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Science

Geomorphology of the Inskip Peninsula, Queensland, Australia

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ABSTRACT
The Inskip Peninsula is the link between two major coastal dune fields; Fraser Island (the world's largest sand island) and the adjacent Cooloola Sand Mass. There has been a notable lack of research into the geomorphology of the sand masses and the relationship between the two dunefields. This paper presents a detailed geomorphological map of the Inskip Peninsula at a scale of 1:10,000. The Peninsula can be divided into three parts; an eastern section dominated by late Holocene strandlines and foredunes with an active spit at the northern limit of the peninsula; a central zone composed of broader foredune ridges and swales and an eastern zone comprised of remnants of older parabolic sand dunes and foredune remnants. The map provides a framework for ongoing work on landscape reconstruction.

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coastal geomorphology; coastal dunes; spit; landforms; sea-level-change; Fraser Island

1. Introduction

Southeastern Queensland contains one of the best records of Quaternary coastal dunefield development in the world and is an excellent area to investigate Quaternary sea level and climatic changes, and their regional and hemispheric impacts. Australia's east coast comprises a major depositional system containing three of the world's largest sand islands: Fraser, North Stradbroke and Moreton Islands, in addition to the mainland attached Cooloola Sand Mass (Miot da Silva & Shulmeister, 2016). Major sand islands and sand masses have been mapped, and some luminescence dating has been applied (Brooke, Pietsch, Olley, Sloss, & Cox, 2015; Lees, 2006; Thompson, 1981; Tejan-Kella et al., 1990; Ward, 2006; Walker, Lee, Olley, & Thompson, 2018), but investigations of the dune fields are still surprisingly limited. The Inskip Peninsula provides an excellent opportunity to examine the relationship between two of the major dunefields (Cooloola and Fraser Island) and to investigate the impact of the terminal Pleistocene-Holocene marine transgression in the geomorphological record. It is unknown if the Cooloola Sand Mass and Fraser Island have only recently been separated or if the dunefields are largely independent on Quaternary time scales. This paper and the associated map present the results of detailed mapping in a densely vegetated area using a combination of analyses of remote sensed data, notably LiDAR, and ground mapping. The geomorphological map of the Inskip Peninsula supports an ongoing sedimentological and geochronological investigation of both the Cooloola Sand Mass and Fraser Island. It demonstrates older dune and lake features on the Peninsula, which was originally believed to be a strandplain featuring only sand ridges and recurved spits (Thompson & Moore, 1984).

2. Study area

During the Quaternary (last 2.6 Myr), the sea level varied repeatedly and substantially through glacial (low-stands) and interglacial (high-stands) periods. The last full interglacial/glacial cycle (last 125,000 years) featured interglacial sea level high-stands close to modern mean sea level (MSL) between ∼130 and 120 ka (e.g. Chappell, 1974; Roy & Thorn, 1981), glacial low-stands that reached their nadir during the last glacial maximum (LGM) between ca. 21–18 ka with sea levels 120–130 m below MSL (Chappell, 1974; Roy & Thorn, 1981) and a rapid sea level rise during the transition to the Holocene (e.g. Sloss, Murray-Wallace, & Jones, 2007). Sea-level reached 5–7 m below modern MSL by 8 ka (Chappell, 1983; Flood, 1984; Lewis, Wüst, Webster, & Shields, 2008). Sea level continued to rise to reach modern levels around 7.5 ka and achieved a Holocene sea level high-stand of 2–3 m higher than modern MSL between 7 and 4 ka (e.g. Lewis, Sloss, Murray-Wallace, Woodroffe, & Smithers, 2013; Sloss et al., 2007; Woodroffe, 2009). Since 4 ka sea-level sea-levels have fluctuated but have generally declined (Gontz et al., 2015; Lewis et al., 2013).

