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Research Paper

The dimensions of geotourism with a spotlight on geodiversity in a subdued landscape

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ABSTRACT

Landscapes of high relief are often favoured tourist destinations and at the same time display complex geomorphology that may be the result of diverse geology summarised into the concept of geodiversity. In contrast areas of subdued landscape, while topographically unappealing, may also be geodiverse but need careful explanation and promotion to attract the geotourist. The mid-west of Western Australia is an area of low relief with a long history of weathering, ostensibly of little interest to visitors, is underlain by a diverse geology that is displayed in an incised landscape where erosion by rivers and the ocean displays geodiversity in attractive detail. The mid-west of Western Australia is the result of sedimentary basin formation during the separation of the Gondwanan Indian plate from the western edge of the Archean Yilgarn granitic craton. A plutonic Precambrian basement is overlain by Ordovician sediments comprising the Tumblagooda sandstone and then Permian and younger Mesozoic rocks, often capped with a complex weathered regolith. Geology is exposed in the Murchison and Irwin River valleys where interpretive signs explain the origin of the landscape and sequences of rock. Extensive weathering products from the Tertiary period, such as laterite and sandplains, provide opportunities to explain processes such as deep weathering, mobilisation and re-deposition of sediments that are integral to the development of landscapes in general. We thus provide a conceptual understanding of the nexus between tourism and geodiversity via the applied science of geotourism in a predominantly subdued landscape. We make the point that there is a general lack of attention paid to regolith in the geotourism literature, hence we have provided a relatively detailed account of a large expanse of sandplain that occurs in the study area. Furthermore, regolith geodiversity has not been investigated in the context of its wider geotourism potential and while this case study is preliminary in its wider scope, we provide a platform for further research.

1. Introduction

Areas with picturesque landscapes are popular with tourists who appreciate extensive natural vistas and desire to escape from the built environment of city life. Such areas have been termed geodiverse (Gray, 2019) and are often represented by spectacular geomorphology that is usually underpinned by a variety of lithologies, as for example, Torres del Paine, National Park in Chile (Altenberger, Oberhänsii, Putlitz, & Wemmer, 2000). On the other hand, Migon (2021) has concentrated on the geomorphology of only one general rock type – granite and put forward the thesis that diversity within granite landscapes is an important component of geoheritage. While highly scenic landscapes are attractive to many tourists, information presented at a relatively super-

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ficial level, regarding their evolution, can add to the visitor's experience and understanding of present and past environments in which rocks and landscapes have formed (for example, Anderson, Molnar, & Kessler, 2006; Johnston & Van Kranendonk, 2018; Lane, 2017; Newsome, 2022). Areas of low relief, however, may have less apparent attraction even if there is a considerable deep time story that explains the features of the area. In this case there needs to be an explanation of landforms that reveal the history of an area, and this educational aspect is one of the core tenets of geotourism (Dowling & Newsome, 2018; Newsome, Ladd, & Dowling, 2022).

Much has, and continues to be, written about geotourism and its role in engaging the public with geology and landscape, also in its maturation as a form of tourism and in its potential contribution to sustainable development (for example, Chen, Lu, & Ng, 2015; Dowling & Newsome, 2018; Frey, 2021; Gordon, 2018; Herrera-Franco, Montalván-Burbano, Carrión-Mero, Apolo-Masache, & Jaya-Montalvo, 2020; Hose & Vasiljević, 2012; Sadry, 2020). As the complexity and breadth of geotourism has grown there is scope for explaining geotourism as comprising four main dimensions along with allied subjects thus illustrating the numerous manifestations of geotourism as an applied science. Therefore, following on from the geosystem services approach of Gray (2019) where geodiversity is central, in this paper we present an extended model of geotourism where geodiversity is a core dimension.

The degree of landscape relief strongly influences human perceptions of any terrain in terms of the utility for land use, aesthetics and may even have religious/cultural connotations (e.g., Uluru in central Australia; Watarrka Foundation, 2022). In general, areas of high relief have the potential for significant aesthetic appreciation and are likely to support 'natural' vegetation while areas of low relief are more likely to be cleared for agricultural or pastoral activities, have less natural vegetation and may appear to be less visually attractive. Differences in landscape structure will be related to the age of the terrain and the underlying geology. This is certainly the case for large parts of the mid-west and southwestern parts of Western Australia where formal geotourism is still being developed. There has, however, been good progress in recent times where regional local government and tourism agencies have capitalised on well-described and tested geological and landscape destinations. This has resulted in the development of guidebooks, geotrails, geotourism interest groups and geopark initiatives (e.g., Gozzard, 2015; Lane, 2017; King & Chapple, 2020; Briggs et al., 2021a, b; GSWA, 2021; Georegion, 2021).

The purpose of this paper therefore is to consider an expanded scope of geotourism and promote further understanding of geotourism in Western Australia. Accordingly, we provide an explanation as to where geodiversity fits into the practical picture of geotourism and go on to consider geodiversity from the perspectives of regional geology, geodiversity within one geological unit and then according to weathering and regolith formation in a specifically defined area of the mid-west of Western Australia. The area has a diverse geology (Morey, Haig, McLoughlin, & Hocking, 2005) but rather than providing a detailed account of this we focus on considering a hierarchy of geodiversity for the purposes of geotourism engagement.

