mainly subsistence farmers, still plant their own seed, which can impact the spread of the disease in seasons in which conditions are conducive for the spread of disease.

The findings of this study indicate recurring incidences of high proportions in commercial farms, as reported previously.[2] High BBS incidences in strip and national cultivar trials and in subsistence farms and home gardens were also high, which could be attributed to continuous use of contaminated seed. The current BBS incidences and severities signify the importance for the development, through backcross breeding, of BBS-resistant dry bean cultivars if incidences and severities of greater proportions are to be avoided, thereby ensuring sustained dry bean production in South Africa.

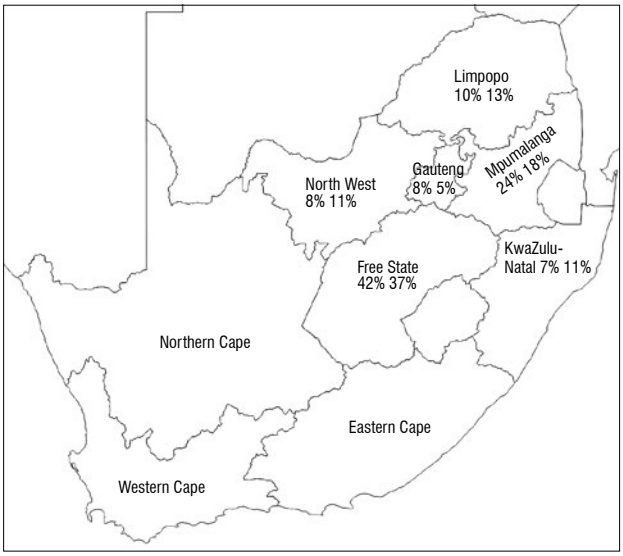

Figure 1: Dry bean production levels in the six main production provinces of South Africa during the 2008/2009 (left value) and 2010/2011 (right value) growing seasons.

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Authors' contributions

H.T.H.M. was the student project leader, D.F. was the student mentor and co-promoter, and N.W.M. was the student promoter. H.T.H.M. conducted the experiment and wrote the manuscript, D.F. advised on initiating the experiment and contributed to the write-up, and N.W.M. contributed to the write-up.

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An investigation of the nature of a Pc5 pulsation event using SuperDARN and magnetometer data

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Pc5 pulsations are global magnetohydrodynamic events in the magnetosphere. We employed an Automated Pulsation Finder program to identify significant Pc5 pulsation events in SuperDARN radar data. The event presented here was visible in the Goose Bay, Saskatoon and Þykkvibaer high-frequency radars, located in the northern polar region. These observations were coordinated with magnetometers within their field of view. These two instrument types – radars and magnetometers – complement each other. These observations represent a significant fraction of the globe in longitude. Pulsation studies of this nature are rare in the literature. Combining these two instrument types, we investigated the nature of the pulsation and determined its qualitative polarisation characteristics. A complex demodulation technique was employed to determine amplitude and phase relationships between field components observed by the radars and magnetometers, which, in turn, afforded resolution of other characteristics of pulsations, such as wave number and phase velocity. The results are discussed in the context of the magnetohydrodynamic theory of magnetic pulsations, speculating on its generation mechanism. Investigation of this mechanism will be the subject of a future publication.

Introduction

Ultra-low frequency (ULF) hydromagnetic waves, often referred to as geomagnetic pulsations, have been observed for many years in magnetometer data as well as by very high frequency (VHF) and high-frequency (HF) radars, and are endemic within the magnetosphere. A subset of these waves, pulsations in the Pc5 band (1–5 mHz), are global magnetohydrodynamic events in the magnetosphere. Numerous papers have reported the observation of Pc5 pulsations with power at discrete and stable frequencies, the most commonly occurring being at frequencies of 1.3 mHz, 1.9 mHz, 2.6 mHz and 3.3–3.4 mHz.[1-5] The quantisation of the resonance frequencies is predicted by the cavity mode theory which was first developed by Kivelson and Southwood[1] and later modified into waveguide theory[1,6] to account for the azimuthal propagation of the compressional mode. However, Ziesolleck and McDiarmid[7] showed that the waveguide/cavity mode frequencies do not necessarily represent a unique set of frequencies. In order to understand the stability and reproducibility of these frequencies, many authors have focused on investigating possible excitation mechanisms.[4,8-11]

A field line resonance is essentially a standing shear Alfvén wave on a magnetic field line between the two conducting ionospheres.[12] Field line resonances can arise from an external influence in the solar wind, such as Kelvin–Helmholtz instability, or from an abrupt change in solar wind dynamic pressure, coherent waves in solar wind, which in turn can excite field lines inside the magnetosphere into compressional oscillation.[13] The field lines on the L-shell with the same characteristic frequency will resonate and large oscillations will be set up over a narrow range of latitudes. Southwood[14] and Chen and Hasegawa[15] predicted that an enhancement in amplitude at the resonance L-shell is accompanied by a phase change of approximately 180°. This behaviour is the result of the fact that L-shells nearer the earth have higher frequencies than the driver and lead it in phase, whereas those that are near magnetopause have lower frequencies than the driver and lag it in phase. Walker et al.[16] provided compelling evidence in favour of this theory by using STARE radar data to plot the amplitude and phase of an electric field. Field line resonances generated by all these mechanisms tend to have small azimuthal wave numbers, *m*. The generation mechanism remains in debate. All the mechanisms mentioned above have been shown to be present.

Another type of pulsation in the Pc5 band can be generated by drift-bounce resonance with energetic ring current particles. These are often compressional in nature and tend to have larger values of *m*. The drift-bounce resonance occurs when a particle drifts in one bounce period by an integral number of azimuthal wavelengths, Doppler shifted by the azimuthal phase velocity of the wave. The high-energy particles which constitute the bulk of the ring current may be responsible for exciting compressional Pc5 through drift-bounce resonance.[17,18] The resonant particle has a drift path which oscillates between L-shells at the same characteristic frequency as the oscillations in perpendicular, parallel and total particle kinetic energy.

The drift-bounce resonant interaction of the energetic ring current particle with Alfvén waves has been proposed as a possible excitation mechanism.[19]

Magnetometers and HF radars are synergistic instrument types. Magnetometers have high temporal resolution whilst HF radars have good spatial resolution. Furthermore, ionospheric conditions not conducive to observing pulsations in radar data are favourable for observations in magnetometer data, and vice versa. In this study, we used three SuperDARN HF radars together with ground-based magnetometers to study a Pc5 pulsation event. SuperDARN is an international project of which the South African radar at SANAE, Antarctica forms a part. Our emphasis in this study was the determination of the physical character of the Pc5 pulsation, using HF radar and magnetometer ground-based instruments. An event was identified by using the pulsation finder to find a significant pulsation in one HF radar and then proceeding to search for a similar resonance in other radars and magnetometers at similar magnetic latitudes.

Instrumentation

We focused on a Pc5 pulsation event occurring between 20:00 and 22:00 UT on 6 October 2006 observed by the Saskatoon, Goose Bay, and Þykkvibaer HF radars. These three radars are part of the SuperDARN international network of HF radars that monitor ionospheric plasma convection over an extensive area of mid- and high latitudes in both hemispheres. The HF radars of the system each operate in a frequency range of 8–20 MHz, and use an electronically phased antenna array to sweep the beam through successive positions with azimuthal separation of 3.24°. In full scan mode, a radar runs through a 16-beam scan with a dwell time of between 3 s and 7 s (depending on the radar), which gives a full 16-beam scan that covers 52° in azimuth once every 1 min or 2 min, respectively. For each beam, the backscatter power, line-of-sight Doppler velocity, and spectral width are gated in up to 75 cells. These are 45 km long in standard operation extending from an initial range of 180 km. The spatial coverage of an HF radar is up to 2000 × 2000 km^2. HF radars operate by utilising coherent scatter from field-aligned irregularities of electron density in the E- and F-regions of the ionosphere. They 'see' the electric field perturbation associated with the pulsation and not the magnetic field. This distinction has implications for which kind of pulsations (compressional or Alfvén) are seen by the different beams. Their spatial coverage makes them ideal tools for resolving pulsation resonance structures. The ULF oscillations in these ionospheric regions are observable in the line-of-sight Doppler velocity, with the magnitude of the measured flow oscillations being dependent upon the direction of the flow oscillations relative to the beam direction. Pc5 oscillations in the F-region are therefore visible as alternating bands of negative and positive Doppler velocities. The F-region has previously been shown to be associated with Pc5 field line resonance.[2,20,21]

The magnetometer data were obtained from the Greenland Magnetometer Array[22], the Canadian Array for Realtime Investigations of Magnetic Activity (CARISMA)[23] and the International Monitor for Auroral Geomagnetic Effects (IMAGE)[24]. The Greenland, CARISMA and IMAGE arrays cover polar cap, cusp and auroral regions. The large latitudinal coverage allows features such as the phase change across resonance and the amplitude peak of the wave to be observed. Each station is equipped with a three-component ring core fluxgate magnetometer, which records the geographical (X, Y and Z) coordinates, which are rotated into geomagnetic (H, D and Z) coordinates before analysis. The data are sampled at a rate of 20 s, 1 s and 10 s, respectively. These magnetometer arrays give exceptionally high quality data and they all have a good temporal resolution.

Observations and discussion

High-frequency radars

We analysed in detail a Pc5 pulsation event, which was observed between 20:00 and 22:00 UT on 6 October 2006. The investigation started by using an Automated Pulsation Finder program.[25] The Automated Pulsation Finder highlighted a significant peak in beam 10 and range gate 32 of the Goose Bay radar. Groundscatter was not excluded from the analysis as it has been shown that pulsations may be visible in such scatter.[26] Although the pulsation was initially detected in beam 10, we chose to analyse only those cells that were aligned along a specific magnetic latitude. Each record of data corresponding to a beam number and range gate to be processed by the Automated Pulsation Finder had an uneven sampling period, because of periods of no backscatter, and the original data record was not always suitable for pulsation analysis. The temporal resolution of the data used in the pulsation finder was 1 s. This higher time resolution had no impact on the frequencies of interest. The results of the Automated Pulsation Finder are shown in Figure 1a, which shows the line-of-sight Doppler velocity recorded at Goose Bay, filtered in the Pc5 band, and the corresponding power spectrum. The red line shows the level at which peaks in the spectrum are significant. The term 'significance detector' is used to describe a routine to process a set of data and then return those points that are either a significant part of a data group or not part of a group. The routine is as follows:

- Clean the data by removing outliers by removing echoes with a spectral width greater than 150 m/s; the remaining velocity values should fill more than 80% of the 2-h cell record.
- Interpolate the missing points using cubic spline interpolation.
- If there is a peak in the whole or part of the spectrum, calculate the mean and standard deviation of all the amplitude values within the 1–5 mHz frequency.
- Set the significance level at mean plus three standard deviations of the data. If any amplitude values in the 1–5-mHz range fall above the significance level, then the frequency that corresponds to the amplitude is considered significant.

In our data, the detector recorded a significant resonance in the frequency band 2.2–2.5 mHz in beam 10 in range 32. The range–time summary plot of the line-of-sight Doppler velocity of beam 10 of the Goose Bay radar is shown in Figure 1b. The velocity is indicated by the colour bar on the right of the figure. Blue indicates velocities moving toward the radar, while red corresponds to the velocities moving away from the radar. The range–time plot is a reliable source to check pulsation activities. The solid rectangle shows the location of pulsation activity in this beam. The ionospheric perturbations visible in the range–time plot as bands of alternating positive and negative (shades of blue and red) Doppler velocities are characteristic of Pc5 pulsations. Figure 2 shows the latitude profile of amplitude and phase along beam 10 of Goose Bay. This plot is derived from range gates 28 to 34, excluding range gate 30, from beam 10, using the analytic signal. The solid line represents the fitted curve, which shows the characteristics of field line resonances. The region of resonance is clearly visible as a narrow peak in amplitude around 73.7° magnetic latitude with a standard phase change with increasing latitude, i.e. a decrease in phase as the resonance is crossed. In the case of the

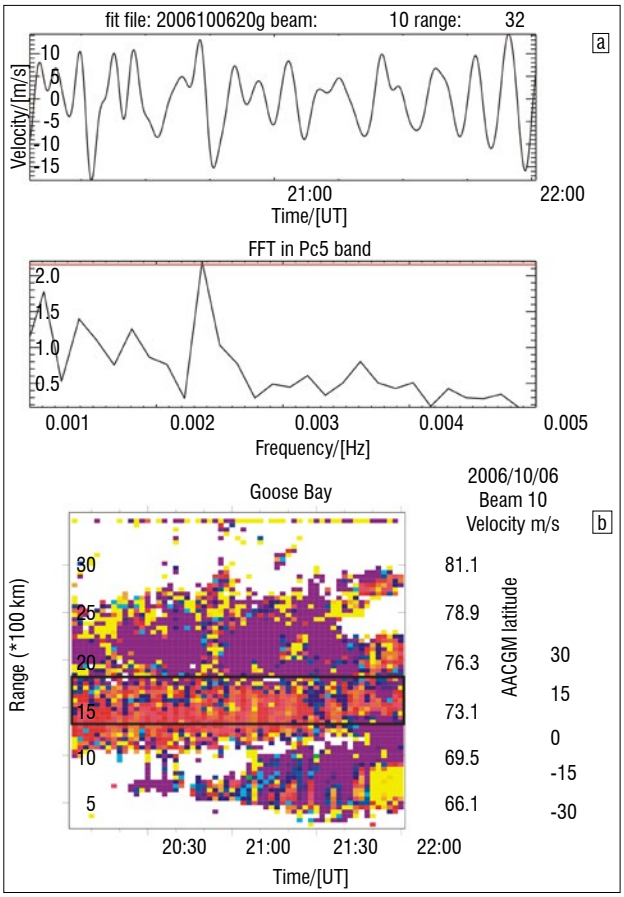

Figure 1: (a) The top panel shows Pc5 band filtered data and the bottom shows the corresponding power spectrum and the significant limit level from filtered data. The peak detector recorded the peak in frequency band 2.2–2.5 mHz as significant. (b) A time–range summary plot of Doppler velocity measured by beam 10 showing range gates and altitude-adjusted corrected geomagnetic (AACGM) latitude.

other radars, we could not plot the latitude profile of amplitude and phase because there were not enough cells that were magnetically aligned or close to each other.

Figure 3 shows a map of the locations of the three SuperDARN radars – Saskatoon, Goose Bay and Þykkvibaer – and the magnetometer stations of the CARISMA, Greenland and IMAGE arrays. These radars have a good spatial resolution over a large range of magnetic latitude and longitude. Once we identified the Pc5 ULF pulsation event in one radar (Goose Bay), we then proceeded to analyse all the beams and range gates of the Saskatoon and Þykkvibaer radars which were located within the same range of magnetic latitudes (i.e. within the solid red lines). The beams are numbered from west to east in the field of view of the radar.

Figure 4 shows the time series of Doppler velocities for different beams and range gates at the magnetic latitudes of the Goose Bay radar that are of interest. The time series was analysed to obtain power spectra that are similar to the one observed using the Automated Pulsation Finder, as shown in Figure 5. The beam and range gate plots presented here are magnetic latitude aligned and showed peaks in the 2.2–2.5-mHz frequency band. The data used in these plots had a time resolution of 120 s, which limits the pulsation that can be observed to an upper frequency of 4.17 mHz. The investigation of the Pc5 pulsation event observed by the Automated Pulsation Finder was extended to other radars within the same magnetic latitudes. Velocity data from 20:00 to 22:00 UT from these two radars were passed through a Fourier analysis to obtain the power spectra. The results from Saskatoon and Þykkvibaer radars are shown in Figures 6 and 7, respectively. The shading highlights peaks in the 2.2–2.5-mHz frequency band. There is evidence of Pc5 ULF pulsation events in the frequency band 2.2–2.5 mHz observed by Saskatoon and Þykkvibaer radars in the beams and range gates plotted in these figures.