Located between Fraser Island and the Cooloola dune fields in south-eastern Queensland, the study area is the approximately 18 km^2 Inskip Peninsula

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(25°48′28″ – 25°55′48″S and 153°2′38″ – 153°6′42″ E), an elongate, densely vegetated peninsula shaped by the aggradation and erosion of quartz sand (Figure 1). The peninsula is situated on the coastal downdrift system on the east coast of Australia, where sandy sediments from the central New South Wales coast (Colwell, 1982) are transported northward and accumulate in numerous barrier systems, sand islands and coastal sand masses along the shore of the north Tasman Sea and south Coral Sea from South Stradbroke Island to Fraser island (e.g. Gontz, McCallum, Moss, & Shulmeister, 2016). The peninsula is characterised by shore parallel ridges, relatively small parabolic dune remnants (>20 m height) and a recurved spit tip. Sand mining was conducted from 1966 to 1976 (Grimes, 1992) and influenced the geomorphology of the northern part of the peninsula, though the impact is hard to observe in the field.

3. Climate and vegetation

The climate of the Cooloola-Fraser Island region reflects its location in the sub-tropics and is classified as Cfa in the Köppen classification system. The climate is dominated by the sub-tropical high pressure cell for most of the year. This brings a moist onshore SE flow into the area. During the austral summer ex-tropical storms can penetrate the area from the Coral Sea to the north, while in late winter westerly winds often dominate. The nearest (automatic) weather station at Rainbow Beach (25°54′3″S, 153°5′21″E) is located at the southern end of the Inskip Peninsula. Mean monthly minimum and maximum temperatures for the hottest and coldest months range from 22.1°C to 28.9°C in January to 10.3°C and 21.2°C in July. The mean annual rainfall oscillates around 1460 mm/a (all meteorological data from the Australian Government Bureau of Meteorology's Climate Database: http://www.bom.gov.au/climate/data/). Precipitation usually exceeds evaporation in the first six/seven months of the year, but in late winter the vegetation may show some moisture stress (Walker, Thompson, Fergus, & Tunstall, 1981).

The natural vegetation of the peninsula grades from pioneer taxa along the coastal dunes with *Banksia integrifolia* and *Casuarina equisetifolia* woodland close to the coast to *Eucalyptus intermedia* forest in the western inland. Common tree species on high ground such as dune and foredune ridges are *E. intermedia*, *Tristaniaconferta*, *Callitriscolumellaris*, *E.tesselaris*, *Casuarina littoralis* and *B. serrata*, with *Alphitoniaexcelsa*, *Dodonaea triquetra*, several *Acacia spp*. and *Livistona sp*. in the understory. *Callitris* forms pure stands on some of the ridges. In the more marshy areas, such as dune swales, *Melaleuca quinquenervia* and *Imperatacylindrica* dominate. The mined areas were revegetated