2. Methods

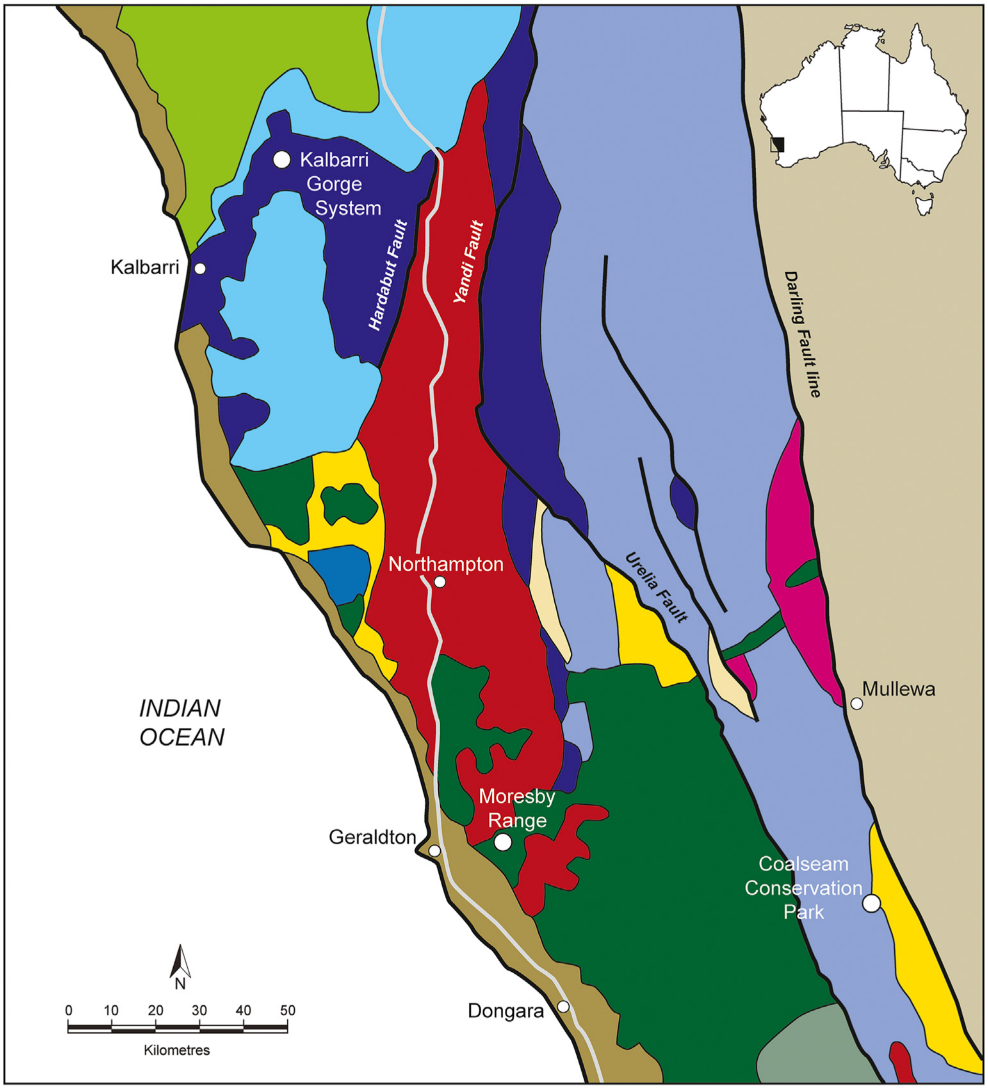
2.1. Theoretical applications

The methodological approach applied in this paper consists of expanding existing theory by incorporating geodiversity as one of four core dimensions of geotourism. Furthermore, for the purposes of fostering geotourism in Western Australia, we take the before mentioned geodiversity dimension and consider geotouristic information at three different levels. The mid-west of Western Australia is used as a case study area as it provides the opportunity to profile aspects of the regional geology, highlight some of the detail contained within one age/unit of rock and re-visit the question of regolith which has recently been discussed by Newsome et al. (2022). Additional core literature that is highlighted to inform geotourism programmes in the area includes the work of Newsome (1998, 2000), Morey et al. (2005) and Morey and Haig (2011).

2.2. Case study of geodiversity in a subdued landscape

The mid-west of Western Australia occupies the western edge of the Australian continent between approximately 31^0 and 27^0 south and 114^0 and 116^0 east bounded on the west by the Indian Ocean and the Yilgarn Plateau to the east (Fig. 1 and 2). The landscape is mostly of low relief with much of the native vegetation cleared for agriculture and pastoralism. Remaining natural vegetation is low growing scrub and heathland (kwongan) that is generally species rich and in places dominated by low growing *Eucalyptus*, *Acacia* and *Banksia* species. Soils are in general sandy and nutrient poor requiring regular fertilisation to maintain agricultural productivity.

The eastern part of the case study area comprises the regolith dominated Victoria Plateau (250 m asl) which is underlain by Permian rocks. Four rivers drain the area and comprise the Murchison River in the north with the Chapman and Greenough Rivers in the central part and the Irwin River in the south (Fig. 2). These rivers only flow following winter rains or after heavy rain associated with the passage of a cyclone. In the central and southern parts of the region the western edge of the Victoria Plateau presents as a low mesa landscape composed mainly of Jurassic rocks (Moresby Range) in the west and Permian sequences (Nangetty) in the most southern parts. While various sedimentary rocks are exposed in parts of the Greenough and Irwin River valleys (Table 1) there are 3 areas (Kalbarri Gorges, Coalseam Conservation Park and the Moresby Range) where the geology can readily be accessed and seen, two of these sites (Kalbarri Gorges and Coalseam Conservation Park) are already established and have been profiled as geo-attractions for some time (Fig. 1).



Quaternary		Marine shoreline and aeolian deposits, generally calcareous
Cretaceous		Marine limestone, chalk, marl and greensand
		Marine and continental shale, siltstone and sandstone, minor conglomerate
		Marine and continental sandstone and siltstone
Jurassic		Continental sandstone, shale, siltstone and coal measures, minor marine limestone and sandstone
Triassic		Marine and continental sandstone and shale
Permian		Marine and continental sandstone, siltstone and shale, coal measures
		Glacigene, marine and continental siliclastic sedimentary rocks: minor limestone
Carboniferous		Marine and continental limestone, dolomite, sandstone, siltstone and shale, minor conglomerate
Carboniferous - Devonian		Marine and continental limestone, conglomerate, sandstone and siltstone
Ordovician		Continental and paralic sandstone, minor conglomerate
Precambrian		Gneiss
		Granite with gneiss, with occasional sedimentary and ultrabasic rocks

Fig. 1. Simplified geological map indicating geodiversity in the study area.