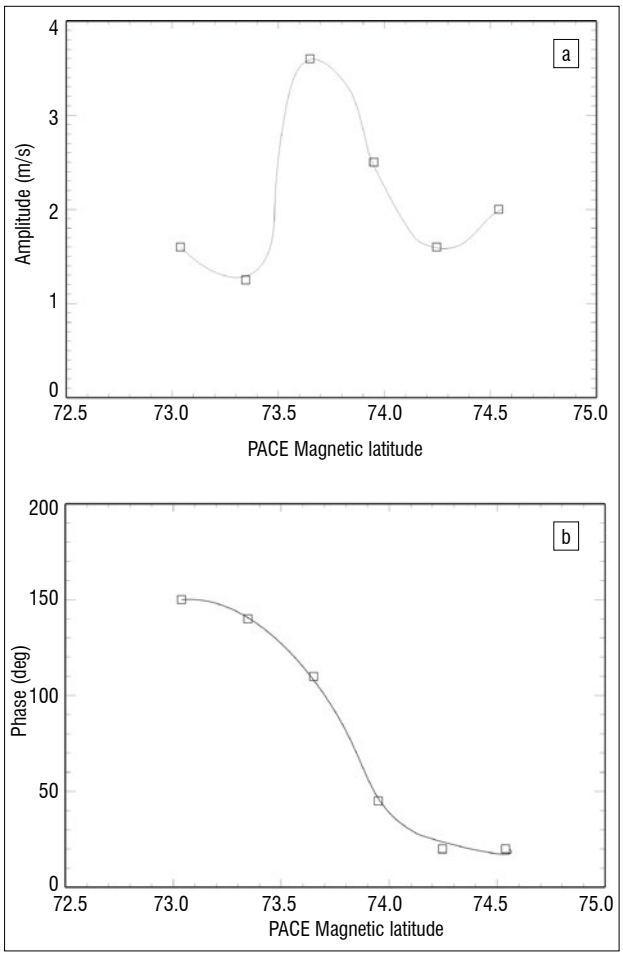

Figure 2: Latitude profile of (a) amplitude and (b) phase along beam 10 (the beam most aligned with the magnetic meridian) of Goose Bay.

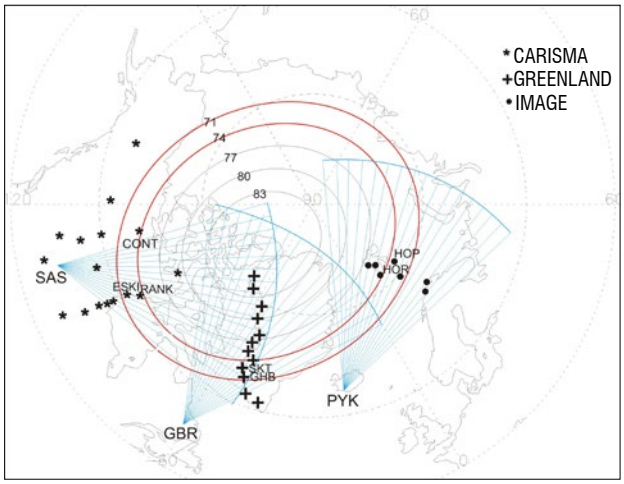

Figure 3: Fields of view of the SuperDARN radars at Saskatoon (SAS), Goose Bay (GBR) and Þykkvibaer (PYK), plotted according to geographical coordinates. The solid lines indicate the altitude-adjusted corrected geomagnetic (AACGM) magnetic latitude.

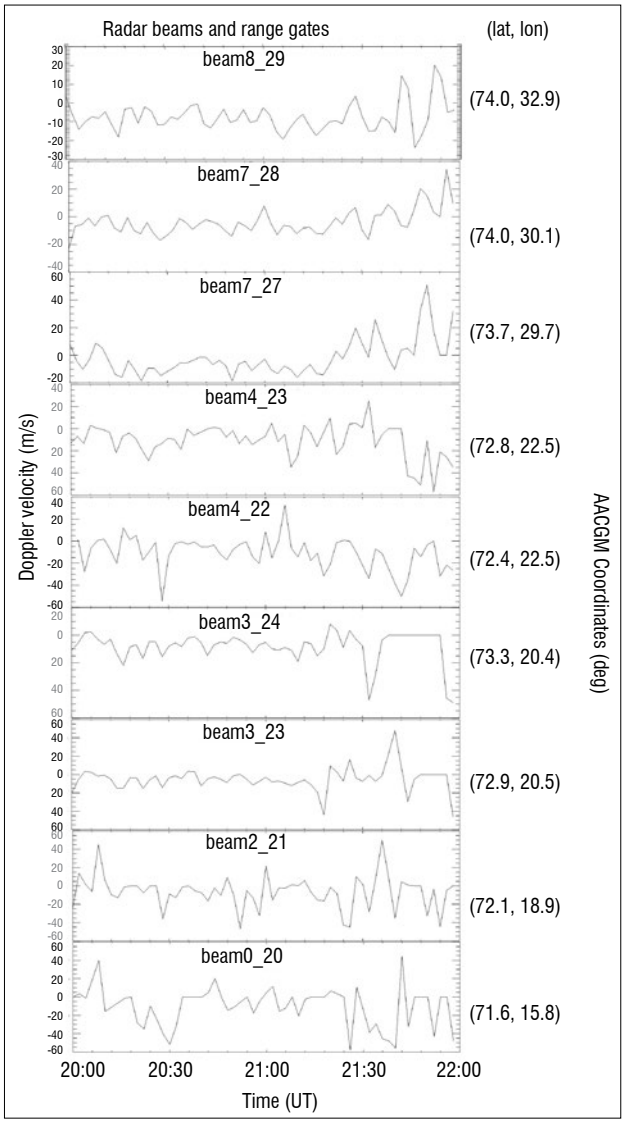

Figure 4: Doppler velocities of the Goose Bay radar of the given beams and range gates.

Magnetometers

Magnetometer stations that lie within the red lines shown in Figure 3 were chosen for more detailed analysis. The following magnetometer stations are located within or near the field of view of one of the three radars: Contwoyto (Saskatoon); Sukkertoppen/Maniitsok and Nuuk/Godthaab (Goose Bay); and Hornsund (Þykkvibaer). The Contwoyto station is in the same magnetic latitude range as other stations but not in the field of view of the mentioned radars. Some other magnetometer stations within the field of view do not have data while others did not have a significant peak in the 2.2–2.5-mHz band. Those magnetometer stations were not included in the study. The shading highlights peaks in the 2.2–2.5-mHz frequency band, which confirms the Pc5 pulsation event observed by these SuperDARN radars, as shown in Figure 8. The event observed using the Automated Pulsation Finder appears in other radars and magnetometer chains as a field line resonance, with an H-component amplitude peak and associated phase change across the resonant magnetic latitude.

During this interval, the CARISMA, Greenland and IMAGE magnetometer networks were located in the magnetosphere in the evening and nightside sectors in local time: 16:00–18:00, 17:00–19:00 and 21:00–23:00, respectively. This allowed us to investigate the spatial behaviour of the wave. Field line resonances are toroidal mode waves with magnetospheric magnetic perturbations in the azimuthal direction. Because of the rotational effect of the ionosphere, the large ionospheric perturbations on the ground are observed in the magnetic H-component.[27] Similarly, poloidal mode waves are characterised by magnetic perturbations in the radial direction which translates to a large perturbation observed in the magnetic D-component in ground magnetometer data. However, no ULF wave is purely Alfvén in nature; there will always be an accompanying compressional mode component. When identifying field line resonance signatures, one must take into account both the amplitude of the H- or D-component and the associated phase change. Figure 8 shows the corresponding spectral power for the four magnetometer stations selected from CARISMA (Contwoyto), Greenland (Sukkertoppen/Maniitsok and Nuuk/Godthaab) and IMAGE (Hornsund) for H-component only. The geographical and geomagnetic coordinates of these magnetometer stations are shown in Table 1. These magnetometer stations lie within a narrow magnetic latitude but cover an extensive range (nearly 180°) of longitude.

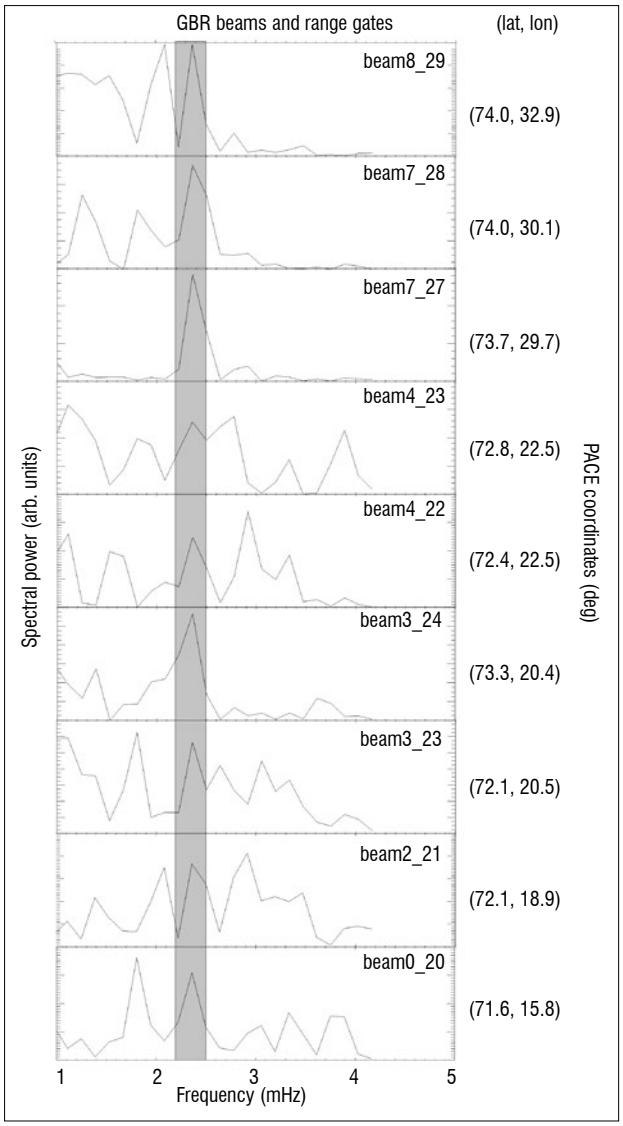

Figure 5: Spectral power of the Goose Bay radar corresponding with beams and range gates.

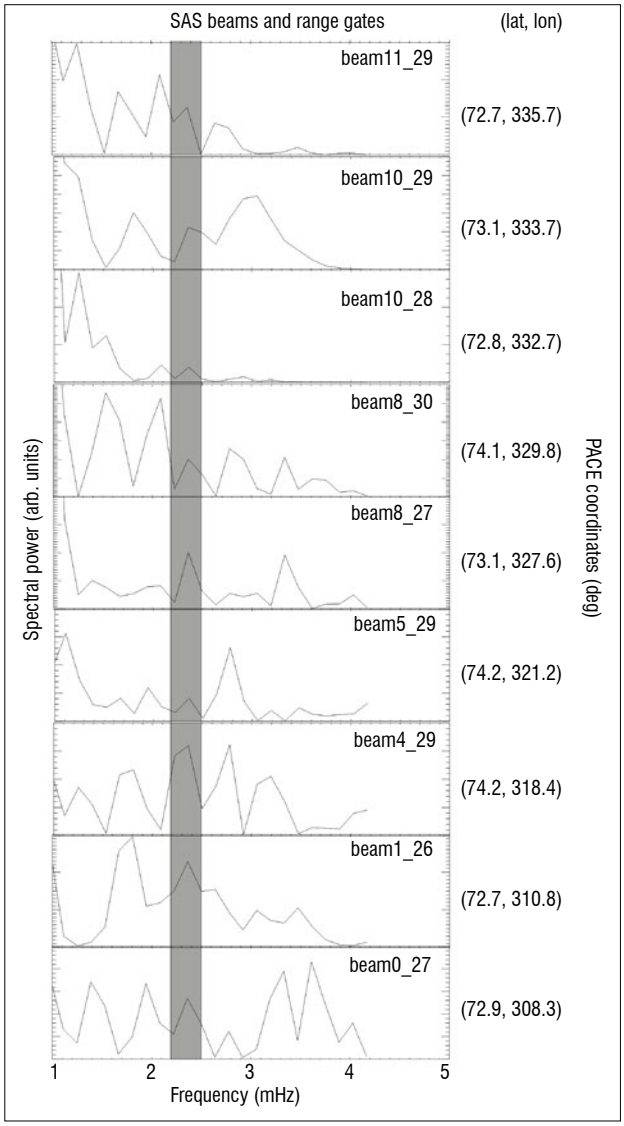

Figure 6: Fourier power spectra of the Saskatoon radar for the given beams and range gates.

Table 1: Geographical and geomagnetic coordinates of magnetometer stations

Station code	Geographic latitude	Geographic longitude	CGM latitude	CGM longitude	Instrument
CONT	65.754	248.750	72.82	304.82	CARISMA
SKT	65.42	307.10	70.98	36.66	Greenland
GHB	64.17	308.27	69.52	37.32	Greenland
HOR	77.00	15.60	74.13	109.59	IMAGE

CGM, corrected geomagnetic; CONT, Contwoyto; SKT, Sukkertoppen/Maniitsok; GHB, Nuuk/Godthaab; HOR, Hornsund.

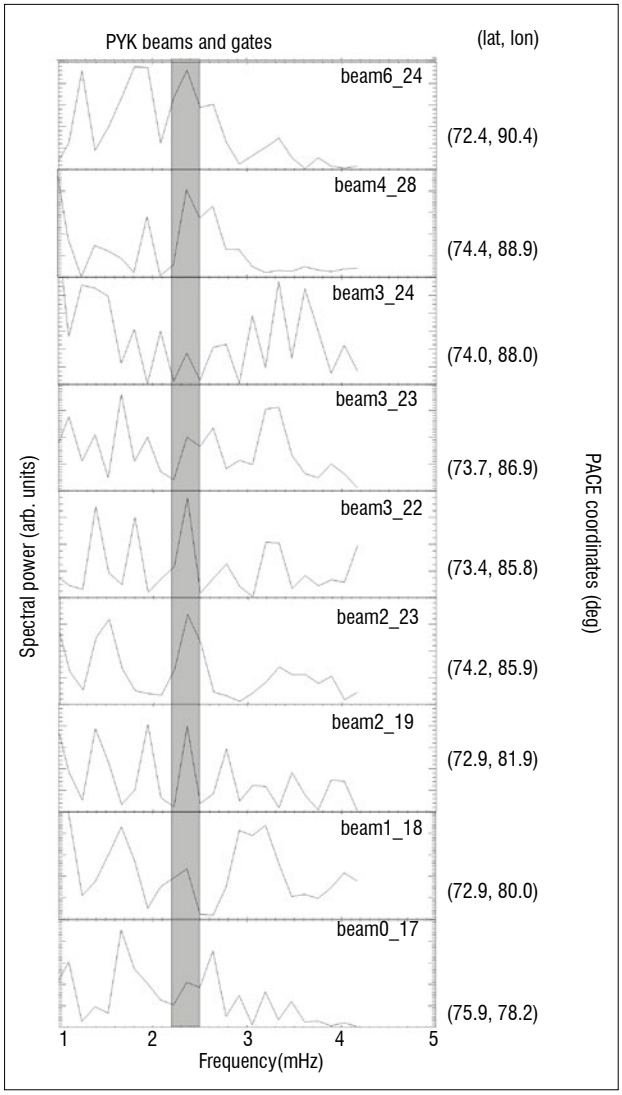

Figure 7: Fourier power spectra of the Þykkvibaer radar for the given beams and gates.