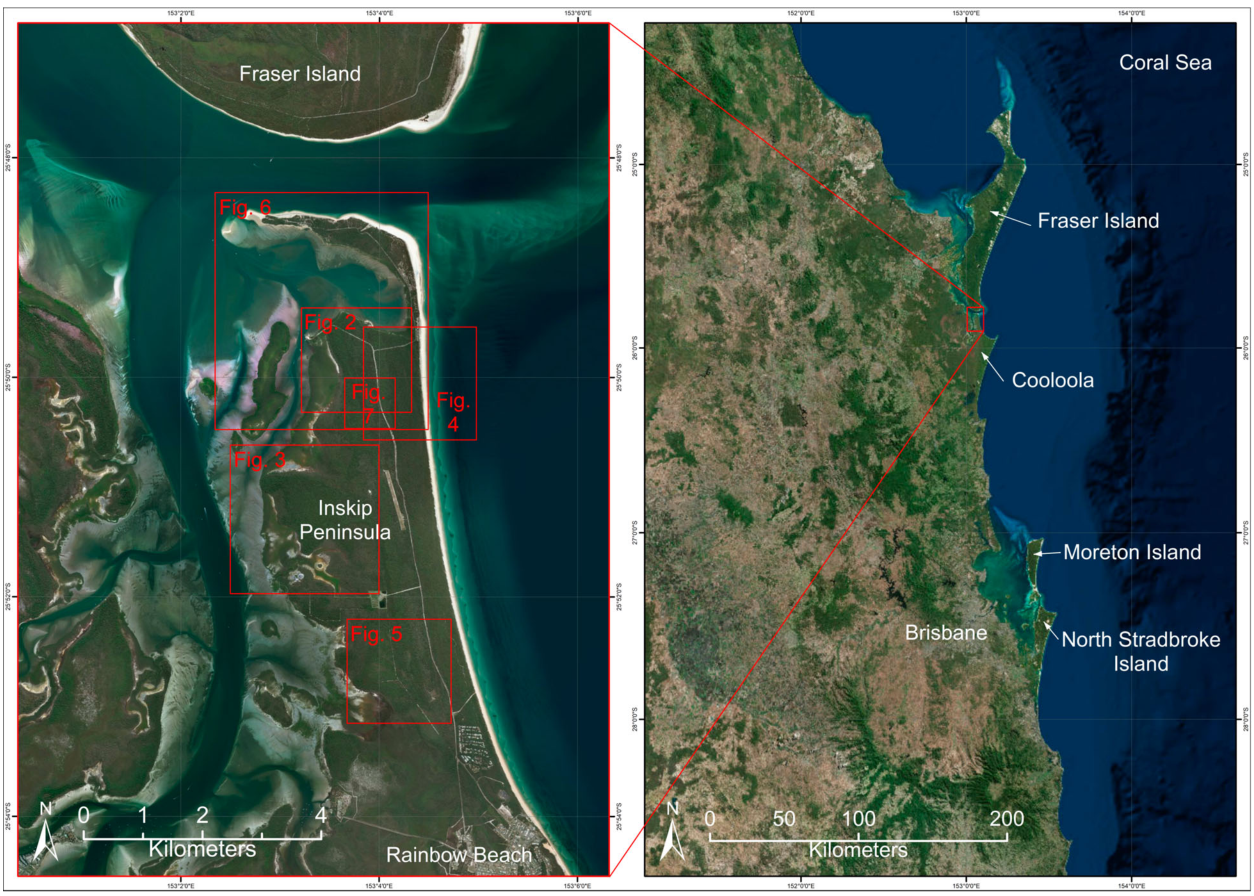

Figure 1. Map of study area. (a) Inskip Peninsula. (b) Southern Queensland coast.

with *Acacia concurrens* and other *Acacia* species including *A. flavescens*, *A. aulococarpa*, along with *Callitrisco-lumellaris*, *D. triquetra* and *Lantana camara* (Thompson & Moore, 1984).

4. Methods and data

The production of this detailed geomorphological map is based on the interpretation of remotely sensed imagery and ground-truthing of aeolian and littoral landforms during field survey.

4.1 Data sources

Digital elevation models (DEMs) were obtained from the State of Queensland (Department of Environment and Resource Management). The chosen imagery was taken from a fixed wing aircraft using Airborne Laser Scanning (ALS) between 17 July 2009 and 29 September 2009, with the related field survey being undertaken between 13 August 2009 and 20 August 2009, as part of the 2009 Fraser Coast LiDAR capture project undertaken by Vekta Pty Ltd on behalf of the Queensland Government. Orthorectification of the imagery allowed the use of the MGA56 projection with the Geocentric Datum Australia GDA94 as the horizontal datum and the Australian Height Datum AHD1971 (Geoid Model – Ausgeoid98) as the vertical datum. The 1:1000 tile layout had a high spatial resolution, allowing the visual distinction and classification of small-scale features. A 1 m DEM was used to create 0.25 m contours by triangulation. Base maps in combination with provisional geomorphological maps and DEM imagery were used both to develop familiarity with the landscape and to choose areas for later fieldwork.

Satellite imagery used in the figures was obtained via ESRI ArcGIS Desktop 10.5 (Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community).

4.2 Ground truthing

Field work and ground truthing was conducted at the Inskip Peninsula in March 2017. Prior to the fieldwork campaign, several preliminary maps were constructed based on the DEMs. Aeolian and littoral landforms were visually identified based on their morphology and sampled for further analyses. Draft maps (DEM and geomorphology) were used for orientation on the peninsula and the location of features like ridges and swales.