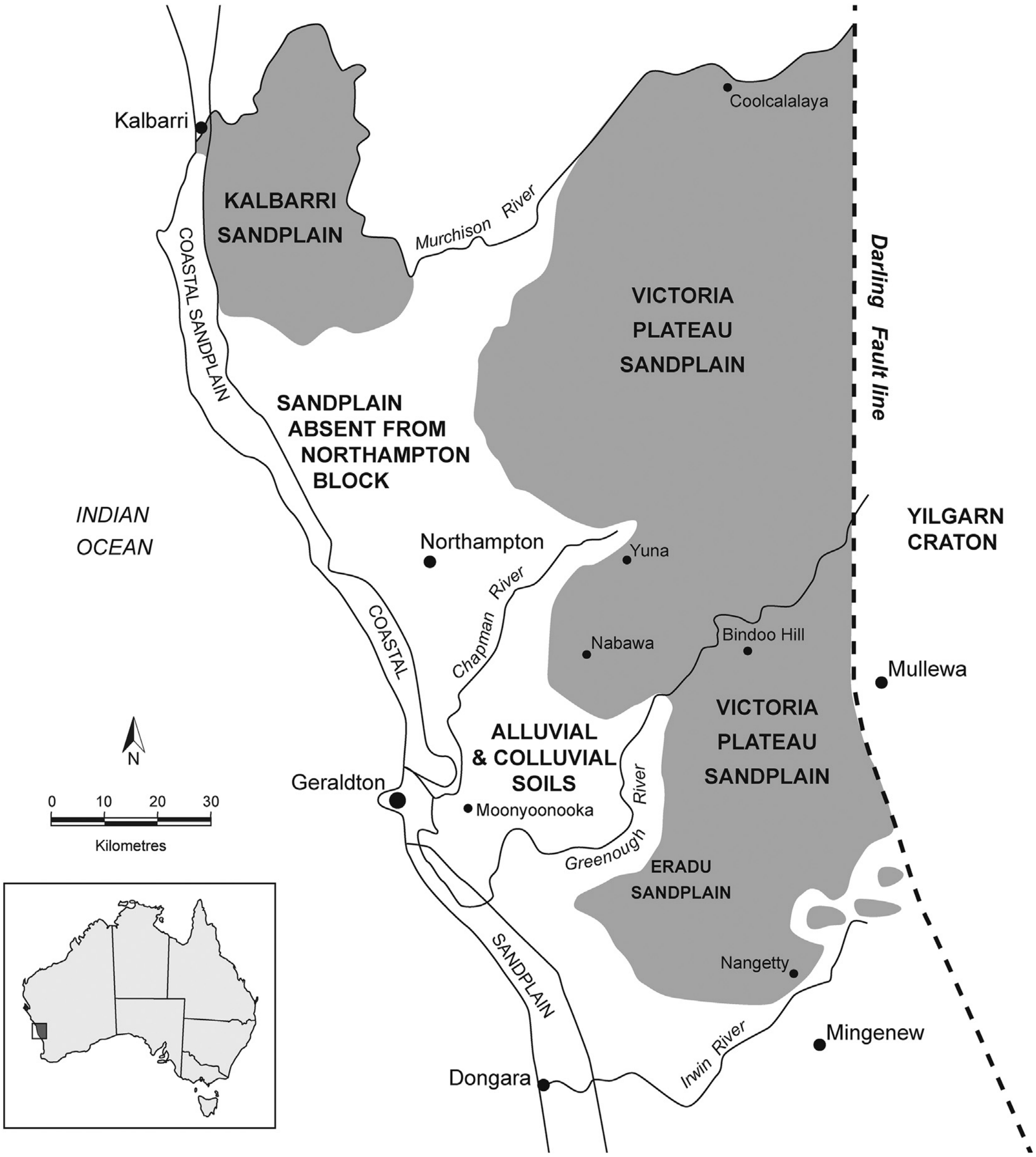


Fig. 2. Occurrence and extent of sandplain regolith in the study area.

3. Dimensions of geotourism

To understand its application in the tourism system geotourism is conceptualised as comprising abiotic, biotic and cultural components (Dowling, 2020). The abiotic aspect includes landscape and geology of which geodiversity is centre stage, the biotic component refers to how geology relates to ecology and biodiversity, while the cultural dimension embraces how geology has shaped human occupancy, response to and use of the landscape (Dowling, 2013; Newsome et al., 2022).

Because of the expanding literature base and increasing development of geotourism as an applied science there is further value in viewing geotourism according to four core dimensions namely: geodiversity, biodiversity, cultural and socio-political influences (Fig. 3). The importance of each of these dimensions will vary depending on the focus of the geotourism attraction in any area. The geodiversity dimension thus consisting of geology, geomorphology, regolith and soils will be particularly relevant in areas of high relief and/or complex and visible geology. The biodiversity dimension relates to the variability and age of the landscape and the underlying substrate and how these components control the distribution, occurrence and abundance of plants and animals. The cultural dimension concerns the use of the landscape and geological materials. On the other hand, the socio-political dimension is where human society manages and learns about the abiotic environment (geodiversity dimension) to create knowledge and administrative structures that bring about the reality of identifying geoheritage, practising geoconservation and creating

Table 1
Simplified account of geological units occurring in the case study area.

Age	Geological unit	Exposures in study area	Lithological characteristics
Quaternary	Tamala Limestone	Along coast from Geraldton to Kalbarri.	Coarse to medium grained calcarenite and fossil reef limestone
Tertiary	Pindilya formation (Victoria Plateau Sandstone)	Sporadic exposures near Darling Fault, Northern Perth Basin and in Coalseam Reserve, Irwin River	Silcreted sandstone and conglomerate. Fine grained sandstone and some siltstone
Cretaceous	Birdrong Sandstone	Very little outcrop in the area	Poorly indurated quartz sandstone
	Yarragadee formation	Irwin River Valley, ~ 11 km north northwest of Mingenew	Beds of sandstone, siltstone, claystone and shales
	Kojarena Sandstone	Railway cutting east of Geraldton at Bringo	Ferruginous sandstone. Claystone at base
Jurassic	Newmarracarra Limestone	Railway cutting east of Geraldton at Bringo	Limestone, calcareous sandstone, siltstones and shale
	Bringo Shale	Railway cutting east of Geraldton at Bringo	Shale
	Colalura Sandstone	Railway cutting east of Geraldton at Bringo	Ferruginous sandstone and conglomerate
	Moonyoonooka Sandstone	Ellendale Pool, Greenough River, SE of Geraldton	Felspathic sandstone, siltstone and shale
Triassic	Kockatea Shale	Outcrops limited, mainly to the west of Northampton Block.	Thin beds of sandstone, siltstone and shale, rare stromatolite beds
	Wagina Sandstone	Greenough River near Eradu.	Medium to fine grained clayey sandstone. Siltstone and shales
	Carynginia formation	Cliff faces on the south branch of the Irwin River in Coalseam Conservation Park	Interbeds of sandstone, siltstone and shale
Permian	Irwin Coal Measures	Coalseam Reserve, Irwin River	Beds of sandstone, conglomerate, siltstone, shale and minor coal seams
	High Cliff Sandstone	Coalseam Reserve, Irwin River	Sandstone and siltstone
	Holmwood Shale	Exposures along northern segments of Irwin River Valley	Sandstone, siltstones, shale and limestone
	Nangetty formation	Nangetty Hills	Tillites, sandstones, siltstones and shales
Carboniferous-Devonian Ordovician	Sandstone Tumblagooda	Murchison River Valley	Very fine to coarse grained sandstone. Feldspathic sandstone, conglomerate and siltstone.

Note: Adapted from Geological Survey of Western Australia (1990) and Morey and Haig (2011).