Complex demodulation

To analyse the instantaneous characteristics of the signal, we applied a complex demodulation technique to determine the analytic signal.[28] This allowed the examination of the variation with time of the instantaneous amplitude and phase of a selected frequency band. In the analysis of the resonance frequency band 2.2–2.5 mHz, the analytic signal was

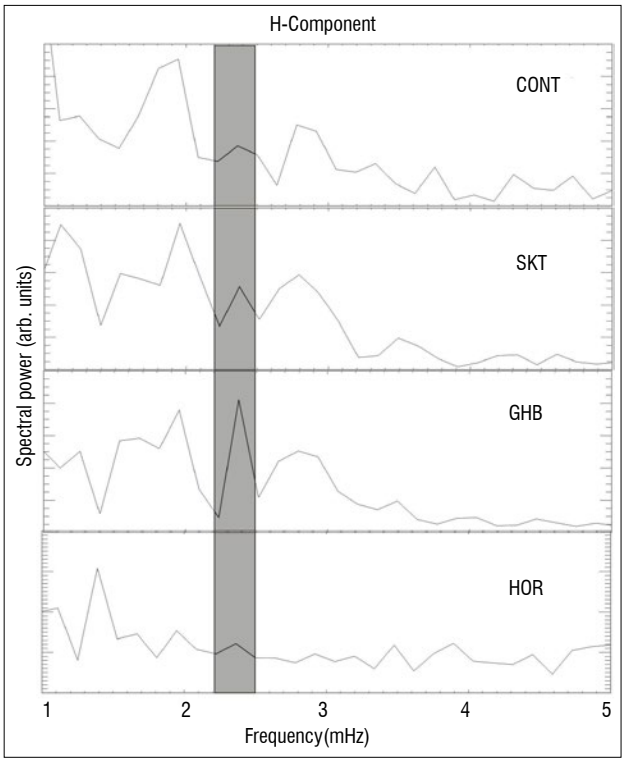

Figure 8: Corresponding spectral power for the magnetometer stations: Contwoyto (CONT), Sukkertoppen/Maniitsok (SKT), Nuuk/Godthaab (GHB) and Hornsund (HOR).

calculated from different beams and range gates of the radars in which a given field line resonance was maximum, as shown in Figure 9 for Goose Bay. Similar analyses of Saskatoon and Þykkvibaer radars were performed, but are not shown here due to space constraints. The phase of the resonance was measured across the field of view at constant magnetic latitude, yielding the phase versus longitude relations shown in Figure 10. The slope of these relations yields the azimuthal wave number, m: 12±2.1 for Saskatoon, 13±2.9 for Goose Bay and 19±5.0 for Þykkvibaer. The m-value and the resonance frequency were used to calculate the azimuthal phase velocities. The m number changes as we cross magnetic longitude. The azimuthal phase velocity is given by

$$v=\frac{2\pi fR\cos\lambda}{m}, \qquad \text{Equation 1}$$

where f is the ULF wave frequency, λ is the geomagnetic latitude, R is earth's radius and m is the azimuthal wave number. These slopes correspond to westward phase velocities of ~2.2 km/s, ~2.0 km/s and ~1.4 km/s, respectively, at the ionosphere. This method was previously employed by Fenrich and Samson[3]. The filtered oscillation and its envelope and their phase for Sukkertoppen/Maniitsok and Nuuk/Godthaab (part of the Greenland network which lies under the field of view of Goose Bay radar) are not shown here. The signals have a packet structure with amplitude growing and decaying with time. In some cases, the phase may change abruptly between packets where the amplitude is small. With magnetometer data, we use the phase difference to observe the azimuthal wave number m. The azimuthal wave number value is calculated using differences in the H-component phase. The values are given by

$$m=\frac{\Delta\emptyset}{\Delta\lambda}, \qquad \text{Equation 2}$$

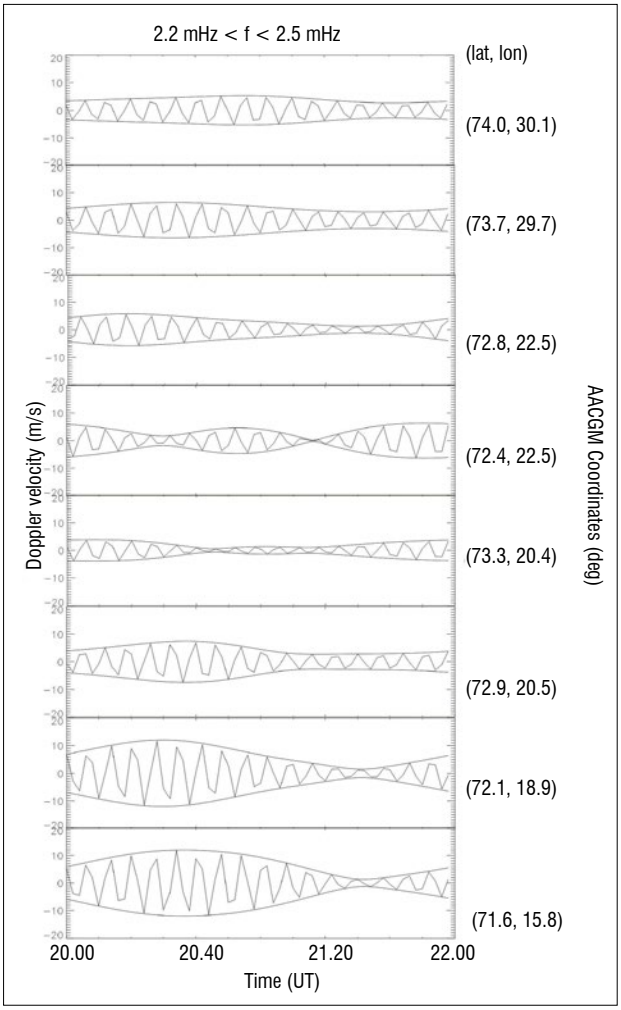

Figure 9: Stackplot of the analytic signal amplitude envelopes for various beams of the Goose Bay radar at the mentioned range gates.

where $\Delta\emptyset$ is the phase difference of the H-component between two stations and $\Delta\lambda$ is their geomagnetic longitude difference. The coordinates for the relevant stations are provided in Table 1. Positive *m*-values represent waves with westward phase propagation while negative *m*-values represent waves with eastward phase propagation. An *m*-value of $\sim+11$ represents a wave with westward phase propagation.

The resonance frequency observed at Goose Bay radar using the Automated Pulsation Finder also appears in other radars, but not as the dominant peak; other beams and range gates in all three radars show significant peaks. The magnetometer stations that are within the field of view of the radars and those in the magnetic latitude of radars showed some peaks. These peaks show characteristic features of the field line resonances as resolved by the spatial resolution of radars, as it is shown in Figure 2. The region of resonance is clearly visible as a narrow peak in amplitude 73.7° magnetic latitude with standard phase change with increasing latitude. Once again, the *m* number increases from west to east as you cross the field of view; this finding is not surprising because a constant *m*-value would assume cylindrical symmetry. There is no reason to assume the wave would have this property. The observed azimuthal wave *m* from magnetometer stations is smaller than the azimuthal wave number observed from SuperDARN radars. The difference could be because when the ionospheric distribution of Hall currents also has a finite scale size in longitude, then azimuthal wave *m* numbers measured by ground-based magnetometers will be different compared with values in the ionosphere.[29] The azimuthal wave number is calculated using the phase versus longitude relation.

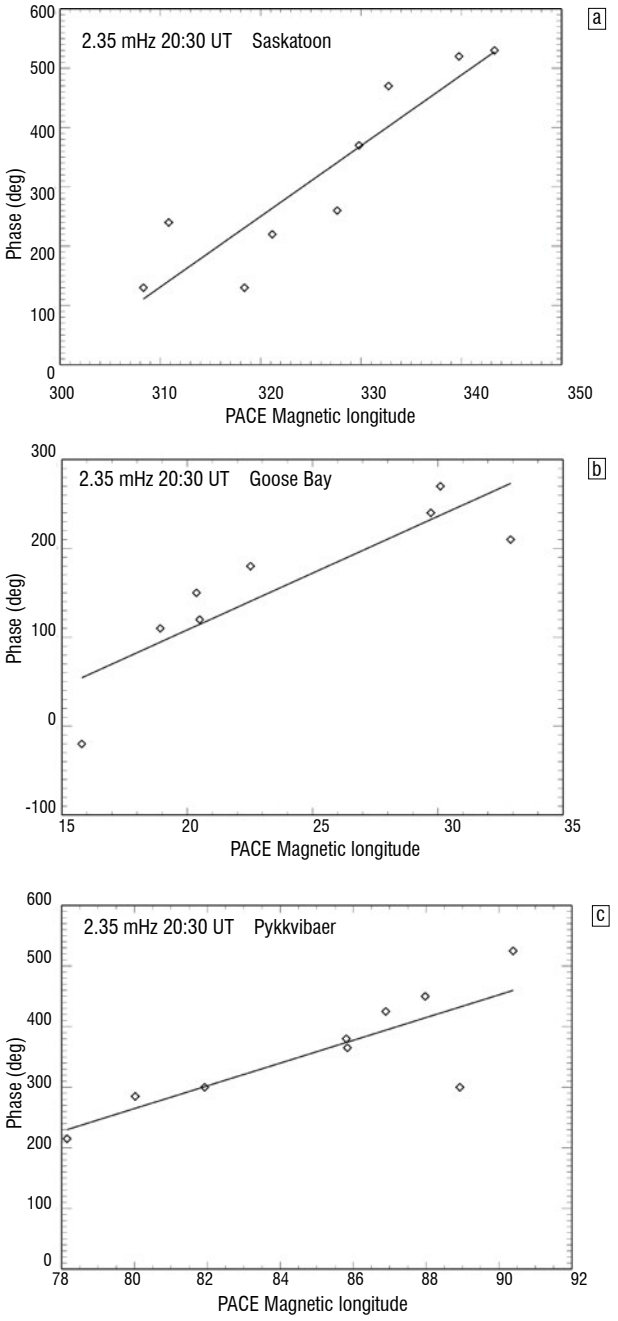

Figure 10: Plot of phase versus longitude measured at 20:30 UT for the 2.35-mHz frequency. The slope of these relations yields the azimuthal wave number, *m*: (a) 12±2.1 for Saskatoon, (b) 13±2.9 for Goose Bay and (c) 19±5.0 for Þykkvibaer, corresponding to westward phase velocities at the ionosphere.

Conclusions

The Pc5 pulsation event investigated was a field line resonance. Analysis of the Goose Bay radar beam most aligned with the magnetic meridian demonstrated an amplitude peak over a narrow latitude range and associated phase change across the resonance (Figure 2). Field line resonances tend to have lower azimuthal wave number (*m*) values and thus often have external sources. In addition, pulsations excited by external sources have phase velocities that are anti-sunward. However, in this instance, the field line resonance is sunward propagating with a relatively high azimuthal wave number. This may be more consistent with a drift resonance source, although a drift resonance generation mechanism is more commonly associated with a compressional oscillation. It has been shown that drift resonance can be associated with

field line resonances in a study by Ozeke and Mann[30] of the properties of high *m* Alfvén waves. This is an interesting finding that needs further investigation and is the subject of ongoing investigation.

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Authors' contributions

Z.M. collected the data and performed the analyses; J.A.E.S. and A.D.M.W. formulated the idea and provided guidance and suggestions.

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Assessing the photoprotective effects of red ochre on human skin by in vitro laboratory experiments

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Archaeological indicators of cognitive complexity become increasingly prevalent during the African Middle Stone Age, with the habitual exploitation of red ochre widely viewed as a key feature of the emergence of modern human behaviour. Given that some of the uses of ochre remain ambiguous, we present the preliminary results of an ongoing study in which we explore the efficacy of red ochre as a photoprotective device or sunscreen. The capacity of ochre to inhibit the susceptibility of humans to the detrimental effects of ultraviolet radiation was confirmed through the in vitro calculation of the sun protection factor values of samples derived from the Kunene Region in Namibia and the Bokkeveld Group deposits, Western Cape Province, South Africa. Visible spectroscopy was employed to determine colourimetric parameters of samples and assess the correlation between ochre colour and sun protection factor. The possible role of ochre as a sunscreen agent for hominin populations, including modern humans, during the Middle Stone Age in Africa is explored. We conclude that the habitual use of red ochre as a photoprotective agent likely played a role in the ability of prehistoric humans to adapt to novel environmental circumstances.

Introduction

Environmental variables have been shown to exert a substantial influence on ecosystems, communities and populations.[1,2] Of the various climate-driven selective pressures that operated during the evolutionary history of *Homo sapiens* in Africa, negotiating the risks and benefits of persistent exposure to sunlight presented an enduring challenge. Most important in terms of human health are longwave ultraviolet A (UVA) (400–315 nm) and medium-wave ultraviolet B (UVB) (315–280 nm) radiation.[3] Excessive UVA exposure results in DNA damage, skin aging and mild erythema, whereas UVB is responsible for sunburn with subsequent DNA damage and skin cancers. Shortwave UVC (280–200 nm) is potentially the most dangerous type of UV radiation (UVR) for humans, but is largely absorbed by the ozone layer.[4]

Sunlight is an essential environmental factor in most ecosystems and the beneficial effects of moderate exposure to sunlight are well known.[5] Positive correlations exist between adequate UVR exposure, vitamin D synthesis, calcium absorption and human fertility.[6] Vitamin D (1.25 dihydroxyvitamin D_3) in turn reduces the incidence of rheumatoid arthritis, coronary heart disease, diabetes, multiple sclerosis, osteomalacia, rickets, schizophrenia, autoimmune diseases and also several types of cancer.[7] Conversely, excessive UVR exposure can lead to malignant skin diseases including cancer and mitochondrial (mtDNA) and nuclear (nDNA) molecule damage.[8,9]

It has furthermore been proposed that excessive UVR may have had far-reaching effects on mammalian evolutionary processes. UVR has been implicated in several extinction events, including the disappearance of megafauna during the late Pleistocene[10,11] and the extinction of a number of hominin species[12,13]. These hypotheses are difficult to test because of the uncertainties concerning the dating of extinction events and in calculating the impact of UVR changes at different latitudes and among different populations. The absence of the MC1R gene variant (R307G) in analysed Neanderthal and Denisovan genomes further indicates that extensive variability in skin colour existed among archaic hominids, and that at least some of these individuals had darker and therefore more UVR-resistant skin tones.[14,15] Fluctuations in UVR may nevertheless have generated a selective pressure on human populations, which could have influenced the life expectancy, particularly in the case of colonisation of different territories or altitudes within a given region, of at least some individuals within such populations.

Ultraviolet radiation protective mechanisms

Several theories have been proposed to explain the variation in human skin pigmentation.[16,17] At present, the most widely accepted factor explaining the geographic distribution of autochthonous human skin pigmentation is UVR exposure.[18] Evidence for natural selection operating at low latitudes (establishing and maintaining dark pigmentation under high UVR conditions) and high latitudes (which favours the development of light pigmentation under low UVR conditions), suggests that human skin colouration is a Darwinian adaptation.[7,16] The gradient of skin colours observed from the equator to the poles consequently results from two clines operating over a spatially varying optimum of UVR distribution.[19] The association between skin pigmentation in indigenous populations and latitude is therefore traceable to the correlation between skin colour and the intensity of UVR exposure.

That darker skin pigmentation conferred significant adaptive benefits is confirmed by the preservation, amongst modern human populations, of the MC1R, SLC45A2 and 70 other genetic mutations at loci implicated in pigment production.[17,20] Unlike SLC45A2, which occurs only amongst Europeans, the SLC24A5, TYRP1 and KITLG mutations are present in a number of sub-Saharan populations. Although these alleles in all probability arose within and spread from Africa during early modern human migrations, some may result from a series of admixture events with groups containing Eurasian genetic ancestry.[21]

In behavioural terms, cultural innovations seeking to reduce the impact of UVR, such as the topical application of powdered clays including ochre, could also have reduced the pressure induced by increasing exposure to UVR. Changes in climate and ecology have been shown to provoke speciation and extinction[22] and it has been proposed that these may have acted as selective pressures for enhanced cognition[23,24]. Given that darker-skinned individuals

are also susceptible to the harmful effects of UVR,[19] the development of effective sun-protection strategies may have been essential in prehistory.

Ochre as a sunscreen

Ochre is a pervasive artefact in historical, Iron Age, Later Stone Age (LSA) and Middle Stone Age (MSA) contexts throughout southern Africa. The term 'ochre' is widely used by archaeologists to designate any earthy materials comprising anhydrous iron (III – ferric or Fe^{3+}) oxide such as red ochre (which includes unhydrated haematite or Fe_2O_3) and partly hydrated iron (III) oxide-hydroxide such as brown goethite (FeO(OH)).[25,26]

The habitual exploitation of red ochre by *H. sapiens* has been interpreted as evidence for colour symbolism[27], as a proxy for the origin of language[27,28] and as an essential element of symbolic and fully modern human behaviour[29,30]. Although the collection and processing of ochre is not limited to our species[31,32], the routine exploitation of red ochre may represent a species-specific behavioural trait for *H. sapiens*[27,28].

There is sufficient archaeological evidence for the use of red ochre as a body cosmetic during the MSA. Examples comprise the adherence of red ochre residues to perforated marine shell beads derived from African MSA and Levantine Mousterian contexts dated from 92 000 years ago (ka) to 60 ka.[32-34] As strung beads are generally worn around the neck or wrists,[35] these residues almost certainly derive from direct contact with red pigments applied to human bodies. But because evidence regarding the exact motives for red ochre exploitation during the MSA and LSA is not freely available, diverse interpretations for its usage have been proposed. The most familiar explanation concerns the use of red ochre as a body decoration in largely symbolic contexts.[27] In the absence of direct evidence, this inference is based largely on an analogy with modern hunter–gatherer societies.[36,37] Red ochre was also used as a constituent in paint[38], for knapping stone implements[39], as an element in lithic hafting mastics[40] and possibly as a hide-processing ingredient[41].

Ethnographic accounts illustrating the use of red ochre as a cosmetic substance have been reported for southern African San hunter–gatherers[37], Tswana[36] and Xhosa[42] agro-pastoralists and also Khoe pastoralists[43]. While these examples relate largely to the intermittent topical application of red ochre in symbolic contexts, foremost modern examples of the habitual use of red ochre as a body cosmetic comprise the Cushitic-speaking Hamar in Southern Ethiopia[44] and the Ovahimba of northwestern Namibia (Kunene Region; Figure 1) and southwestern Angola (Kunene and Namibe Provinces)[45,46].