4.3 Map production and design

There are several geomorphological mapping concepts, systems and symbol options (cf. Dramis, Guida, & Cestari, 2011; Griffiths, Smith, & Paron, 2011; Leser & Stäblein, 1985; Verstappen, 2011). The mapping symbology was selected to address the chronological and dynamic aspects of coastal geomorphology. Symbol and block colours were used to delineate coherent and individual coastal features and landforms. The map was constructed at various scales down to 1:2000 to attain a high level of detail. The final map was adjusted to 1:10,000, to allow it to fit on an ISO A0 page. More than 140 landforms have been mapped, across six main landform types in addition to anthropogenic impacts.

4.3.1 Software and digitalisation

Aeolian and littoral landforms and patterns were identified and digitally mapped using ESRI ArcGIS Desktop 10.5 software to allow continued correction and modification. Data sets were stored as vector lines or polygons and thematically organised by landform type. A hill-shade DEM provided topographic coherence and was used to ascertain the quality of georeferencing. The DEM was also used to create 10, 5, 2 and 1 m interval contours to investigate and interpret sloped features, notably the parabolic dune structures.

4.3.2 Accuracy and completeness of the map

To secure the accuracy and completeness of the map, the skill, precision and experience of the person constructing the map is the most important factor (Smith & Wise, 2007), as the formal and correct identification of landscape features is often subjective and interpretational (Napieralski, Harbor, & Li, 2007). In order to minimise misinterpretations, the map was reviewed by experienced coastal and aeolian geomorphologists and sedimentologists. The accuracy of the final map relies on the quality and resolution of the original data sets.

5. Description of the mapped features and interpretation of the depositional environment

The mapped landforms include foredunes, parabolic dunes, spits, erosional cuts and areas influenced by sand mining activities. Geomorphological features have been classified based on their height, elevation above sea level and more general geomorphological aspects such as shape, steepness and spacing. The features were then compared to coastal and dune features presented in various publications (Boyd, Dalrymple, & Zaitlin, 1992; Hesp, 1984, 2002; McKee, 1979; Ward, 2006; Ward & Grimes, 1987).

The landscape formations of the Inskip Peninsula have been divided into three divisions based on their relative ages, their dominant topography and their developmental processes. The far west of the peninsula comprises parabolic dune remnants. The middle of the peninsula contains large foredunes. The eastern coastal