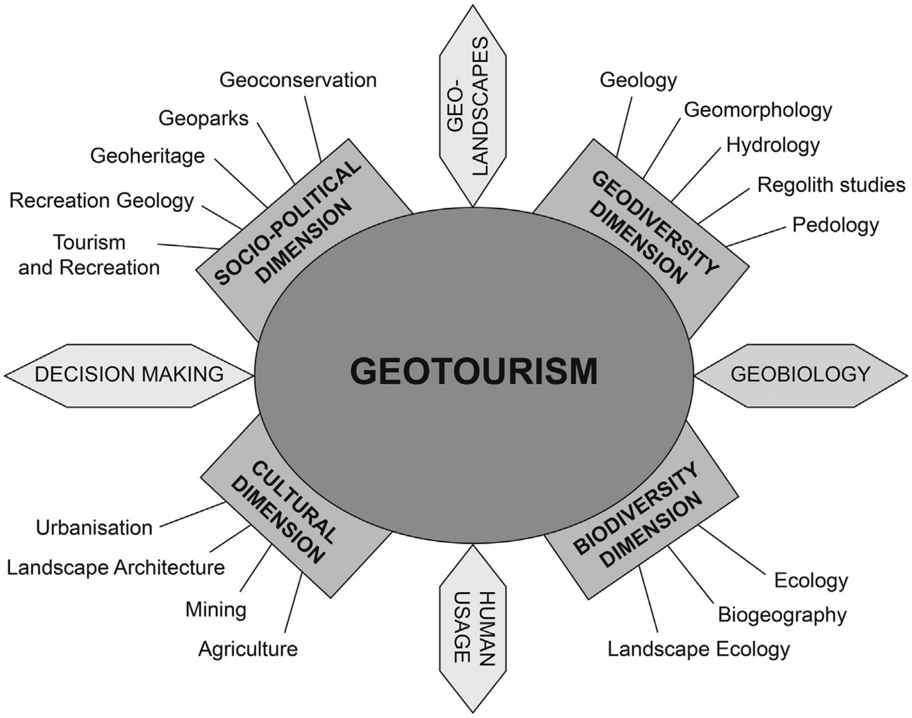


Fig. 3. The four major dimensions and extended subject content of geotourism.

geoparks (Bentivenga, Cavalcante, Mastronuzzi, Palladino, & Prosser, 2019; Briggs, Dowling, & Newsome, 2021b; Gordon, 2019; Gray, 2019).

The complexity, actual and potential interactions between the four main dimensions is perhaps best illustrated by the concept of recreation geology which has been included as part of the socio-political dimension (Fig. 3). Recreation geology can be viewed as the science of understanding human aspects of human visitation which may degrade geology and landscape thus requiring appropriate attention in the form of geoconservation practices, site access management, regulation of visitor numbers and communication and education (for example see Newsome, Dowling, & Leung, 2012; Dowling & Newsome, 2017; Migoń, 2022). Fig. 3 thus represents geotourism in all its complexity and illustrates the breadth of the subject. Further relationships between the different dimensions are represented by 'decision making' indicating the interconnection between the socio-political and cultural dimensions. 'Human usage' further reflects connection between the cultural and biodiversity dimensions, and 'geobiology' (Xie & Yin, 2014) forms a link between the geodiversity and biodiversity dimensions. The term 'geo-landscapes' can be applied to represent a big picture expression of how humans see and value a particular landscape where there are prominent geological attractions.

The landscape perspective might be regarded as a core aspect of the geotourism experience as humans have a long history of aesthetic appreciation of scenery. Hose (2010) provides an historical account of landscape appreciation from a British perspective and Chen et al. (2015) discuss aesthetic appreciation of scenery in China that dates back as far as 265 CE. While these authors acknowledge that mountain and river landscapes command substantial aesthetic appreciation, human modified landscapes (cultural dimension, Fig. 3) are also of geotourism interest. An attempt to represent this latter point and place the geo-landscape in perspective in an Australian context is depicted in Fig. 4 where geology is a clear visual element in the geo-landscape (Murchison Gorge in the mid-west of Western Australia). Other types of landscape that can be recognised are where natural vegetation is prominent (Coalseam Conservation Park) or composite (mid-west landscape), which is a mixture of agricultural (human modified) and natural (upstanding and undeveloped relief within the same landscape). Cultural landscapes are clearly represented by the built environment (Perenjori Hotel, Fig. 4), but may also include agricultural land and modified natural vegetation. Furthermore, the semi natural (mosaic of agricultural and uncleared land in the mid-west) and agricultural landscapes (mid-west wheat field) (see Fig. 4) reflect strong cultural imprints on the landscape. Such cultural influences can be expressions of the activities of indigenous people, early and late (sometimes colonial) human historical influences such as mining and agricultural development and/or represent contemporary human values such as conservation and tourism (Briggs, Newsome, & Dowling, 2021a, b).

Given all these aspects and manifestations of what geotourism is and can be, one of the over-riding features for geotourism to function properly is awareness and learning. Each dimension represented in Fig. 3 requires its own set of knowledge. For example,

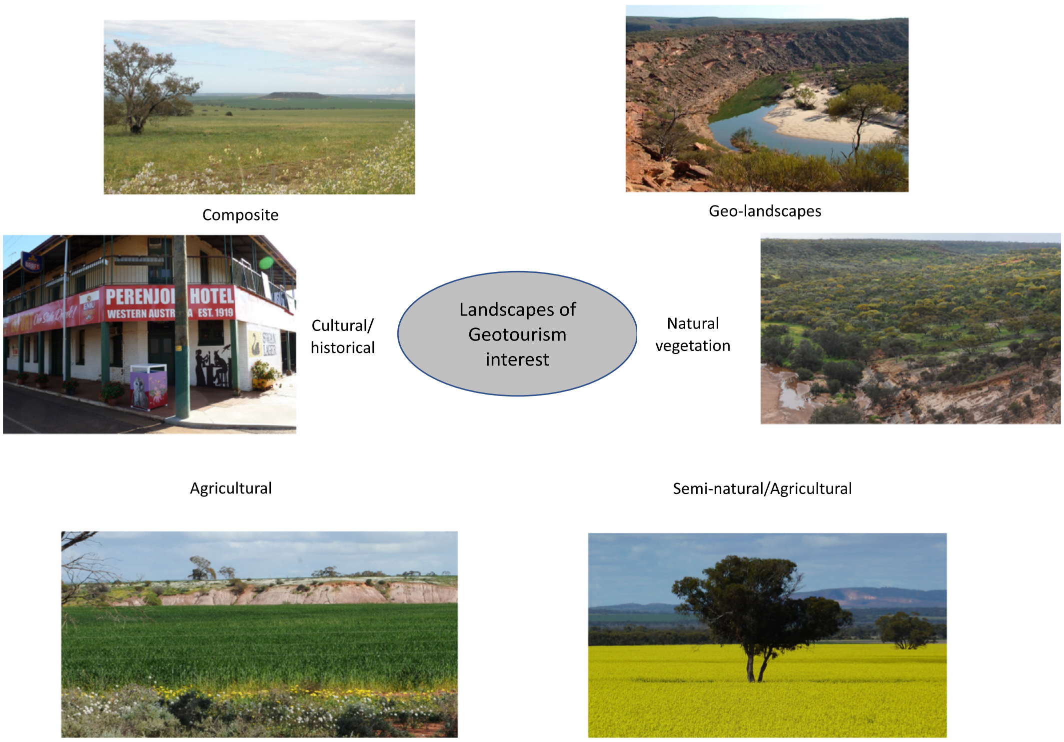


Fig. 4. Different landscapes of geotourism interest. Clockwise from top left – Landscape west of Nabawa showing agricultural land. A mesa carrying natural vegetation is visible beyond the western edge of the Victoria Plateau; Inland gorge, Tumblagooda Sandstone, Kalbarri national Park; Vegetation at Coalseam Conservation Park dominated by *Eucalyptus* and *Acacia* trees and showing Permian sediments of the High Cliff exposure at lower right; Oilseed rape crop, Morawa area (east of Mingenew) of the mid-west, in the foreground while higher land in the background has a cover of natural vegetation; Wheat crop on regolith over Permian sediments near Morawa; Perenjori Hotel established early in the development of the mid-west region.