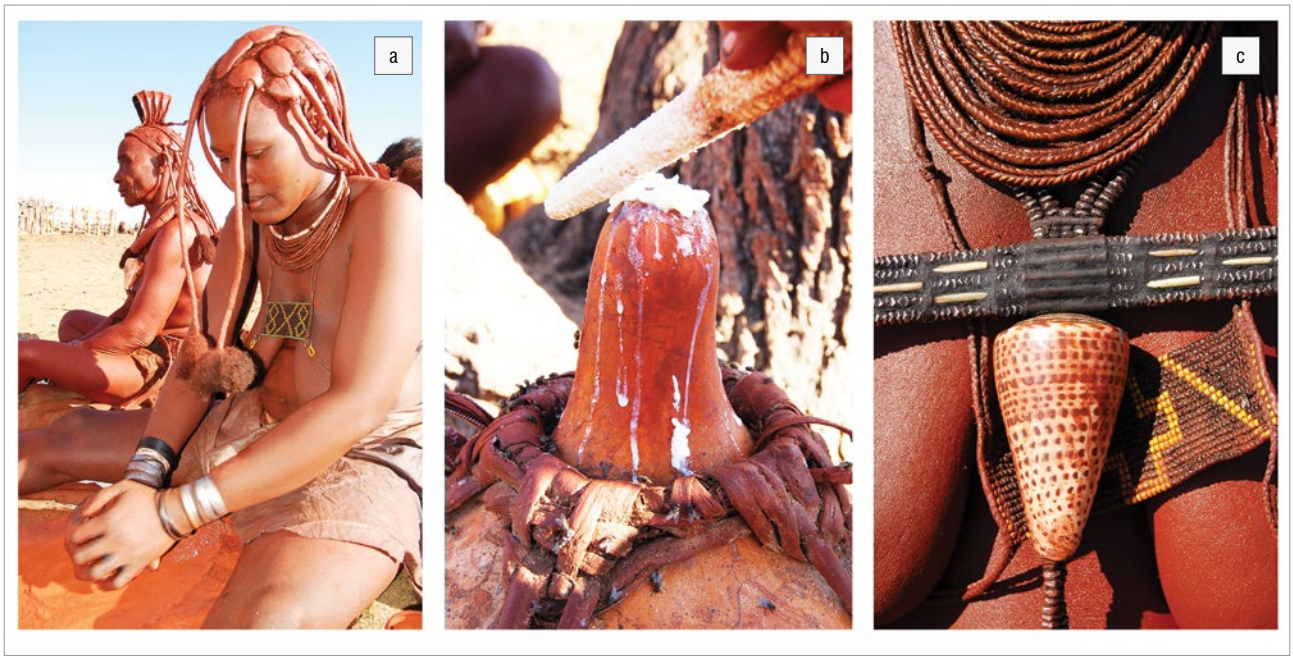
Ovahimba women are renowned for covering their bodies, hair and personal attire with a red ochre-based substance (Figure 2). This substance is known as *otjise* and is comprised of clarified butter (*omaze uozongombe*) and red (*otjiserundu*) ochre powder. Ochre powder is produced by crushing and grinding ochre chunks between round upper and flat lower grinding stones. Clarified butter is produced by shaking cream-rich milk in a *Lagenaria* sp. calabash gourd to separate fatty substances from the watery solution. The extract is boiled in an iron pot above an open fire and the resultant greasy substance is recovered and stored. Whereas ochre processing forms part of the sociable settings of daily life, the application of *otjise* occurs in the confines of women's huts. *Otjise* also features prominently in initiation ceremonies, is applied by men when they are to be wed or undertake long journeys and is applied to human corpses prior to interment.[45,47] Ethnographic interviews recently conducted amongst the Ovahimba furthermore reveal that, besides the intrinsic social and inexorably symbolic significance of *otjise*, it also fulfils several secondary functions, including that as a topical sun-protection element or sunscreen.

Materials and methods

Ochre

We used 24 ochre samples derived from ethnographic and non-archaeological geological sources likely to have been exploited during the MSA. Of these samples, 12 were collected from the Okamanga,

Figure 1: The location of the Kunene Region of northern Namibia within southern Africa.



Photos: Riaan F. Rifkin

Figure 2: The production and application of *otjise*. (a) Red ochre powder is obtained by grinding chunks between a round upper and a flat lower grindstone, (b) after which it is mixed with milk-derived clarified butter and (c) applied to the hair, body and ornaments.

Ovinjange and Otjongoro villages in the Kunene Region of northern Namibia. Half of these samples (Samples 1–6) were processed into powder by Ovahimba women. Samples 7–12 were acquired in Opuwo and were processed experimentally by direct grinding onto a coarse quartzite stone surface. This method closely resembles the technique used to produce ochre powder during the MSA.[48] Informed consent was obtained from all research participants and the principles of the Declaration of Helsinki were strictly adhered to. Ochre Samples 13–24 – comprising yellow, grey and red specimens – were collected from the Palaeozoic Bokkeveld Group shale deposits of the Cape Supergroup (South Africa). Six of these samples were processed into powder by direct grinding onto a coarse sandstone surface, and the remaining six by way of the technique employed by Ovahimba women (Table 1).

Ultraviolet irradiation

The assessment of the efficiency of a sunscreen is based on the value of its sun protection factor (SPF), which reflects the degree of protection against UVR-induced erythema. SPF values most generally denote the efficiency of a sunscreen to protect the skin from UVB. A sunscreen with an SPF of 2 filters out 50% of UVB, an SPF of 15 filters out 93% UVB and an SPF of 50 filters out 98% UVB.[4,49] Theoretically, the application of a product with an SPF of 5 provides sun protection for five times longer than unprotected skin.

The UVR protection capacities (SPF values) of ochre samples were established by means of a series of in vitro experiments performed on ochre samples in dry powder form. The experiments were carried out at the Photobiology Laboratory (Department of Pharmacy, Medunsa Campus) of the University of Limpopo, South Africa.[50] A calibrated multiport solar simulator (Solar Light Co., Glenside, PA, USA) was used as the UV irradiation source. In accordance with the SANS 1557/ISO 24444 SPF testing protocol, ochre powder samples were applied to Transpore® tape at a ratio of 2 mg/cm^2 and analysed in compliance with the SANS 1557:1992 procedure. Although Ovahimba women typically apply 4.2 mg *otjise* per cm^2, it was decided to adhere to the standard 2 mg/cm^2 ratio to acquire comparable SPF values. Actual SPF values are therefore likely to be significantly higher than the results reported here. Critical wavelength was determined using the Optometrics SPF 290 method. The critical wavelength is that below which 90% of the UV protection is situated and the higher the critical wavelength, the higher the UVA protection ranges of the products.

Visible spectroscopy

It has been shown that clays exhibiting high UVR protection rates and low UVR-transmission values are most generally red.[51] To determine whether colour does in fact play a role in the UVR reflectance and absorption capabilities of ochre, visible spectroscopy was employed to obtain L*a*b* values for each sample. An Avantes AvaSpec 2048 spectrometer (Avantes Inc., Broomfield, CO, USA) equipped with a 2048-pixel charge-coupled device detector, and set to operate in the retrodiffusion mode, was used for this purpose. This instrument is fitted with an optical fibre probe which is positioned 2 mm from the sample surface at an angle of 2°. An AvaLight-HAL illumination source (Avantes Inc., Broomfield, CO, USA) was used. The equipment was calibrated with a Halon D65 white reference sample in the same lighting conditions as for the archaeological samples. The colour parameters were obtained by Avasoft 7.5 software.

Results

Sun protection factor assessment

The in vitro SPF values of experimental ochre samples ranged from 1.9 (±0.1) to 13.1 (±1.3). The yellow (13 and 19) and grey (14 and 20) samples had the lowest in vitro SPF values, and the red samples the highest. When compared by processing method, samples processed by Ovahimba women had the highest mean SPF (8.9±1.2), those experimentally ground directly onto a grindstone had a mean SPF of 6.2±2.4 and those ground using the method employed by Ovahimba women had a mean SPF of 3.4±0.8. When comparisons were made of the direct grinding method (onto a coarse stone surface) and the simulated traditional grinding method (that employed by the Ovahimba), the former produced in vitro SPF values of the order of 0.5 to 4.0 units higher than the latter. The critical wavelengths of the samples are comparable, falling within the range of 387.7–390.0 nm. In contrast to the increase in SPF produced by the direct grinding method when compared with the simulated traditional method, the critical wavelengths are marginally lower (± 1 nm) in the directly ground samples (Table 2).

Table 1: Experimental ochre samples subjected to in vitro ultraviolet radiation analyses

Sample	Source	Description	Processing method
1	Okamanga	Ground red ochre powder	Ethnographically ground (by Ovahimba)
2	Okamanga	Ground red ochre powder	Ethnographically ground (by Ovahimba)
3	Okamanga	Ground red ochre powder	Ethnographically ground (by Ovahimba)
4	Okamanga	Ground red ochre powder	Ethnographically ground (by Ovahimba)
5	Ovinjange	Ground red ochre powder	Ethnographically ground (by Ovahimba)
6	Otjongoro	Ground red ochre powder	Ethnographically ground (by Ovahimba)
7	Opuwo	Fine-grained red ochre	Ground directly onto quartzite slab
8	Opuwo	Fine-grained red ochre	Ground directly onto quartzite slab
9	Opuwo	Fine-grained red ochre	Ground directly onto quartzite slab
10	Opuwo	Fine-grained red ochre	Ground directly onto quartzite slab
11	Opuwo	Fine-grained red ochre	Ground directly onto quartzite slab
12	Opuwo	Fine-grained red ochre	Ground directly onto quartzite slab
13	Napier	Soft yellow limonite	Ground directly onto quartzite slab
14	Bredasdorp	Soft grey shale	Ground directly onto quartzite slab
15	Napier	Medium hard red shale	Ground directly onto quartzite slab
16	Napier	Medium hard red shale	Ground directly onto quartzite slab
17	De Hoop	Soft light red shale	Ground directly onto quartzite slab
18	Cape Point	Hard orange shale	Ground directly onto quartzite slab
19	Napier	Soft yellow limonite	Experimentally ground (like Ovahimba)
20	Bredasdorp	Soft grey shale	Experimentally ground (like Ovahimba)
21	Napier	Medium hard red shale	Experimentally ground (like Ovahimba)
22	Napier	Medium hard red shale	Experimentally ground (like Ovahimba)
23	De Hoop	Soft light red shale	Experimentally ground (like Ovahimba)
24	Cape Point	Hard orange shale	Experimentally ground (like Ovahimba)

Table 2: Sun protection factor (SPF) values of ethnographic and experimental ochre powder samples obtained by in vitro analyses

Sample	Source	Colour	SPF	σ	UVAPF	σ	Critical wavelength (nm)	σ
1	Okamanga	Dark red	13.1	1.1	4.0	0.3	389.2	0.1
2	Okamanga	Dark red	8.6	0.6	8.0	2.7	389.1	0.1
3	Okamanga	Dark red	6.8	0.5	3.5	0.4	389.6	0.0
4	Okamanga	Dark red	7.0	0.9	3.4	0.4	389.6	0.3
5	Ovinjange	Dark red	12.4	2.6	13.7	2.8	389.4	0.0
6	Otjongoro	Dark red	6.3	1.3	6.3	1.3	389.5	0.1
7	Opuwo	Dark red	10.5	3.9	11.5	3.7	389.4	0.2
8	Opuwo	Dark red	7.3	3.2	8.8	3.5	389.7	0.1
9	Opuwo	Dark red	5.5	0.9	6.3	0.9	389.8	0.2
10	Opuwo	Dark red	8.3	1.0	10.3	1.0	389.8	0.2
11	Opuwo	Dark red	4.0	0.5	4.7	0.4	390.0	0.0
12	Opuwo	Dark red	3.8	0.3	3.3	0.3	388.2	0.3
13	Napier	Yellow	6.4	2.2	5.9	1.9	387.7	0.3
14	Bredasdorp	Light grey	2.4	0.3	2.1	0.2	387.5	0.1
15	Napier	Light red	4.1	0.3	4.0	0.3	389.2	0.1
16	Napier	Maroon	7.7	3.1	8.0	2.7	389.1	0.1
17	De Hoop	Dark red	3.0	0.5	2.9	0.4	389.1	0.0
18	Cape Point	Orange-red	7.5	0.4	7.9	0.5	389.4	0.0
19	Napier	Yellow	5.6	0.2	5.4	0.2	388.4	0.1
20	Bredasdorp	Light grey	1.9	0.1	1.8	0.1	388.4	0.2
21	Napier	Light red	3.3	0.4	3.5	0.4	389.6	0.0
22	Napier	Maroon	3.2	0.4	3.4	0.4	389.6	0.3
23	De Hoop	Dark red	2.6	0.1	2.7	0.1	389.5	0.2
24	Cape Point	Orange-red	4.6	0.3	5.2	0.3	389.7	0.1

Colourimetry

As calculated from the L*a*b* coordinates (ΔE), Ovahimba ochre samples exhibit negligible differences in colour (Table 3). The colour distance between samples falls below 5 ΔE, the limit above which a colour difference is significantly perceived by humans. Ovahimba samples display the same range of hue and chroma (similar a* and b* values) as the other red ochre samples. Only lightness (L*) values are dissimilar, with Ovahimba red ochres being darker. Hues are not markedly different, with the ratios of a* to b* being relatively constant, but the brightness of Ovahimba samples is less pronounced (Table 3).

Table 3: Colourimetric L*a*b* values for experimental ochre samples

Sample	Colour	L*	a*	b*	Delta E
1	Dark red	39	32	30	
2	Dark red	37	29	28	4.1
3	Dark red	40	30	28	3.0
4	Dark red	37	29	28	4.1
5	Dark red	40	32	30	1.0
6	Dark red	40	31	29	1.7
7	Dark red	39	31	29	1.4
8	Dark red	41	32	31	1.2
9	Dark red	40	32	30	1.0
10	Dark red	39	31	29	1.4
11	Dark red	41	29	28	1.1
12	Dark red	46	24	21	13.9
13	Yellow	81	9	43	49.6
14	Light grey	88	-1.5	8	63.6
15	Light red	47	30	30	8.2
16	Maroon	52	28	28	18.7
17	Dark red	59	24	25	22.1
18	Orange-red	47	33	35	9.5
19	Yellow	71	11	43	40.4
20	Light grey	84	-1	8	60.0
21	Light red	46	24	21	13.9
22	Maroon	51	22	18	19.7
23	Dark red	56	19	18	24.5
24	Orange-red	42	30	30	3.6

Whereas red experimental samples display a mean SPF value of 6.9 and a UVAPF value of 6.3, non-red samples exhibit mean SPF and UVAPF values of 4.5. Given that the red ochre samples from Okamanga, Ovinjange and Opuwo exhibit higher in vitro SPF values than those derived from the Bokkeveld shales, it is likely that higher Fe_2O_3 contents correlate with increased in vitro SPF values. However, it is not only elemental composition that determines the colour of ochre.[52] Mineralogical and elemental composition and structural morphology, including grain size and crystallography, also influence colourimetric properties.[17]

It has been demonstrated that different ochre processing techniques result in differences in pigment powder consistency and colour[48] – an observation confirmed in this study. Powder extracted by direct grinding presents higher chroma (a* and b* values) than powder obtained by conventional grinding. Noticeable differences in colour resulting from different processing techniques are exhibited by the Napier 15 sample (ground directly onto a coarse quartzite slab as evidenced by examples from MSA and LSA contexts) and Napier 21 sample (ground between an upper and lower grindstone as done by the Ovahimba) and the Napier 16 (direct) and 22 (conventional) samples. With the exception of samples 16 and 18, SPF values increase significantly when L* is lower than 45 (Figure 3a). However, L* remains stable while SPF values increase. SPF values also increase when a* is higher than 25, although a* remains stable when SPF values increase (Figure 3b).