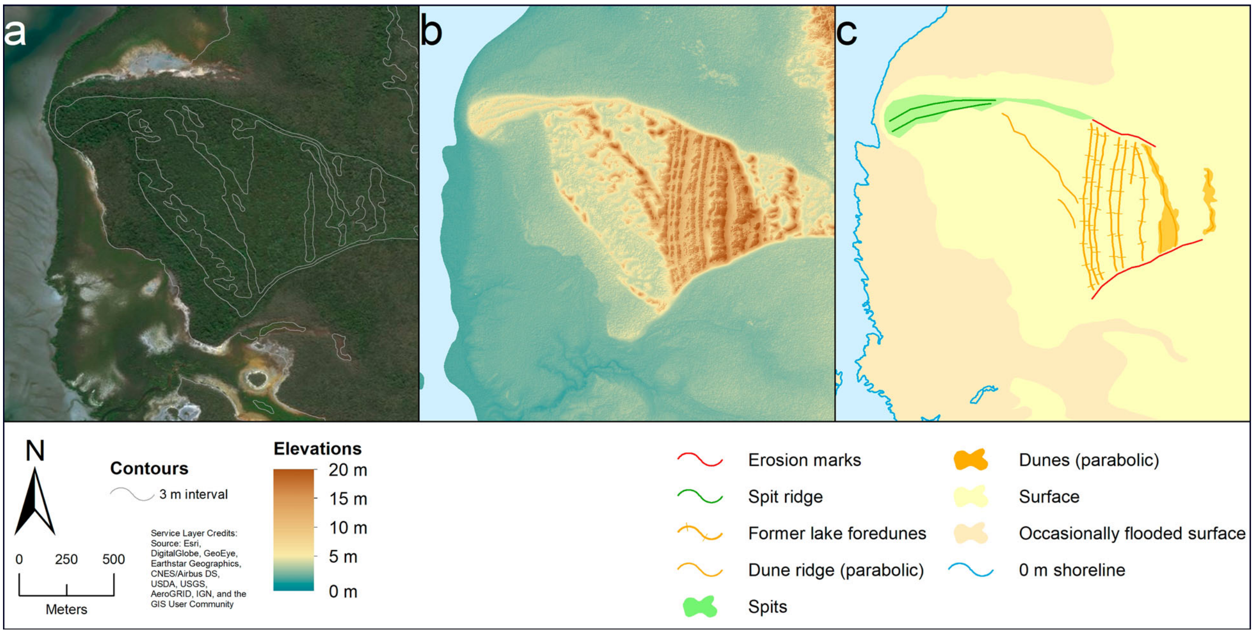

Figure 2. Western section of the peninsula. (a) Satellite imagery with contours. (b) DEM imagery. (c) Mapped features.

zone contains numerous narrow foredune ridges and swales (lee dune depressions).

5.1 Western section and Pleistocene landforms

The western section comprises several sections of dune remnants and is characterised by its wedge shape (Figure 2). There are four parabolic dune ridge remnants on the western side of the wedge (25°51′3″- 25° 51′21″S and 153°3′33″ – 153°3′54″E). Hesp (2011) defines parabolic dunes as U- and V-shaped, short to elongate trailing ridges, which often evolve out of blow outs in coastal environments. The best-preserved parabolic dunes (Figure 3) are located in the northern part of the peninsula (25°49′35″ – 25°50′13″S and 153° 3′33″ – 153°3′48″E). These U-shaped parabolic dunes (up to 18 m high) of various lengths (80–500 m) may be part of the same dunefield as the parabolic dune remnants on the wedge. Bordering the parabolic dune remnants in the west, six lower (6 m), north–south orientated ridges (~700 m long) form the middle part of this section (25°50′59″ – 25°51′27″S and 153° 3′23″ – 153°3′33″E). These ridges could be either transverse dunes or old lake foredunes on an older higher dune complex. Such features are visible in the southern part of Fraser Island in the ‘Yankee Jack’ dune unit