the socio-political dimension is dependent upon social science research and the geodiversity dimension has its own component scientific knowledge grounded in tectonics, geochemistry, mineralogy and petrology. Articulating complex explanations of the origin of the Earth, the nature of rocks and the expression of landscape can be technically complex and has previously been a challenge in the popularisation of geology (Migoń, 2018). Our purpose onwards from here is to call attention to the geodiversity of the study area to provide additional impetus for geotourism development.

4. A focus on the 'geodiversity dimension' in the landscape of the mid-west of Western Australia

4.1. The geology that underpins the landscape of mid-west of Western Australia

The area is underlain by parts of two sedimentary basins, Carnarvon Basin to the north and Perth Basin to the south that originated as part of the east Gondwana rift system in the Palaeozoic (Morey et al., 2005). The basins developed west of the Yilgarn plateau which is composed of Archean granitic rocks. Final break-up of the land mass was from 155 to 136 Ma but sedimentation occurred before and during the Ordovician with the basins encompassing several sub basins, troughs and the development of plateaus that remained as higher areas between the two basins. The Northampton Block is a basement high area of Proterozoic granites occurring between the Carnarvon and Perth Basins.

An overview of different lithological units in the study area is summarised in Table 1. The earliest Palaeozoic rocks lie on a Precambrian basement within this region and are primarily sandy sediments that comprise the Ordovician Tumblagooda Sandstone. This formation thins south of Kalbarri and the best exposures are in the Murchison Gorge. The Murchison River has a convoluted path of incised meanders passing through a joint controlled gorge after it exits from the eastern Archean plateau on its way to the sea in the west. The Ordovician is exposed in the gorge wall and has an unconformable contact with overlying Cretaceous sediments that can be seen at coastal cliffs south of the Kalbarri township (Fig. 1). To the east between the Urella and Darling Faults there are minor Carboniferous and more extensive Permian sediments. Rocks include glacio-marine tillites, poorly sorted gravels and some fine-grained sandstones with drop stones (Table 1). Along the Irwin River at Coalseam Conservation Park there are good cliff exposures of Lower Permian near-shore marine and deltaic sediments (siltstones, shales, limestones and sandstones) passing up into relatively thin coal deposits, probably derived from Permian near coastal swamps, which are interbedded with clastic sediments (Fig. 5). Triassic sediments unconformably overly the Ordovician in places in the Kalbarri area but exposures are uncommon. As shown in Fig. 1 fault activity has produced north-south slices of sediments of different ages in contact throughout the area. The Permian occupies the subsurface of the eastern side of the Perth Basin and Jurassic sediments are west of the Urella fault line with Cretaceous sedimentary rocks south and west of the Coalseam Conservation Park area.

The Tertiary period (65–2.5 Ma) was mainly a time of intense weathering over the older sedimentary and plutonic rocks of the area. There has been some (probably) Pliocene (5–2.5 Ma) deposition of mineral sands somewhat inland from the present coast along what would have been a previous coastline, but these are not exposed except in mines south of Dongara. Subsequent to this in the Quaternary further coastal deposition occurred with beach ridge, dune and reef materials accumulating and extending various distances inland (Fig. 1). Fossil coral reefs in a coastal cliff 2.5 m above present sea level have been dated at last interglacial age (120–132 Ka) not far north of Dongara (Johnson, Baarli, & Scott Jr, 1995). In many places along the coast the cliffs are formed of lithified dune and beach materials of the Tamala Limestone which extends along the coast from Kalbarri to south of Perth and

Fig. 5. Section at Coalseam Conservation Park in the Irwin River valley. The darker gray base of the section rising towards the right is the Holmwood Shale. On the left-hand side this is overlain by the High Cliff Sandstone and above that lies the Victoria Plateau Sandstone. The reddened upper part of the section is laterised Victoria Plateau Sandstone**.**

at variable distances inland. Reefs and off-shore islands comprise mainly calcarenite formed from dunes emplaced as the sea level receded during the Last Glacial Maximum around 20–15 Ka.

Weathering profiles and surficial deposits derived from the underlying Mesozoic and older rocks are prominent in the study area. In river gorge and gully exposures of older rocks there is usually a weathering zone well displayed at the top of the sequence. Depth and intensity of weathering depends on the underlying rock, the duration over which the rock has been subjected to weathering and landscape position that has influenced the ease of erosion of the weathered material. Contemporary erosion is more rapid on steep slopes that are close to rivers. Incised rivers erode cliffs on the outside of meanders and can renew exposures after floods but on meander cores also deposit alluvium that can hide exposures.

Explaining landscape level geology is a complex task for the non-specialist but gaining a landscape overview and working with the field guides produced by Morey et al. (2005) and Morey and Haig (2011) will help to build a programme in selecting suitable content for geotourism purposes. Accordingly, the brief overview provided here emphasises the big picture geodiversity of the study area. Various exposures and river cuttings (Table 1), viewpoints from mesas such as in the Moresby Range and a detailed exploration of Coalseam Conservation Park can enhance the experience of a traveller across what is ostensibly a subdued landscape.

4.2. Geodiversity within one rock unit

Kalbarri National Park is a well-established tourism attraction because of the Murchison River Valley. Here uplift has created inland gorges and coastal erosion of the Tumblagooda Sandstone has resulted in spectacular scenery (Fig. 6). In this sense this area is an exception in the otherwise largely subdued and apparently featureless landscape that occurs further inland and south of Kalbarri (Figs. 1 and 2). Generally considered to be Ordovician (485–443 Ma) in age the Tumblagooda Sandstone comprises medium to coarse grained sandstones, mudstones and some conglomerates. Its geology, however, is complex and detailed work has been conducted to understand its significance as a trace fossil bearing rock (Shillito & Davies, 2020). However, the geodiversity expressed in the sandstone is a timely reminder of its value in the popularisation of geology for geotourism purposes as indicated by existing facilities in Kalbarri National Park including a geotrail, viewing platforms with interpretive panels and a cantilevered skywalk that projects out over one of the inland gorges. While large scale geomorphology is a major feature and

Fig. 6. Kalbarri National Park. Inland gorge of the Murchison River (upper photo) and coastal cliffs and stack (lower) south of the Kalbarri township.