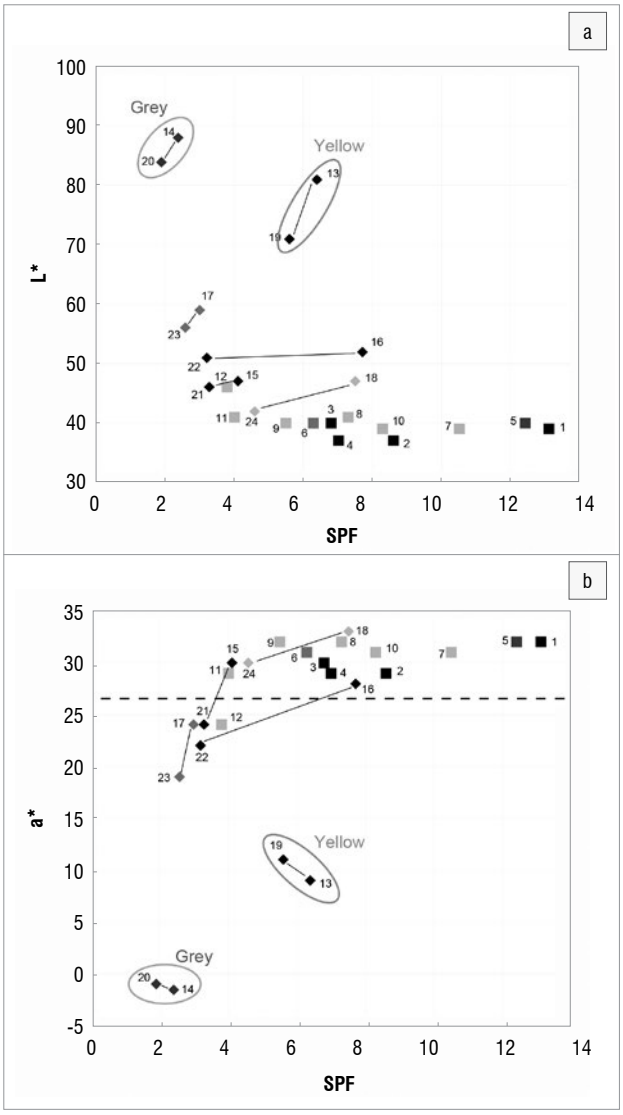


Figure 3: Bipolar plots of sun protection factor (SPF) values in relation to the colourimetric values (a) L* (the lightness–darkness axis) and (b) a* (the red–green axis).

Discussion

Hypotheses abound for human variation in skin pigmentation, with most models focusing on human depigmentation and not on the state of pigmentation of our hominin ancestors.[16] The epidermis of most primates is unpigmented because of the absence of melanocytes, suggesting that this is the primitive condition for primates. Darker skin tones conceivably emerged as a characteristic trait of *H. erectus* ca 1000 ka, possibly because a darker complexion provided superior protection against UVR for increasingly hairless hominins. As *Homo* left the African tropics, lighter skin pigmentation evolved to facilitate the synthesis of vitamin D.[53] This cline of depigmentation is evident along

the southeastern edge of southern Africa, where adequate vitamin D production can occur throughout most, but not all, months of the year. In this region, the mean daily minimum erythemal dose is not sufficient to produce vitamin D in darker (V and VI) skin types. Reduced UVR exposure and decreased potential for vitamin D biosynthesis therefore generated positive selection for skin depigmentation.

In addition to the incidence of lighter skin types amongst autochthonous groups along the southern and eastern coastline of South Africa and Mozambique[54], the preservation of the SLC24A5, TYRP1 and KITLG alleles amongst sub-Saharan populations[20] suggests that these are ancestral southern African mutations. The skin colour of southern African MSA *H. sapiens* is therefore likely to have resembled the olive-brown 'Capoid' skin type IV (Von Luschan 16 to 21) typical of some indigenous southern African groups. This skin type is characteristic of more than 90% of southern San individuals,[55] has a natural SPF of 3.5, a high tanning capacity and low susceptibility to UVR-induced damage. In terms of avoiding vitamin D deficiencies and the detrimental effects of UVR, and given the positive correlations between adequate UVR exposure and human health, an olive-brown skin tone represents the optimum skin type for inhabitants of southeastern sub-Saharan Africa. It stands to reason that, given the natural SPF of 3.5 for skin type IV, ochre samples exhibiting SPF and UVAPF values of >10 are likely to provide sufficient protection from UVR without generating vitamin D deficiencies. Additional in vivo experimental assessment is required to confirm this notion.

Conclusion

It is possible that the habitual exploitation of ochre during the MSA reflects some form of cultural adaptation to rapidly changing environmental circumstances. The habitual use of red ochre as a sunscreen may have presented an advantage for populations that migrated from higher into lower latitudes. As is the case for the positive impact of technological innovation in enhancing early human subsistence strategies,[40,56] the topical application of ochre may have served to limit the adverse effects of increasing UVR exposure. While it is difficult to establish a precise scenario for the emergence of such an innovation, one could envision a tentative situation in which the habitual use of red ochre as a sunscreen may have originally arisen locally, and perhaps in response to changing UVR exposure rates produced by alternating orbital climatic cycles,[57] subsequently providing an adaptive advantage for migrating populations. Ochre might therefore have acted as a means by which migrant populations could have traversed and settled within new ecological niches and regions incompatible with their constitutive skin colour.

It is also possible that the intensification in the exploitation of red ochre during the MSA reflects a technologically mediated response to increasingly complex social circumstances, and that this response may have resulted from efforts to satisfy a growing demand for ochre implicated in innovative functional applications. The use of red ochre as an ingredient in novel pigment-based compounds, similar to lithic hafting mastics for which direct evidence exists in MSA contexts,[39,40] strengthens the perception that the use of red ochre as a sunscreen may also be indicative of the cognitive complexity of MSA *H. sapiens*. In social terms, the ability to create and maintain durable cooperative relationships during the MSA is illustrated by the relatively extensive geographic distribution of Still Bay and Howieson's Poort sites across southern Africa.[58] This distribution signifies that human groups were integrated into structured social networks similar to those documented for ethnographically known foragers from at least 75 ka. It must, however, be brought to mind that the exploitation of ochre is not limited to *H. sapiens* and that the capacity to attribute specific meaning to conventional signs is not unique to our species.[30-32] Moreover, although current evidence concerning ochre exploitation supports proposals for socially complex and emotionally driven prehistoric lifestyles, it does not provide explicit evidence for symbolic thought and behaviour.[59]

While suggestions concerning the efficacy of red ochre as a sunscreen are intriguing, the results presented here should be regarded as preliminary. As an initial screening method, in vitro tests provide a reasonable comparison of the relative SPF protection offered by the ochre samples. To obtain confirmation that red ochre does provide a significant degree of protection from UVA and UVB radiation, ongoing research is exploring the sun protection efficacy of ochre by way of in vivo SPF assessment. The effects of chemical and physical characteristics besides colour, including mineralogical and elemental composition and structural morphology, also necessitate further exploration before the efficacy of ochre as a sunscreen for early *H. sapiens* can be validated. The establishment of analytical baselines for modern pigment-based compounds is expected to enhance current understandings of the applications for which prehistoric mixtures may have been used. Evidence for knowledge concerning the chemical and physical properties of ancient ingredients, and how these may change when mixed together, can add valuable insight into the minds of our ancestors.[60] Future research should endeavour to identify correlations between increased periods of ochre exploitation and known instances of sudden changes in climate. It is conceivable that increases in the amount of ochre may coincide with periods during which amplified rates of UVR may have posed an increased risk to human health.

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Authors' contributions

R.F.R. developed the research concept; R.F.R. and F.D. undertook the field research; R.F.R. and B.S. performed the experimental research; F.D., B.S. and L.D. performed the analyses; and R.F.R. and F.D. wrote the paper.

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Investigating the risk of lightning's pressure blast wave

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We investigated the pathology of human trauma associated with lightning's pressure blast wave. Within what range is a human at risk and what are the risks? Two theories for the trauma currently exist: the flash moisture vaporisation theory and the sixth mechanism theory. We performed a simple proof-of-concept experiment in a high-voltage laboratory to determine which theory makes for better predictions. The experiment confirmed the existence of a non-discriminant pressure blast wave around a spark in air. The lightning data were compared with the known medical data. Findings may now help explain some of the more curious lightning injury patterns seen on lightning-strike victims.

Introduction and background history

It is well known that injury from lightning is capricious and unpredictable. Clothing may be torn off, which can lead to the suspicion of foul play if the lightning aspect is obscure, or unwitnessed. The clothing is typically ripped open as if by an internal explosion, and belts and boots may be similarly ruptured.[1] Two theories currently exist as to why the clothing of a victim of a lightning strike ruptures, tears and tatters: the flash moisture vaporisation theory and the sixth mechanism theory.

Flash moisture vaporisation theory

Ohashi et al.[2-4], through a process of elimination, came to the conclusion that blast injury results from the explosive vaporisation of superheated water along the path of the surface flashover. To investigate their hypothesis, an experimental model of a lightning strike was created in the adult Wistar rat. Saline-soaked blotting paper was used to simulate wet clothing or skin, and an artificial lightning impulse was injected. The resultant lesions were consistent with their hypothesis that the blast was reinforced by the concussive effect of water vaporisation. Solid organ rupture, pulmonary and intracranial haemorrhage, and skull fracture were created in a model of a direct lightning strike in rats. These injuries were thought to be caused by the concussive effect of rapidly expanding steam produced by superheating water on the body surface by a surface flashover (streamer). This mechanism has been proposed to explain some of the common findings in patients who have sustained lightning injuries.

Sixth mechanism theory

The sixth mechanism theory was recently proposed. The sixth mechanism of lightning injury may be thought of as a 'pressure-shock wave' which is directly proportional to the current of the lightning discharge, and which is present immediately surrounding lightning's luminous channel. A laboratory experiment was designed which helped confirm the sixth mechanism's existence. Its existence may also help explain some of the more curious lightning injury patterns seen on lightning-strike victims.[5]

Cooray et al.[6] reported that injuries can be caused by shock waves created by the lightning channel; however, they did not commit to a specific distance within which a victim would be at risk from blast wave injury. During a lightning strike, the channel temperature is raised to about 25 000 K (24 727 °C) in a few microseconds, and as a result, the pressure in the channel may increase to several atmospheres. The shock wave associated with the lightning flash may reach overpressures of 10–20 atmospheres (1013–2027 kPa) in the vicinity of the channel. In addition to causing damage to the ears and eyes, this shock wave may also cause damage to other internal organs such as the spleen, liver, lungs and bowel tract. Moreover, it may suddenly displace the victim from one place to another, causing head and other traumatic injuries.[6]

If flash moisture vaporisation theory were indeed a reality, why are forensic pathologists not reporting scald burns on lightning strike victims? Superheated water would likely cause scald burns on the skin of lightning fatality victims. Forensic pathologists instead report scorch burn wounds on the skin, singeing of hair and torn-and-tattered clothing akin to explosive (blast) barotrauma.[1,7]

Uman et al.[8] published a paper on a shock wave from a 4-m spark. The shock wave emitted by a 4-m spark of energy 2 x 104 J was measured at distances from spark midgap of between 0.34 m and 16.5 m. Close to the spark, a single dominant shock wave was observed; farther from the spark, a number (generally 3 or 4) of significant shock waves was observed. For distances less than 2 m, both the shock overpressure and the duration of the overpressure were a factor of between 1.5 and 5 lower than predicted by cylindrical shock-wave mathematical theory. The discrepancies between the experimental data and cylindrical shock-wave mathematical theory were partially explained by consideration of the spark channel tortuosity.

Plooster[9] studied the cylindrical pressure wave resulting from instantaneous energy release along a line in a quiescent atmosphere by numerical integration of the equations of gas dynamics. An approximate equation for the radial dependence of shock strength, applicable to most of the numerical solutions, was presented. Plooster's experimental measurements of shock strengths from detonation of long explosive charges were shown to be in relatively good agreement with the numerical solutions.

Previously, wires were passed through gels to investigate the nature of the shock wave.[5] What would happen if there were no wire? Would the blast effect simply dissipate on the surface of the skin? There is nothing in the

medical literature that suggests that the pressure blast wave of a lightning strike would rip a cavity in human flesh. More rigorous scenarios and analyses are needed. The lightning data with regard to structural risk do not seem to align well with the medical data. It is for this reason that an experiment without a wire path for the current needed to be designed. The experiment also needed to be constructed in such a way as to focus on the real questions: at what range is a human at risk and what is that risk?

Materials and methods

A simple proof-of-concept experiment was created to determine which theory makes for better prediction with regard to lightning explosive barotrauma. Previous experimental set-ups were examined[8-10] and the 'sixth mechanism experiment' was designed (Figure 1).

The experiment was conducted to test for the presence or absence of a blast wave surrounding lightning's luminous channel in air. The testing took place at the University of the Witwatersrand's School of Electrical and Information Engineering High Voltage Laboratory and utilised an 8/20-μs current impulse generator (built in-house at the School of Electrical and Information Engineering's High Voltage Laboratory). The magnitude of the current impulse was measured by means of a Pearson coil (model 301X, Pearson Electronics, Palo Alto, CA, USA) connected to a Rigol DS 1064B digital oscilloscope. An isolation transformer was used to protect the oscilloscope from any surges that may have occurred on the mains supply during the experiments. It must be noted that this wave form does not represent that of natural lightning, which has a longer rise and fall time.

The 8/20-μs waveform is commonly used to simulate induced lightning currents and was thus selected for the purposes of our experiment. These waveforms are indicative of induced currents from a nearby direct strike. The energy is lower (because of the shorter duration) and therefore this waveform seemed suitable for a proof-of-concept approach.

A further consideration with respect to this waveform was that the current waveform of a direct lightning strike is modelled as a 10/350-μs waveform. This means that the rise time (time to get from 10% of peak to 90% of peak) is 10 μs. The fall time (time to reach 50% of the peak value) is 350 μs. A lightning waveform, as a consequence of its long duration, delivers a significant amount of energy, as one would expect from a direct lightning strike. In a laboratory environment, this energy is difficult to manage.

The experiment consisted of discharging high-voltage sparks through a 250 mm x 250 mm piece of dry graph paper, saline-soaked graph paper and distilled water soaked graph paper. Distilled water was chosen for its similarity to rain water and saline was chosen as an alternative to sweat. The peak current versus the maximum diameter of tattering were then plotted on the respective graph papers. All graph papers were tested at generator charging voltages of 15 kV, 18 kV and 20 kV. These voltages equated to peak currents of 24.5 kA, 29.2 kA and 32.5 kA, respectively. Maximum and minimum diameters were then measured with scientific callipers. Finally, an average diameter for the irregular tears was determined using mathematical principles. Because of the fact that risk is determined as distance from lightning's luminous channel, the perimeter length (circumference) of the tear was not measured.

If sixth mechanism theory (meaning a pressure blast wave around lightning's channel) were indeed a reality, all papers – wet and dry, conductive and non-conductive – would show tearing and tattering. If flash moisture vaporisation theory were the reality, only the wet papers would tear and tatter, or there would be more tearing and tattering in the wet papers.

The maximum radial diameters of the tearing and tattering probably would provide the best indication as to the range within which a human would be at risk and what that risk would be.

Preliminary findings are presented here; a more comprehensive data set is required to test the reliability and validity of the results.

Results

Figure 2 and Figure 3, respectively, show the dry and saline-soaked graph papers after they were subjected to an impulse. The majority of knowledge related to lightning parameters has been derived by 'scaling up' the equivalent information obtained during experimentation using long linear electrical discharges generated under laboratory conditions.[8]

The minimum, maximum and average diameters of the resultant tears after dry, distilled water- and saline-soaked graph papers were subjected to increasing impulses are shown in Table 1.

Figure 4 shows the maximum tearing diameters against the peak generated currents for dry, distilled water- and saline-soaked graph papers. Trendlines showed greater tearing of the paper soaked in 0.9% saline than of the dry or distilled water soaked papers. The tearing diameter of the paper soaked in 0.9% saline was higher than those for the dry and water-soaked papers. However, it can be seen that there is not much difference between the maximum tearing diameter for the dry paper and that for the paper soaked in distilled water.

Tearing and tattering occurred in all the papers, confirming the existence of a non-discriminant blast wave around a long, linear spark (lightning's luminous channel).

The greater extent of tattering in the saline-soaked paper could be because of the conductive nature of saline. The saline-soaked paper probably 'held on' to more charge than the other specimens.

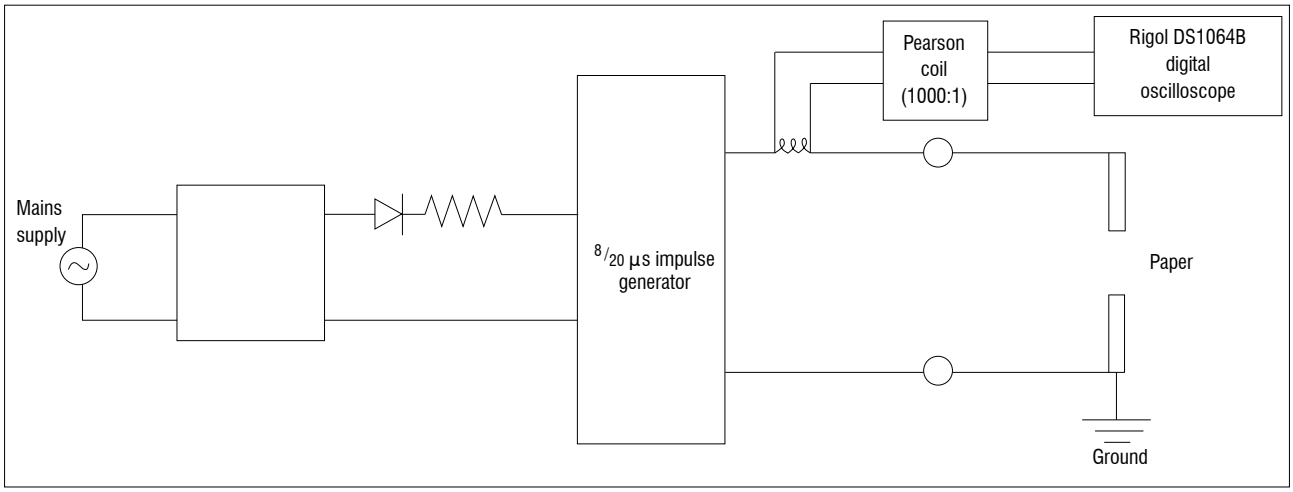


Figure 1: The 'sixth mechanism experiment': Physical layout of the current impulse generator and test object (graph paper).

Discussion

We know that there exists a pressure blast wave around lightning's luminous channel. We have known about it since the time of Gaius Plinius Secundus, better known as Pliny the Elder (23 AD – 79 AD). Pliny the Elder was a Roman author, naturalist and natural philosopher, as well as naval and army commander. His dictum was 'the man who sees the lightning flash and hears the thunder, is not the one to be struck'[11].

One can hear thunder from as far away as 25 km,[12] which means that there is a tremendous amount of energy involved in the generation of thunder. However, before thunder occurs, there is a pressure blast wave. This pressure blast wave is caused by the superheating of the air around the lightning bolt, which travels at supersonic speeds. It is this supersonic blast wave which decays, within metres, and transforms into thunder. Many people think that lightning injuries in humans are chiefly caused by lightning's electricity and heat. While this belief is true for the vast majority of lightning-related deaths and injuries, the accompanying pressure blast wave can also do serious harm.

As mentioned, the temperature of the lightning bolt channel is raised to about 24 727 °C in a few microseconds. This increase causes the temperature around the channel to rise suddenly, resulting in the pressure in the channel suddenly increasing to several atmospheres. Charles's law dictates that the volume of a gas is directly proportional to its temperature, that is, the higher the temperature of a gas, the greater its volume. The combined and ideal gas laws therefore predict pressure changes with temperature changes. This sudden rise in volume causes a sudden cylindrical-shaped pressure shock wave, which may reach pressures of more than 10–20 atmospheres (1013–2027 kPa) in the vicinity of the lightning bolt channel. This energy is enough to form a small crater in a concrete pavement. When a lightning flash makes contact with rocky soil, the electric current tends to follow the interstices between the rocks or cracks. Rocks may be split asunder or even thrown aside with explosive violence.[13] Whether this effect is a result of cracks being filled with moist soil (flash moisture vaporisation theory) or solely a result of the lightning's pressure blast wave (sixth mechanism theory) has been the topic of debate.

Lightning's pressure blast wave has been known to tear and tatter clothing, indirectly fracture long bones, rupture a person's eardrums and damage their lungs. The blast causes a pocket of air behind the sternum (pneumomediastinum)[14] and it may cause injury to the chest wall and lungs[15]. These findings are similar to those one would expect to find in victims of bomb explosions. The force may cause a victim to fall, causing head and other traumas. Lightning strikes have even been known to cause shrapnel injury– one victim had multiple small fragments of shattered concrete pavement embedded in her skin.[16]

The human body is paradoxically both very robust and very fragile. Humans can survive relatively high blast overpressures without experiencing blast-related pathologies.[7] Thus far, blunt force trauma injuries, torn and tattered clothing, fractures, traumatic perforation of tympanic membranes, lung contusion and haemorrhage, and pneumomediastinum, as a result of lightning strikes, have been documented in the medical literature. The aforementioned injuries appear to represent the documented risks, seen in practice, to date.[5]

The findings reported in flash moisture vaporisation theory can all adequately be explained by sixth mechanism theory. The purpose of this paper was to compare the theories and determine which theory provides for better predictions with regard to lightning explosive barotrauma.

A blast consists of a wave of compression passing through the air. The velocity of the shock wave depends on its distance from the epicentre;

Table 1: Minimum, maximum and average diameters (mm) of tears in dry, distilled water- and saline-soaked graph papers after being subjected to different impulses (kA)

Peak current (kA)	Dry paper			Water-soaked paper			Saline-soaked paper		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
24.5	18	29	21	15	20	15	13	18	15
29.2	10	24	15	8	22	10	29	56	18
32.5	13	43	20	25	39	23	40	80	40

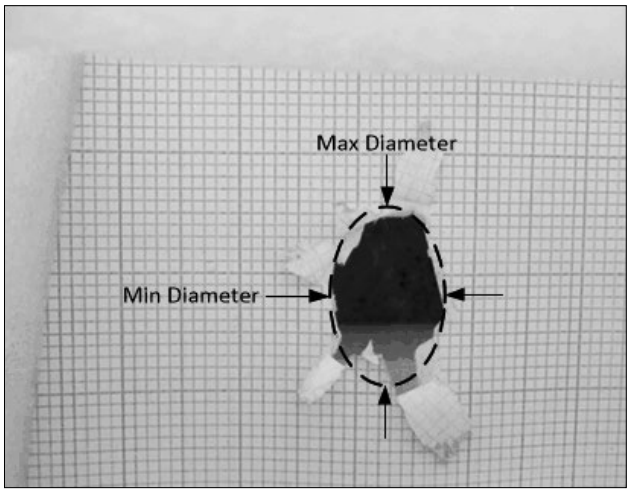


Figure 2: Dry graph paper after being subjected to an impulse of 24.5 kA (generator charging voltage of 15 kV). The maximum and minimum diameters of the tear in the dry graph paper were 29 mm and 18 mm, respectively.

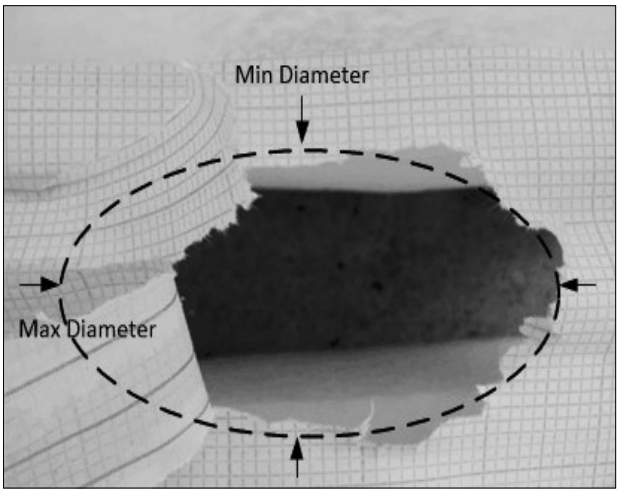
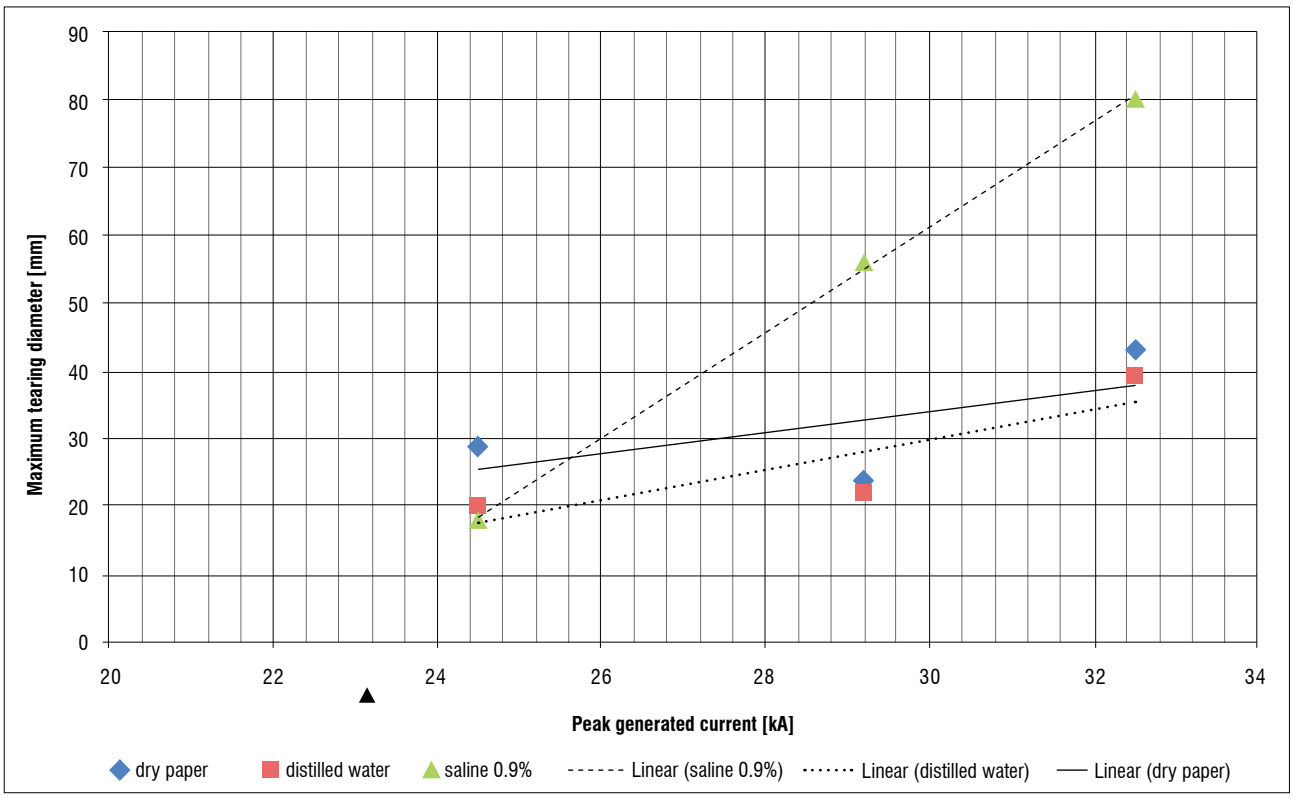


Figure 3: Saline-soaked graph paper after being subjected to an impulse of 32.5 kA (generator charging voltage of 20 kV). The maximum and minimum diameters of the tear in the 0.9%-saline-soaked graph paper were 80 mm and 40 mm, respectively.



Spark gap = 5 mm

Figure 4: Graph demonstrating incremental tearing diameter in dry, distilled water- and saline-soaked papers.

the velocity is many times the speed of sound at the start, but rapidly decreases as the shock wave expands outwards. The magnitude of the blast varies with the energy released and distance from the epicentre; the intensity obeys the inverse square law. An explosion classically gives rise to a narrow wave of very high pressure which expands concentrically from the seat of the explosion at about the speed of sound. The pressure is exceptionally high at the front of the wave but decreases towards its rear and becomes a slight negative pressure, or partial vacuum, before the wave is complete. Such a wave will temporarily engulf a person as it moves through them.[7]

The generation of cylindrical shock waves by the release of energy along a line in a gas has not been as thoroughly studied as the analogous point-source spherical wave problem. Yet there are a number of phenomena, both natural and artificial, which closely resemble line disturbances. Artificial line sources include exploding wires, long explosive charges, electric sparks, and supersonic aircraft or projectiles – lightning discharge being the outstanding natural phenomenon.

Lee[17] combined results from several sources to determine the intensity of the pressure from the stroke current magnitude and the distance from the stroke terminal to a susceptible structure. Hill[18] also looked at peak shock pressures from the lightning stroke channel. Their findings were chiefly aimed at lightning protection of structures and their findings need to be aligned with the medical data.

If one knew the initial conditions (thermodynamics and flow parameters as a function of radius at selected instants of time), one could possibly numerically solve this problem; however, there always are varying initial conditions, for example the magnitude and strength of the lightning discharge.

Depending on what literature one reads, there is also data from weapons tests and blast studies to assess the effect of blast overpressure on structures and people.[19-21] These data provide some guidance on the possible effects of explosions on humans: personnel are typically knocked down by explosive overpressures in air at 7–10 kPa (1.0–1.5 psi); eardrums typically rupture at 35–100 kPa (5.1–14.5 psi); and lung damage is induced at approximately 200–500 kPa (29.0–72.5 psi).

The human body can survive relatively high blast overpressure without experiencing barotrauma. A 34-kPa (5-psi) blast overpressure will rupture eardrums in about 1% of subjects, and a 310-kPa (45-psi) overpressure will cause eardrum rupture in about 99% of all subjects. A study by Richmond et al.[22] suggests a minimum threshold of about 20 kPa (2.9 psi) to produce minor eardrum ruptures.

Theoretically, one could take the aforementioned sixth mechanism laboratory experiment results, together with the known medical literature and the known high-explosive overpressure constants and consequences, and model the risks of natural lightning.

Conclusion

In our laboratory experiment, the diameter of the tear created by a simulated lightning strike was larger in the paper soaked in 0.9% saline than in the dry or water-soaked papers. These findings concur with those of Ohashi et al.[2-4] Despite the difference in size, tearing and tattering occurred in all the papers, suggesting the existence of a non-discriminant blast wave around a long, linear spark (lightning's luminous channel).

The data obtained from our laboratory experiment align relatively well with high-explosive overpressure observations in the field. Sixth mechanism theory would therefore appear to make for better predictions in the field than flash moisture vaporisation theory.

These findings do, however, pose further questions, such as: what parameters, e.g. distance to strike and current level, are necessary to see such blast damage and/or injuries? The answers to these questions are not trivial and the real test will lie in the duplication of these findings in other laboratories, in practical field assessments and in forensic pathology investigations.

Knowledge and insight into lightning's pressure blast wave may have direct and indirect applications to those working in the fields of lightning injury and lightning protection.[23]

Acknowledgements

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Authors' contributions

The work presented in this paper extends and contributes to research in the field of lightning injury mechanisms. R.B.'s contribution was the alignment of the medical, forensic and lightning data. N.J.W.'s contribution was the set-up and performance of the sixth mechanism experiments. Both authors contributed towards the analysis of the results.

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Youngest dinocephalian fossils extend the *Tapinocephalus* Zone, Karoo Basin, South Africa

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The dinocephalians (Synapsida, Therapsida) were one of the dominant tetrapod groups of the Middle Permian (Guadalupian Epoch, ~270–260 million years ago) and are most abundantly recorded in the *Tapinocephalus* Assemblage Zone (AZ) of the Main Karoo Basin, South Africa. Dinocephalians are thought to have become extinct near the top of the Abrahamskraal Formation of the Beaufort Group and their disappearance is one criterion used to define the base of the overlying *Pristerognathus* AZ. Because of the abundance of fossils in the Karoo, the Beaufort Group biozones form the biostratigraphic standard for later Permian terrestrial tetrapod ecosystems, so their stratigraphic delineation is of great importance to Permian palaeobiology. We report two new specimens of the rare tapinocephalid dinocephalian *Criocephalosaurus* from the lowermost Poortjie Member, which makes them the youngest dinocephalians known from the Main Karoo Basin and extends the *Tapinocephalus* AZ from the Abrahamskraal Formation up into the Teekloof Formation. The extension of the *Tapinocephalus* AZ relative to the lithostratigraphy potentially affects the biozone or biozones to which a fossil species can be attributed; this extension has implications for biostratigraphic correlations within the Main Karoo Basin as well as with other basins across Gondwana. These discoveries also indicate that a population of herbivorous tapinocephalids survived as rare constituents of the tetrapod fauna after most generic richness within the clade had already been lost.