Fig. 7. Tumblagooda Sandstone on the coast at Kalbarri National Park. Softer rocks have been preferentially weathered and eroded giving rise to a wave cut notch and adjacent platform. Above this honeycomb weathering of the rock is due to salt action (upper photo). The lower photo shows ripple marks reflecting deposition of sediments in shallow waters.

attraction (Fig. 6) the complexity evident in the rock strata provide excellent subjects for a detailed perspective that can be derived from a suitable geo-tour (for example, Figs. 7 and 8).

There perhaps has never been a more important time to emphasize the astonishing geodiversity of the Tumblagooda Sandstone. Indicative geo-interpretive content can include coastal processes and geomorphology, inland gorge development, tectonics and incised meanders, sedimentary processes and environments, the differences between different types of sedimentary rocks, the significance of trace fossils, weathering and regolith formation. Delving into and further profiling of this unique and interesting geology adds depth to what is an established geotourism destination. Moreover, this is potentially a case where geodiversity is the key to social and economic recovery. The town of Kalbarri, which relies on tourism, was significantly damaged by a cyclone in 2021(ABC, 2021; Nott, 2021). Residents need to re-build personal and commercial infrastructure after the cyclone and Kalbarri's geodiversity 'in the spotlight' can contribute in what may be regarded as a must-see geotourism destination.

4.3. A focus on the subtleties of geodiversity: Weathering and regolith

Throughout the study area the main deep weathering features are sandplains and lateritic profiles. On the granitic terrain of the Northampton Block sandplains are not present and the soils are less sandy and more clay rich. Along the coastal areas there are calcareous sands derived from the Tamala limestone and coastal dunes formed from deflation of sandy beaches (Fig. 2). Lateritic regolith is almost a landscape signature of southwestern Western Australia and extends over large areas (Newsome et al., 2022). The classical profile is of a pale surficial horizon of sand overlying a hardpan zone of iron and/or aluminium oxides deposited in the sub-surface zone. In the mid-west lateritic regolith is a feature of highly weathered country rock depending on the composition of the geological materials. The sand A horizon may be missing due to erosion by wind or water leaving the hard ferruginous part of the profile as a highly resistant cap rock that forms mesas such as the Moresby Range east of Geraldton. The cliff sections in Coalseam Conservation Park display very good examples of lateritic induration of Permian sedimentary rocks (Fig. 5).

Sandplains, however, are extensive in the study area and form an extensive blanket of regolith around Kalbarri and on the Victoria Plateau (Fig. 2) Their individual profiles differ in depth and range from 30 cm to >7 m deep. However, depths of up to 15 m of sand overlying sandstone can be found in some areas. Moreover, sandplain profiles are mostly uniform in nature

Fig. 8. The Tumblagooda Sandstone is a sequence of sandstones and siltstones deposited under fluvial and shallow marine (estuarine) conditions. The upper photo shows alternating bands of sediment with differences in the band width most likely indicative of deposition over different periods of time. Brown bands contain high amounts of iron oxide. Overlapping bedding features indicate deposition under turbulent conditions. The lower photo shows trace fossil arthropod burrows crossing bedding planes of the sandstone.

and do not contain sedimentary structures such as bedding planes which could indicate an aeolian or fluvial origin (Newsome, 1998, 2000; Newsome et al., 2022). However, dunal features which are common on the Victoria Plateau are a legacy of surficial re-working of the sandplain during former periods of aridity when vegetation cover would have been sparse (Newsome et al., 2022). The expression of dune form ranges from ill-defined sand ridges and hummocks to linear dune forms with well-preserved dune crests. Some dunes are circular in shape while others are Y shaped features. Dune mapping by Wyrwoll and King (1984) showed that the dunes have a mixture of west-east and north-south trends. The lack of a more distinct dune orientation pattern is thought to be due to the erosion and degradation of the original dunefield pattern but the initial dunefield could have been an assortment of different dune forms (Wyrwoll & King, 1984).

The Kalbarri sandplain (Fig. 9) occurs at an altitude of 160—180 m and occasionally at 140 m where its western edge meets yellow sands that are associated with the Tamala Limestone. Further east towards the Northampton Block, however, the sandplain can reach altitudes of, up to, 240 m a.s.l. The Kalbarri sandplain occurs north and south of and very close to the edge of the Murchison River Gorge. The carbonate rich Toolonga Calcilutite occurs north of the Murchison River but has no sandplain associated with it and the superficial cover is rocky and carries lithosols. Sandstone underlies the Kalbarri sandplain although the age and ascribed formation of these rocks remains uncertain. Playford, Horwitz, Peers, and Baxter (1970) suggested that the underlying geology may be Cretaceous Birdrong Sandstone. The sandplain continues inland east from the coast for up to 50 km before the Proterozoic geology of the Northampton Block is encountered. Some patches of yellow sand occur on the Northampton Block and in some areas this sand is clearly associated with remnant areas of Mesozoic sedimentary rock and tends to occur in the highest parts of the landscape where they are remnants from the erosion of surrounding areas.

Sandplain in the Coolcalalaya area can be distinguished from elsewhere on the basis that the area contains both yellow (10YR 6/8) and red sands (5YR and 2.5YR) (Munsell Color Co., Inc., 1988). Yellow sandplain is generally more widespread at the western fringe of the sand sheet. Well-vegetated sand ridges with E-W axes and occasional circular dunes occur associated with yellow sand a few kilometres south of the Murchison River Valley. Red sands, however, pre-dominantly occupy the eastern part of the sandplain and tend to be in the upper landscape positions either side of the Murchison River Valley (Fig. 10). The eastern limit

Fig. 9. Deep yellow sand that typifies the Kalbarri sandplain.

Fig. 10. Extensive red sandplain in the Coolcalalaya part of the Victoria Plateau.

of red sandplain is controlled by a change from the sedimentary rocks of the Perth Basin to Archaean rocks of the Yilgarn Craton in the region of the Darling Fault line.

Elevated yellow sandplain north of the Greenough River (10YR 6/8), is generally about 40–50 km inland from the coast, is widespread south of the red and yellow Coolcalalaya sands and extends south to the Greenough River. The landscape in the Nabawa and Yuna regions is typically gently undulating sandplain, with degraded sand dunes, at 220–280 m a.s.l. Sandplain, however, is largely absent in lower-lying areas and along drainage systems. Non-sandstone lithologies such as the Holmwood Shale or clay-rich Permian tillites do not carry sandplain. At the north-western limit of this area the yellow sandplain gives way to more clay-rich soils associated with the Middle Proterozoic geology of the Northampton Block. Further south, and occurring east of Geraldton, the western edge of the sandplain becomes more fragmented and merges gradually into shallow sandy soils which are largely associated with Jurassic sedimentary rocks.