Introduction

The Dinocephalia are a clade of mostly large basal therapsids[1] that were widely distributed around Pangaea in the Guadalupian. The group is known from Middle Permian basins in Russia, Central Asia, China, Brazil, Tanzania, Zambia and Zimbabwe[2-10], but is best represented in the Abrahamskraal Formation of the South African Beaufort Group[11] (Figure 1). Three dinocephalian families have been found in South Africa: the Anteosauridae, the Titanosuchidae and the Tapinocephalidae. The clade is most abundant and taxonomically diverse in the *Tapinocephalus* Assemblage Zone (AZ) — which has yielded all known species of titanosuchids and 18 of the 22 described species of tapinocephalids — but they are also found in the underlying *Eodicynodon* AZ in which they are represented by only two species, *Tapinocaninus pamelae* and *Australosyodon nyaphuli*.[12,13] Together, the *Eodicynodon* and *Tapinocephalus* AZs are the oldest two biozones of the Beaufort Group.[11]

Although dinocephalians were an important constituent of early therapsid faunas, they disappear from the fossil record at the top of the Middle Permian *Tapinocephalus* AZ[11,14,15] and in the Main Karoo Basin their last occurrence is a major criterion defining the base of the overlying *Pristerognathus* AZ[16]. Lithostratigraphically, the *Tapinocephalus* AZ corresponds to the upper Abrahamskraal Formation, apart from its uppermost strata, while the overlying *Pristerognathus* AZ is considered to extend through the uppermost part of the Abrahamskraal Formation and the Poortjie Member of the Teekloof Formation.[17] Changes in the lithostratigraphic position of the contact between the *Tapinocephalus* and *Pristerognathus* AZs have consequences for stratigraphic correlation, as well as palaeobiodiversity studies, because the biozones of the Beaufort Group represent a global reference for terrestrial tetrapod faunas from the Middle Permian to the Early Triassic.[18-21] Furthermore, radiometric dates have recently been determined for several zircon-bearing volcanic ash horizons within the Beaufort Group,[22] so accurate chronology of tetrapod evolutionary patterns in the Permian is dependent on good biostratigraphic resolution relative to the lithostratigraphy.

Two dinocephalian crania, one with associated postcranial fragments including two articulated vertebrae with a high neural spine, have recently been recovered from the basal Poortjie Member of the Teekloof Formation. These discoveries provide new biostratigraphic data that necessitates a shift in the lithostratigraphic extent of the *Tapinocephalus* AZ.

Institutional Abbreviations

BP, Evolutionary Studies Institute (formerly Bernard Price Institute for Palaeontological Research), Johannesburg; CGS, Council for Geosciences, Pretoria; KM, McGregor Museum, Kimberley; NHMUK, Natural History Museum, London, UK; SAM, Iziko: South African Museum, Cape Town.

Material

SAM-PK-K10888 is a partial skull and some associated postcranial elements that were discovered by J.A. and Madelon Tusenius on the Beaufort West commonage, Western Cape Province, to the southwest of that town (32° 23.25' S, 22° 33.24' E). Although the specimen was found ex situ, the low relief of the area and the sub-horizontal strata constrain the provenance of the specimen to a mudrock horizon exposed on the southern side of the valley (Figure 1). Reference to the published 1:250 000 geological map for the area (1979, Beaufort West Sheet, Geological Survey of South Africa 1:250000 Series), combined with stratigraphic fieldwork in the area by the authors, shows that this locality is within the lower Poortjie Member of the Teekloof Formation. As the combination of low relief and poor rock exposure was not conducive to measuring a stratigraphic section between the locality and the base of the Poortjie Member, a stratigraphic section was instead measured between the locality and

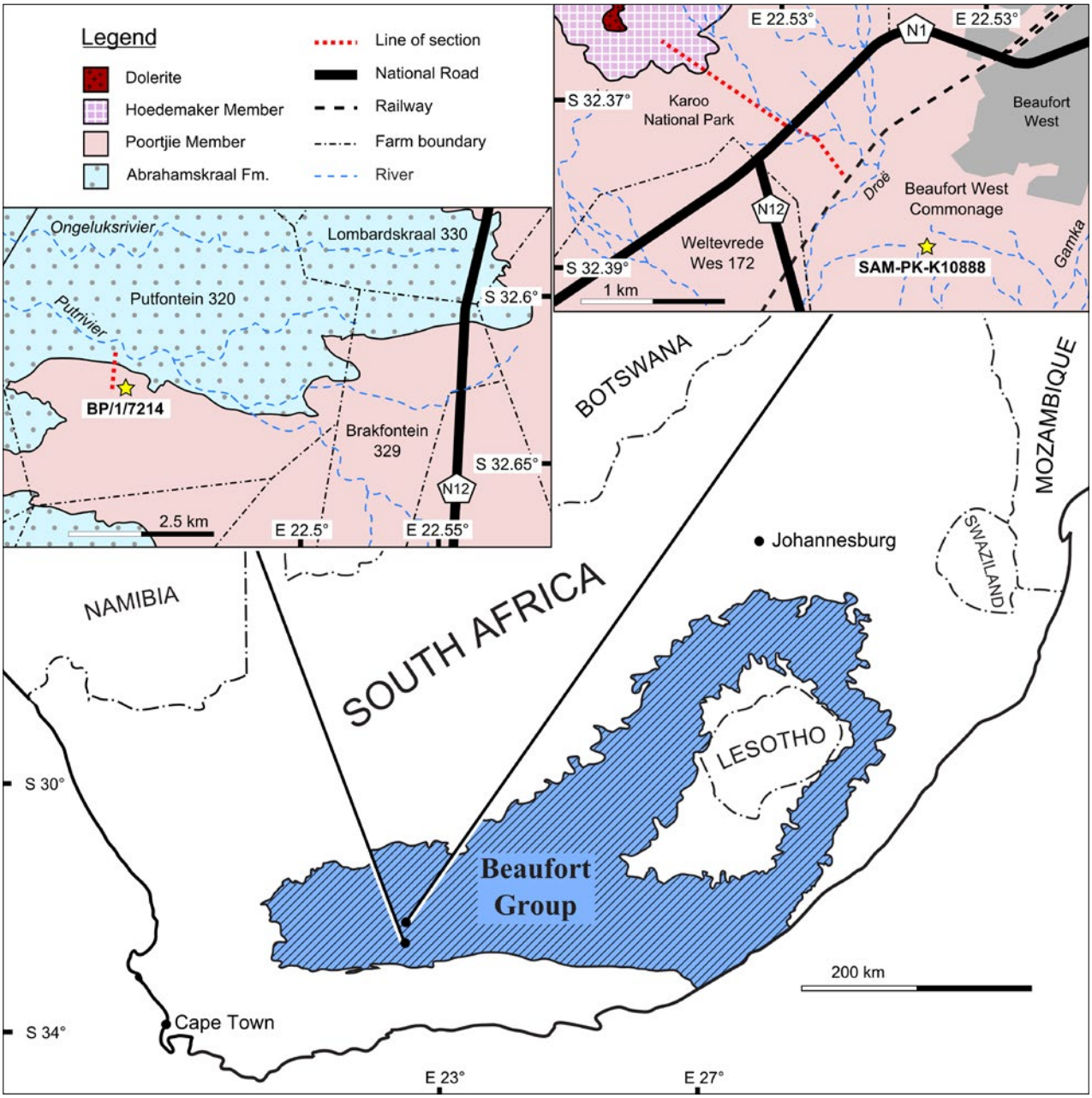


Figure 1: Map of the southwestern Karoo Basin, showing the localities of SAM-PK-K10888 and BP/1/7214 and the line of sections presented in Figure 2.

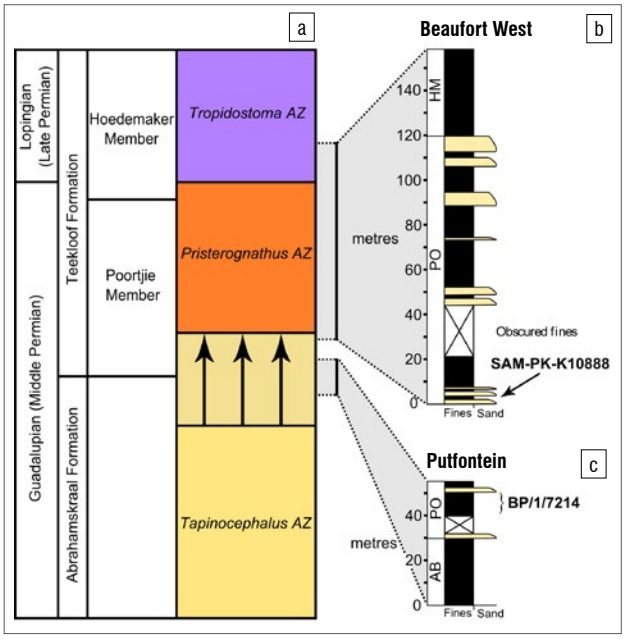
the base of the overlying Hoedemaker Member, using a Jacob's staff and Abney level. This section indicated that the specimen occurred in a horizon 116 m below the top of the Poortjie Member (Figure 2). The Poortjie Member in the Beaufort West area is 160–182 m thick,[23,24] in which case this specimen can be constrained to 40–70 m above the base of the Poortjie Member. This position is consistent with altitude readings for the locality and the mapped base of the Teekloof Formation (1979, Beaufort West Sheet, Geological Survey of South Africa 1:250000 Series), which provides an estimate of 50–60 m, although this may be affected by minor local folding.

The second specimen, BP/1/7214, is also a partial skull and was found by M.D. and Christen Shelton, 70 km further south of Beaufort West on the farm Putfontein, Beaufort West district (32° 37.644' S, 22° 26.366' E). Like SAM-PK-K10888, BP/1/7214 was found ex situ in a stream bed but its provenance can be constrained to a 10-m thick mudrock horizon immediately below the second major sandstone body of the Poortjie Member. The specimen therefore originated 10–20 m above the base of the Poortjie Member (Figure 2).

Description

SAM-PK-K10888 and BP/1/7214 have very similar morphologies (Figure 3). Both comprise the posterior two-thirds of a skull roof up to the posterior border of the orbits and the occiput, although BP/1/7214 is more extensively weathered. SAM-PK-K10888 also preserves the basicranium (Figure 3d). In dorsal view, both specimens display a broadly elliptical shape resulting from the broad frontals being bordered by the narrow interorbital region anteriorly and the narrow temporal roof posteriorly (Figure 3a, 3e).

Although both specimens lack the anterior portion of the skull, they are clearly identified as tapinocephalid dinocephalians by the anteroventral rotation of the occiput and by the presence of pronounced cranial pachyostosis. Furthermore, SAM-PK-K10888 and BP/1/7214 present a set of characters that allow their referral to the tapinocephalid genus *Criocephalosaurus* (replacement name for *Criocephalus* since 2002).[25,26] These include the close proximity of the orbits to one another and their anterior position on the skull compared to other tapinocephalids, a long pineal canal, and an acute angle between the median line of the



AB, Abrahamskraal Formation; HM, Hoedemaker Member; PO, Poortjie Member.

Figure 2: (a) Extension of the *Tapinocephalus* Assemblage Zone (AZ) into the lower Teekloof Formation. Former extent of biozones after Smith et al.[17] Approximate position of the Guadalupian–Lopingian boundary after Rubidge et al.[22] Arrows indicate the extension of *Tapinocephalus* AZ into the Teekloof Formation. (b) Stratigraphic section measured at Beaufort West between the level of the SAM-PK-K10888 locality and the lower Hoedemaker Member. (c) Stratigraphic section on the farm Putfontein.

occiput and the skull roof.[9,25,27,28] Compared with other specimens of *Criocephalosaurus*, the cranial roof of both SAM-PK-K10888 and BP/1/7214 displays moderate pachyostosis that increases the cranial width across the frontals and deepens the parietal along the pineal canal, as is the case in the genotype (KM5138) and the referred specimen (NHMUK R36626). However, the preserved portion of the orbital region in both SAM-PK-K10888 and BP/1/7214 also shows only minor thickening of the prefrontal dorsally and of the postorbital posteriorly (Figure 3b, 3c, 3f and 3g), unlike other examples of *Criocephalosaurus*. This difference may be related to their size, as the two new specimens are the smallest representatives of the genus, with postorbital skull lengths (from the posterior border of the orbit to the posterior tip of the temporal roof) of 160 mm (SAM-PK-K10888) and 169 mm (BP/1/7214).

The parietal in both specimens is a small but deep bone extending across the posteriorly narrowing intertemporal region. In this latter character, SAM-PK-K10888 and BP/1/7214 differ from KM5138, CGP/1/846 and NHMUK R36626, in which the intertemporal region is broad throughout. In SAM-PK-K10888, the posterior portion of the cranium is fractured, creating a roughly sagittal section through the cranial roof, allowing the long pineal canal to be seen (Figure 3h). The canal is orientated parallel to the long axis of the cranium, as in NHMUK R36626. The posteriorly facing pineal opening is large and is surrounded by a thick rim, which is elevated from the parietal surface as in KM5138, CGP/1/846 and NHMUK R36626; this rim contributes to the conical appearance of the posterior end of the skull. The preserved portion of the occiput of SAM-PK-K10888 is formed by the tabular and postparietal bones (Figure 3d), which are elongated dorsoventrally as in the only other specimen of *Criocephalosaurus* that possesses a comparably well-preserved occiput (NHMUK R36626).

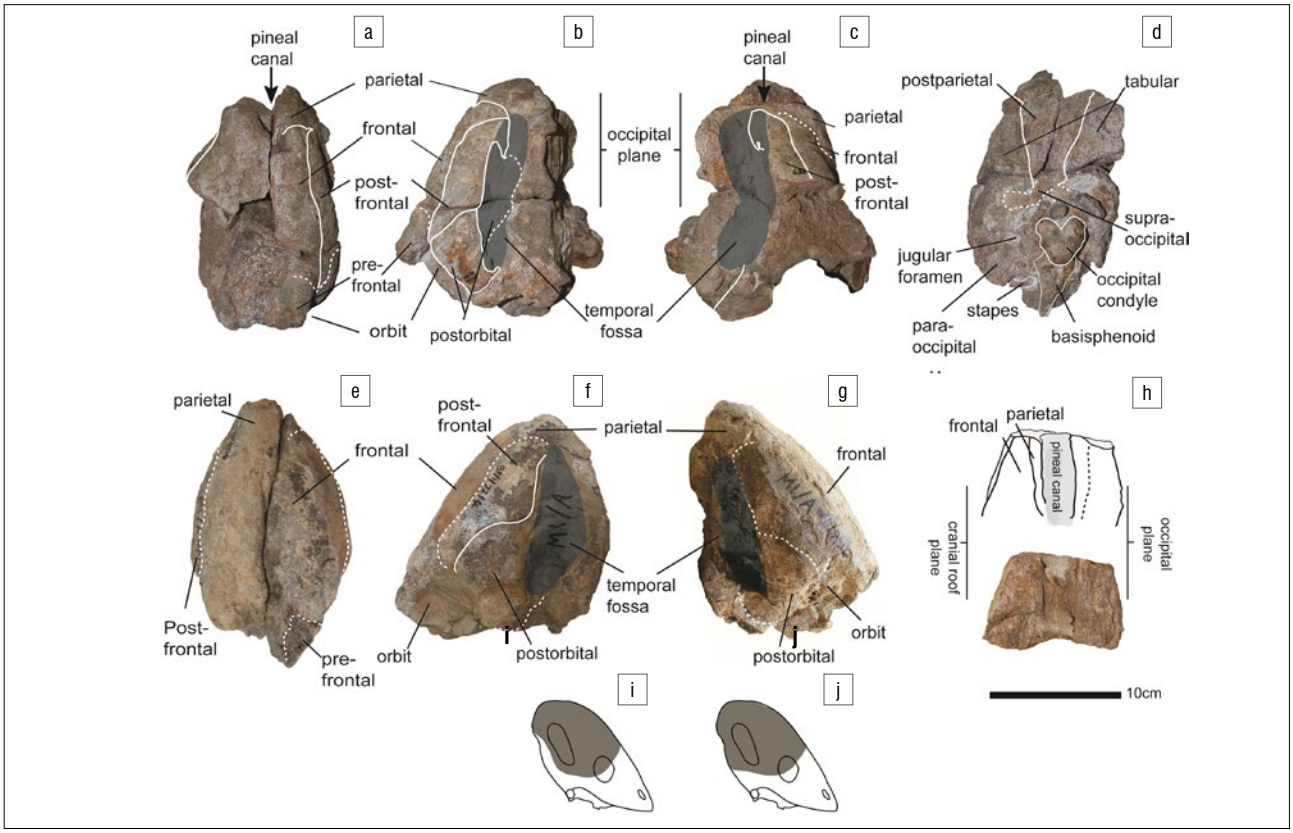


Figure 3: Photos of the specimens (a–d) SAM-PK-K10888 and (e–g) BP/1/7214 showing (a,e) dorsal view, (b,f) left lateral view, (c,g) right lateral view and (d) occipital view. (h) View of sagittal plane on right posterior part of the skull of SAM-PK-K10888, showing the pineal canal orientated parallel to the occipital plane. (i, j) Idealised skull of *Criocephalosaurus* (redrawn from Boonstra[14,28]) showing the portions preserved in (i) BP/1/7214 and (j) SAM-PK-K10888.

Discussion and conclusions

The genus *Criocephalosaurus* has two described species: *C. vanderbyli* Broom 1928, the holotype of which is a weathered cranial roof, and *C. gunyankaensis* Boonstra 1968, which was based on four cranial roofs briefly described by Boonstra[9] and only later referred to *Criocephalus*.[28] The latter specimens are now all missing. A few other incomplete crania were referred to the genus by Boonstra[28], but a survey of museum collections has yielded only four specimens that can reliably be identified as *Criocephalosaurus*: KM5138 (holotype), CGP/1/846, NHMUK R36626 and BP/1/1582. Although specimens SAM-PK-K10888 and BP/1/7214 can be confidently identified as *Criocephalosaurus*, their poor state of preservation does not allow their identification to species level.

Both SAM-PK-K10888 and BP/1/7214 fall within the lower size range of tapinocephalids and are the smallest known examples of *Criocephalosaurus*. Both specimens show only a moderate degree of pachyostosis of the postorbital bar and cranial roof. The latter is steadily reduced posteriorly from the level of the mid-temporal fenestra leading to the conical appearance of the back of the skulls (best illustrated in Figure 3e). Both the overall lesser extent of pachyostosis and the pronounced conical form of the skull differentiate SAM-PK-K10888 and BP/1/7214 from larger specimens, although CGP/1/846 demonstrates a slight tapering of the posterior skull roof towards the pineal opening. Because the degree of pachyostosis is associated with ontogeny in tapinocephalids,[29,30] it is possible that these two specimens represent sub-adults; however, their incompleteness prevents the definitive identification of unambiguous juvenile morphology (e.g. unfused sutures). The fact that both specimens bearing the more gracile morphology occur in the lower Poortjie Member, whereas all larger existing specimens occur in the underlying Abrahamskraal Formation, may also be of significance but this can only be elucidated by the discovery of further material.

The stratigraphic position of the *Tapinocephalus–Pristerognathus* AZ boundary relies on the current definition of the *Pristerognathus* AZ, which is described as 'low diversity dominated by [the dicynodont] *Diictodon* in association with [the therocephalian] *Pristerognathus* and the absence of dinocephalian fossils that are a prominent component of the underlying fauna'[16]. Because both *Diictodon* and *Pristerognathus* are known from the underlying *Tapinocephalus* AZ and the dominance of *Diictodon* continues into the overlying *Tropidostoma* AZ,[17] the *Pristerognathus* AZ can only maintain its integrity when described as an 'interval zone'[31] between the last appearance of dinocephalians and the first appearance of the dicynodont *Tropidostoma*. This lack of new taxa in comparison with the *Tapinocephalus* AZ has in fact led to doubt over the validity of the *Pristerognathus* AZ.[21]

Although it is acknowledged that a biostratigraphic review is required for this interval, the work for which has already begun,[32] the last occurrence of the previously dominant dinocephalians remains a biostratigraphically important event. Despite reservations over the definition of the *Pristerognathus* AZ, we therefore recognise a biostratigraphic distinction between the dinocephalian bearing *Tapinocephalus* AZ and the dinocephalian deficient assemblages above, at least within the Main Karoo Basin. The discovery of tapinocephalids in the lowermost Poortjie Member demonstrates that the dinocephalian record extends into the Teekloof Formation of the Beaufort Group (Figure 2a), and this notion is supported by a probable titanosuchid (BP/1/7184) from the lowermost Poortjie Member near Sutherland.[32] Consequently, the *Tapinocephalus* AZ should be extended by a commensurate degree into the lower Poortjie Member, meaning its upper boundary is therefore correspondingly younger than previously understood.

Regionally, an upward shift in the stratigraphic position of the *Tapinocephalus–Pristerognathus* AZ boundary has implications for the biozone designation of fossil material in existing collections and thus of individual genera. For instance, the extension of the *Tapinocephalus* AZ up into the lower Poortjie Member could constrain the therocephalian *Scylacosaurus* (through specimen SAM-PK-10530) and varanopid synapsids (through specimen SAM-PK-K10407) to the *Tapinocephalus* AZ.[32,33] Globally, this shift could potentially impact palaeobiological studies of Permian tetrapods because biozones are often used as approximations of 'time bins' in calculations of taxonomic diversity trends and those of other biological variables.[17,34-37] Because they represent the youngest dinocephalian fossils from the Main Karoo Basin, the new fossils may also help to elucidate the mode by which dinocephalians became extinct, and, by extension, the cause of the global disappearance of the clade.[38] In particular, the presence of *Criocephalosaurus* in the Teekloof Formation, above the range of any other dinocephalian genus, suggests that a loss of species richness within dinocephalians preceded their extinction.

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Authors' contributions

M.O.D. determined the stratigraphic position of the fossils; S.G. described and identified the fossil material; B.R. was the project leader, provided funding for and intellectual input to the study and co-supervised S.G.; F.A. co-supervised S.G.; J.A. and M.D. discovered the new specimens of *Criocephalosaurus* examined in the study; M.D. and S.J. measured the stratigraphic sections; M.D. and S.G. wrote the first draft of the manuscript; and all authors contributed to the preparation of the final draft.

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Can scientific journals be classified based on their 'citation profiles'?

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Classification of scientific publications is of great importance in biomedical research evaluation. However, accurate classification of research publications is challenging and normally is performed in a rather subjective way. In the present paper, we propose to classify biomedical publications into superfamilies, by analysing their citation profiles, i.e. the location of citations in the structure of citing articles. Such a classification may help authors to find the appropriate biomedical journal for publication, may make journal comparisons more rational, and may even help planners to better track the consequences of their policies on biomedical research.

Introduction

Medical and biomedical research evaluation based on citation analysis has attracted much attention during the last decades.[1-5] Different aspects of citation analysis (in biomedical research evaluation) have been studied extensively in the literature.[6-10]

In research evaluation, classification of scientific publications is of great importance.[11-13] For researchers in academia it is important to publish their results in relevant journals to guarantee visibility. In Journal Citation Reports®, a list of 'subject categories' is prepared (and updated annually) to classify journals, in order to help rank journals in specialised fields. Such a classification has already found some useful applications. For example, the global map of science based on subject categories has been developed,[14,15] and can help to better understand scientific collaborations. Comparative assessment of the 'quality' of research in different subject categories[12,16,17] is important in sustainable development of science and technology.

For research institutes, planners and policymakers, it might be necessary to monitor subject categories of researchers. For example, facilitation and promotion of emerging interdisciplinary and multidisciplinary research may be an objective of science policies.[18,19] There also is a great need for reliable methods for evaluating researchers, because the number of citations (in both scholarly journals[20] and online resources[21]) do not reflect the real impact of scientific papers.

All classification approaches are based on the central assumption that 'objects' in the same field/category have related features. For classification of research articles, similarity of words or citation patterns can be used as the features.

Classification of scholarly publications can be done from different viewpoints. Typically, classifications are done based on subject categories.[22] Lewison and Paraje[23], on the other hand, suggested that biomedical journals be classified according to their approach to biomedicine, namely, clinical or basic.

Voos and Dagaev[24] proposed that the location at which citations appear within the citing publications (e.g. 'Introduction' and 'Methods') influences the meaning and the relevance of citations. This was later shown for larger article data sets when Maričić et al.[25] and also Bornmann and Daniel[26] studied the relationship between location of citation within citing articles and the frequency of citations.

In the present study, we classify journals into four groups based on the scope of their articles: protocol, methodology, descriptive and theoretical. Then, we show that journals in each group show a fairly similar citation pattern. We therefore propose that journals may be classified based on their citation patterns.

Materials and methods

We chose 17 (bio)medical and bioinformatics journals (Table 1). We assumed that all these journals belonged to one of the possible four groups (protocol, methodology, descriptive and theoretical). Citations to the articles published in each journal in 2011 and 2012 were found in Scopus. Then, full-text articles were downloaded, if possible, and the citation profiles (i.e. the sections in which the citations appeared) were analysed manually. Only those citations which appeared in standard sections of an article (Introduction, Methods, Results, Discussion[25]) were considered. It should be noted that multiple citations in a specific section were counted once only.

Results

From the analysis of the 17 journals, 1472 citations were detected in the citing articles. Altogether, 818 citations appeared in one of the four standard sections of an article. We computed the percentage of citations in each of the four sections.

Figure 1a shows the citation profiles of 'protocol' journals. As expected, most of the citations occur in the 'Materials and methods' section. Journals which are devoted to the introduction of new protocols or software are naturally cited by end users who apply these protocols and tools for practical purposes.

There is a subtle difference between 'protocol' and 'methodology' journals: 'protocol' journals focus on describing the procedures to be followed, whereas 'methodology' journals also describe in detail the scientific reasons behind the presented methodology. Consequently, it can be expected that articles in methodology journals are

not only cited in the 'Materials and methods' of citing articles, but also in all other sections. Figure 1b confirms that such a trend is observed in these journals.

Table 1: List of journals in the present study and the categories in which they were classified

Journal category	Name of journal	Total number of citations
Protocol	*WIREs Computational Statistics*	39
	Algorithms for Molecular Biology	75
	Journal of Visualized Experiments	70
	Source Code for Biology and Medicine	31
Methodology	*Bioinformatics*	123
	BioTechniques	234
	Evolutionary Bioinformatics	37
	Computational Biology and Chemistry	111
	Journal of Bioinformatics and Computational Biology	113
Descriptive	*EXCLI Journal*	133
	MEDICC Review	41
	Archives of Iranian Medicine	189
	Journal of Negative Results in BioMedicine	19
Theoretical	*Acta Biotheoretica*	28
	Medical Hypotheses	117
	Biology and Philosophy	86
	Journal of the History of Biology	26

'Descriptive' journals include those journals which mainly discuss experimental or clinical findings. Figure 1c shows that citations to the articles published in these journals mainly occur in the 'Introduction' and 'Discussion' sections of citing papers, followed by 'Methods' and 'Results' sections.

Finally, there are journals which focus on the theoretical aspects of science, including philosophical and historical issues. There are even journals which are devoted to presenting novel (and often radical) hypotheses. These journals are not expected to be cited in the 'Methods' or 'Results' sections of citing articles, which is reflected in the citation profile of these journals (Figure 1d).

Altogether, we observe that, depending on their approach to science, different journals show distinctive citation patterns. Figure 1e shows the average citation profile in each of the four categories.

Discussion

Different aspects of (bio)medical sciences are investigated, including clinical studies, molecular and biochemical medicine, diagnostic methods, traditional medicine, bioethics and even computational modelling in biomedical sciences. The first natural consequence of citation profile analysis is that journals, including biomedical journals, can be classified into superfamilies. Such superfamilies are based on the journal's approach to science, not necessarily the journal subject. Classification of journals may show which journals have the same approach to science, and therefore provide a framework for 'intra-superfamily' comparison of publications.

It is well known that citations can be interpreted based on many factors[27], including in which section of the citing paper the citation appears[24,25,28].

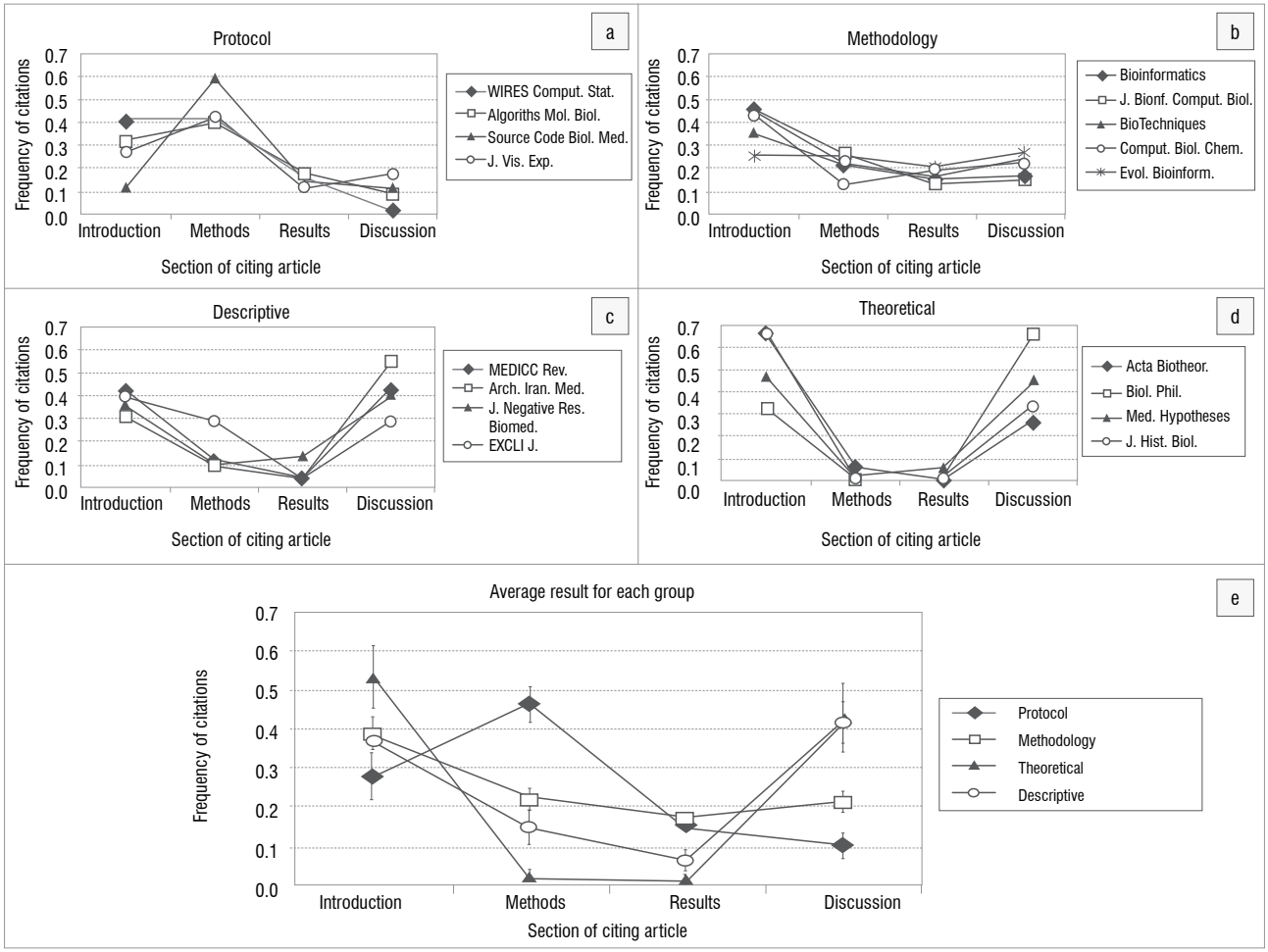

Figure 1: (a) Citation profile of protocol journals; (b) citation profile of methodology journals; (c) citation profile of descriptive journals; (d) citation profile of theoretical journals; and (e) average citation profile of each journal type.

However, citation-based measures of research evaluation do not take into account the differences among citations. We suggest that it is possible to create a context-based measure which takes into account the location of a citation in the citing article, and assign different 'usefulness' weights to the citations. For example, if the applicability of the methods is taken into account, one may give more weight to the citations which appear in the Methods section compared with the citations that appear in the Introduction section. On the other hand, for analysing groundbreaking and paradigm-changing papers, one may assign more weight to the citations in the Introduction section.

In the present study, we manually assigned the 17 journals into the four categories. For future work, one can consider a larger data set of journals and use statistical methods to automatically find the clusters, in order to show if the same four categories are found. A possible drawback of this approach is the potential difficulty of the computations. Current tools for citation analysis, e.g. Web of Science and Scopus, analyse the citations independently of the citation context.[25,26,28] Analysing the citation profiles manually is rather inconvenient; nevertheless, with the online availability of (most) articles in machine-readable formats (e.g. HTML or PDF), text-mining algorithms may be developed to analyse the citation profiles automatically.

A side result of the automatic analysis of citation profiles could be the detection of useful keywords. More precisely, it is possible to check what issues inside a cited paper have attracted the attention of citing authors. Such a survey could provide insights for selecting better keywords for a new manuscript, in order to attract more attention, and, in turn, more citations.

Authors' contributions

S.A.M. was responsible for the experimental and project design and also wrote the manuscript. All other authors were involved in collecting the required data.

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An Ovahimba woman from the Kunene Region, Namibia, whose skin, hair and personal attire are covered in a red ochre mixture called otjise (photo: Riaan F. Rifkin). Although otjise is applied by modern humans primarily for social functions, an article by Rifkin and colleagues on page 65 explores how the topical application of red ochre for sun protection may have provided an adaptive advantage for our prehistoric ancestors.

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