The western limit of the sandplain is demarcated by the dissected Northampton Block and nearby Jurassic rock landscapes. Although the upstanding Jurassic geology does contain many sandstone members, widespread sandplain is absent from these dissected landscapes. Instead, there is only a very thin cover of sand, for example, in the Moresby Range north of Geraldton. The general absence of sandplain in association with Jurassic sandstone lithologies points to denudation processes removing any sand which may have accumulated. This is perhaps evidenced by the accumulation of sand in low-lying areas and stream banks in the Chapman River Valley. There is also evidence of substantial sediment transport in the dry channels of intermittent streams which drain the Northampton Block and nearby Jurassic lithologies. Detailed work by Wyrwoll (1984, 1988) on alluvial sequences in stream channels which drain the Moresby Range, indicates significant accumulations of stream channel sediments in this area during the Late Pleistocene.

This area south of the Greenough River represents the southern portion of an elevated yellow sandplain which stretches almost continuously from the Murchison River to the Irwin River system. As in the rest of the study area, much of this sandplain and associated dunes occurs on a gently undulating, almost flat, plateau. Where the country becomes more dissected, as in the region surrounding the Greenough River, sandplain becomes more discontinuous, and is restricted to high points in the landscape. One of the highest points in the vicinity of the Greenough River is Bindoo Hill (293 m a.s.l.) which carries deep sand. Sandstones, which contain pebbles indicative of Permian glaciogene members, are evident on both the eastern and western sides of Bindoo Hill. The sandstone on the western side is weathered and ferruginised but remains coherent. Sandstone outcrops on the eastern side are also coherent but appear to be relatively unaltered by weathering.

In some areas intermittent drainage channels occur at about 230 m a.s.l. in the landscape and can be seen to truncate dunal features on the edge of the sandplain. Fig. 11 depicts one such feature where the channel banks consist of 1 m of yellow sand and the stream bed contains loose sand which is subject to wind deflation when dry. The eastern meanders of the 'stream' are actively eroding the edge of the sandplain (Fig. 11). Sand is being carried short distances, perhaps for 1–2 km, as the stream terminates only a few kilometres to the south-west. It would appear from such field observations that sand which is being actively eroded is carried only short distances in situations of low drainage density and subdued topography. In contrast such processes in the higher rainfall western and southern parts of the Victoria Plateau appear to have been more effective in eroding and transporting any sand cover, as indicated by the absence of sand in the Moresby Range near Geraldton. Further west, lower in the landscape, and some 25 km from the coast, sandplain gives way to soils associated with the Northampton Block, which then change to the alluvial soils of the Greenough Flats.

In the south the extensive elevated yellow sandplain becomes fragmented and gives way to the clayey soils related to the non-sandstone lithologies which are largely associated with dissected country drained by the Irwin River system. The termination of the plateau sandplain, in the form of an escarpment in this area, provides the geomorphic setting for Nangetty where 3 m of sand overlies a ferruginised sandstone profile at the very southern edge of the elevated Victoria Plateau. Further south and east across to the Coalseam Park lie isolated remnants of the Victoria Plateau in the form of mesas with sandstone capping. Isolated sand

Fig. 11. Intermittent drainage channel, southern Victoria Plateau. Note the active erosion of the sandplain edge with storage of sand in the broad channel bed due to the low drainage gradient.

sheets occur on the summits of some of these mesas comprising sand overlying highly altered sandstone which in turn overlies highly weathered and eroded shales.

Moonyoonooka, situated well outside the elevated sandplains of the Victoria Plateau, is an isolated pocket of deep sand 13 km inland from the coast and at an altitude of about 100 m on the western edge of a dissected landscape drained by the Chapman and Greenough Rivers. The profile comprises a deep (>5 m) yellow sand with weak bedding planes evident from 0 to 4 cm that are indicative of surficial aeolian sedimentation at this site. The most likely source of sediment will be from erosion of exposed agricultural topsoils in the surrounding area.

This rather detailed account of sandplain heterogeneity provides further examples of geodiversity in the region. For the general traveller or even a 'geotourist' it is perhaps the most challenging aspect of all regarding engaging with and learning about the landscape. However, following on from Newsome et al. (2022), who have provided a platform for bringing regolith into geotourism agendas, exploring the sandplain, understanding its relationship with the solid geology and deriving explanations of geomorphological expression is yet another 'geotourism opportunity'.

5. Discussion and future directions

5.1. Subdued landscapes and regolith

The before mentioned three-tiered approach to identifying geodiversity for geotourism purposes provides a starting point in developing geotourism and potentially a geopark in a predominantly subdued landscape where regolith is prominent. Therefore, the account of sandplain regolith in this paper is relatively detailed as compared to most publications which focus on more commonly valued exposures of solid geology and areas which have significant topographic expression. Moreover, when geodiversity and any related geotourism is reported in the global literature there is usually a dearth of content regarding the regolith component (Newsome et al., 2022). Regolith and rock weathered products occur in nearly all terrestrial environments but vary in their extent and prominence. Hence this paper considers regolith as an important component in planning for geotourism in the described study area. This is because sandplain regolith is a significant feature which extends across at least 50% of the landscape. This discussion section therefore provides some preliminary considerations that will require further research and development to realise a regolith-based approach to geotourism in the region.

5.2. Selecting a comprehensive approach to assessing geodiversity in the study area

Raeisi, Dincă, Almodaresi, Swart, and Boloor (2022) provide a comprehensive account of approaches to geosite assessment and inventory for a range of geological contexts. However, we wish to point out that our paper is not specifically about the complex task of geosite inventory and ways of assessing geodiversity. It is a conceptual paper introducing the reader to the nexus between geodiversity and geotourism in a little-known region of the world where geotourism is developing. Overall, there has been a dearth of information about initiating geotourism in subdued, regolith dominated landscapes. Generally speaking, landscape positions such as valleys, gorges and coastal cliffs will usually display the solid geology of an area while plains and mesas will be more expressive of the regolith or younger geological deposits such as loess (e.g., Solarska et al., 2013). Clearly the geology at any region is central to any geodiversity assessment and the ability to view it is very important. However, Jary et al. (2018) caution that in cases of soft rock exposure, erosion by water, modification by surficial processes and the presence of vegetation may need to be considered in assessing any site. Future geosite assessment research in the subdued landscapes of Western Australia could benefit from previous work conducted in Europe in assessing the geodiversity and geotourism potential of loess deposits. Solarska et al. (2013) and Kubalíková and Kirchner (2016) have already suggested scientific, educational, conservation, cultural, ecological, aesthetic and economic values as key criteria in geosite assessment for geotourism development. Such work provides the platform in developing an inventory/evaluation of geodiversity and aids in the identification of some of the management and geotourism development challenges in developing geotourism and/or building the case for a geopark in the mid-west of Western Australia.

5.3. Conceptualising geotourism using the 'dimensions' approach

We reiterate that the purpose of this paper has been to present a three-tiered approach to conceptualising geodiversity in a subdued landscape in the mid-west of Western Australia. In doing so there has been a necessary focus on regolith because of its prominence in the landscape. We have also engaged with the theory behind geotourism to remind the reader that geotourism represents a multi-faceted nexus between geology and tourism, comprising a complex mix of knowledge that can be conceptualised according to four dimensions (Fig. 3 and Table 2). The conceptual nature of the work presented in this case study leaves much scope for the details of potential visitors, tours, and geoconservation to be worked out. Moreover, geotourism is expanding rapidly around the world and in the future, much can be learnt from the rise in publication outputs (e. g., Herrera-Franco et al., 2020, Herrera-Franco, Montalvan-Burbano, Carrion-Mero, Jaya-Montalvo, & Gurumendi-Noriega, 2021, Herrera-Franco, Mora-Frank, Kovács, & Berrezueta, 2022).

There is an active geopark movement globally and, despite Australia lagging behind the rest of the world in geopark development, progress is being made (Briggs, Dowling, & Newsome, 2021a). Table 2 thus provides some direction for initiating a geopark in the study area. Furthermore, Briggs, Newsome, and Dowling (2021b) provide detailed information on the socio-political

Table 2
Interconnections between the dimensions of geotourism in the development of a Sandplain Geopark.

Socio-political	Geodiversity	Biodiversity	Culture
Conceptual thinking and tourism planning	Opportunities provided by the geodiversity of the region	Key attractions and sites	Content and representation
Management structure to guide and maintain the concept and source funding opportunities	Preliminary investigations	Sandplain flora reserves to be included	Stakeholder engagement
Themed tourism Geotrails and demonstration sites	Assessment and inventory to determine potential tourism attractions	Targeted destinations	Identify opportunities
Extent and scale	Three tier approach comprising regional solid geology, geodiversity within one member and a focus on regolith	Focus on floral biodiversity	Develop a plan concerning historical, current, and future human use of the landscape
Environmental management/recreation geology	Geoconservation requirements	Conservation of biota	Relevant site conservation
Marketing	Targeted interests embracing regolith	Adaptations of flora to dry conditions and nutrient poverty	First nations usage of natural resources
Themed delivery of tourism and tour guiding	Geological features and Earth history Interconnections between geodiversity, ecology and land use	Focus on specific species in different reserves	Difficulties of using sandplain for agriculture
Educational materials and information (geotrails, road journeys, interpretive panels, electronic media)	Expand opportunities to showcase solid geology and explain origin of landscapes Regolith as interesting Geoheritage	Unique biodiversity	Historical perspective. For example, first nations to present day people's perspectives on landscape
Maintenance	Geoconservation via site access management and protection	Review protected area management effectiveness and integrity of facilities	Continuity of delivery and review of products
Evaluation of geotourism performance and visitor satisfaction	Modify management practices according to key performance indicators	Site and product monitoring	Site and product monitoring

Note: Refer to Fig. 3 in conjunction with reading this Table.

dimension in developing a geopark in Western Australia. In terms of geodiversity-related content applicable for a sandplain geopark in the mid-west of Western Australia, the initial focus can be on the established solid geology and landscape attractions at Kalbarri and Coalseam Conservation Reserve. Additional work can be directed in identifying geo-routes that focus on river valley sections (see Table 1), key sandplain sites and demonstration excavations. Specific interest in regolith can be fostered by geosites that show the complete disintegration of rocks, contrasting soil and sediment colours, the nature of pisoliths and the re-distribution of iron in weathered profiles. The sheer extent and depth of sand in the study area is astonishing raising questions of origin (see Newsome et al., 2022) and posing the questions of why the sands are different colours and at different depths (e.g., Newsome, 2022). Answering such questions requires in-the-field interpretation. Geotourism of this nature thus necessitates sites where differences can be demonstrated and discussed on-site. Display quarries could furnish this requirement providing issues surrounding landownership, safety and management are resolved.

6. Concluding remarks

Geodiversity of the study area has never been explored in the context of its wider geotourism potential and this case study therefore is somewhat preliminary in its wider scope. We do, however, conceptualise an approach to geotourism that can be taken in this part of Australia. There is a general lack of attention paid to regolith in the geotourism literature, hence we have provided a relatively detailed account of a large expanse of sandplain that occurs in the described study area. Furthermore, we point out that the wider mid-west region of Western Australia is a 'hidden gem' of geodiversity. From a geotourism perspective it may seem there is little of interest in the area apart from Kalbarri National Park and Coalseam Conservation Park. However, there is interesting geodiversity that can be readily accessed given suitable guidance and appropriate information. Most reasonable sized towns in the area have tourism information centres and the ubiquity of electronic facilities (websites, Google, including Google Earth) can now provide information and directions to sites (such as sandplains) that tourists may never have even thought of visiting when they initially began to explore the area.

Unlike much of Western Australia that lies on Archean basement the mid-west geology covers important parts of the geological time scale comprising a range of rock types from plutonic through sedimentary and well displayed weathering profiles. Information about the geology of the area is informative and readily available (Morey et al., 2005; Morey & Haig, 2011) but could be summarised for tourism purposes to simplify content for the layperson. While the landscape seems subdued the river valleys and coastal cliffs have considerable geomorphic interest as they expose geological strata in spectacular and scenic vistas. As some of the primary tenets of geotourism involve educational aspects and community benefit, the development of walk trails and lookout points with interpretive plaques can provide educational information and context for the visitor. Tourists benefit the economy of the areas they visit through using accommodation and commercial facilities. Kalbarri National Park and surrounding areas suffered extreme cyclone damage in May 2021 (ABC, 2021) and as one of the main income streams for the area is tourist visitation attracting people back to the area is vital to maintaining a viable community in the area. Additional appropriately marketed geotourism attractions would benefit the community. As well as benefiting the community there is also a need for local community involvement in protection of localities. Localities of interest need to be managed appropriately to preserve their integrity and at some sites providing amenities for visitors such as toilet facilities and rubbish control is a necessary investment that needs to be funded from State or local government sources. Geotourism is an increasing area of general tourism interest (Dowling & Newsome, 2018) and with the relaxation of COVID-19 restrictions in 2022 there is added potential to bring back business to local communities and to enlighten tourism participants to the evolution of Earth history.

Author credits

David Newsome: Initial conceptualisation, initial drafting, review and editing (75%). **Phil Ladd:** Secondary drafting, revision and editing (25%).

Declaration of Competing Interest

We have no conflict of interest.

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