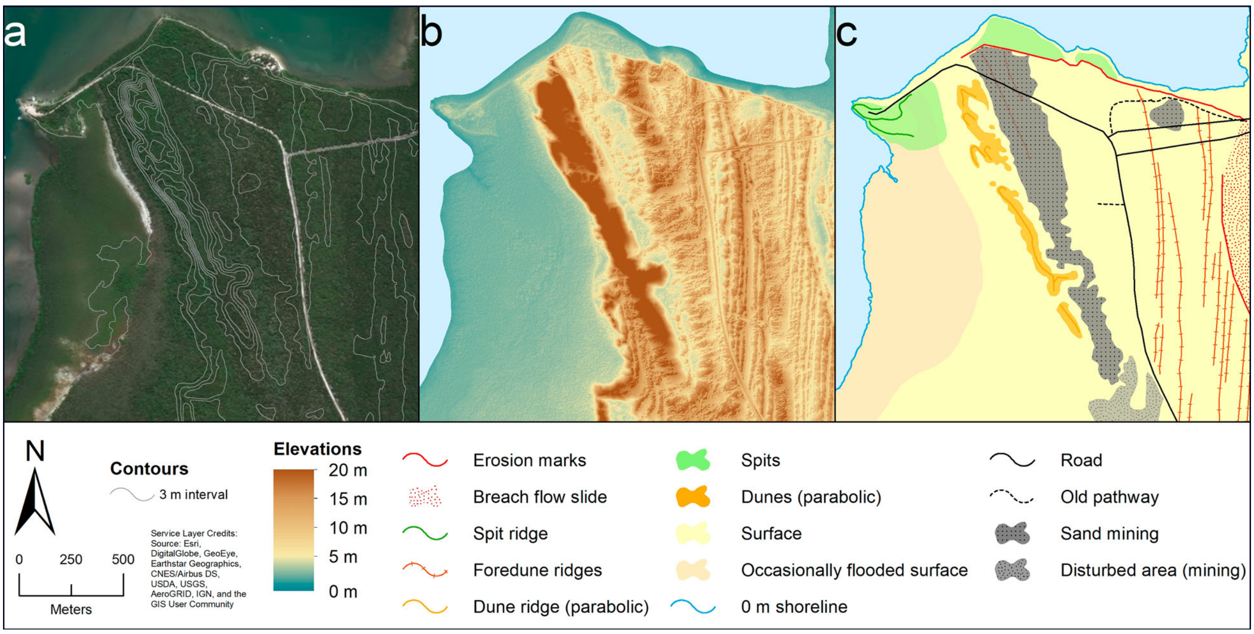

Figure 3. Pleistocene parabolic dunes in the northern region. (a) Satellite imagery with contours. (b) DEM imagery. (c) Mapped features.

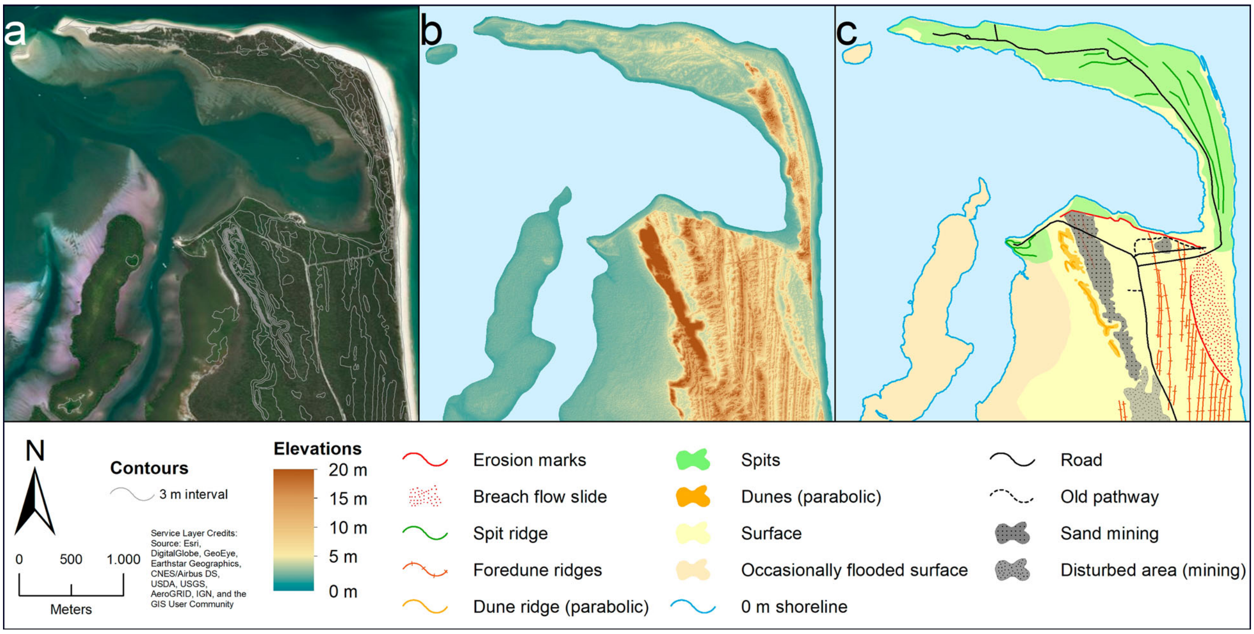

Figure 4. Northern spit complex. (a) Satellite imagery with contours. (b) DEM imagery. (c) Mapped features.

(Ward, 2006). McKee (1979) describes transverse dunes as asymmetrical ridges with steep leeward slopes, gentle windward slopes and only one slipface. Lake foredunes are described by Hesp (2002) as vegetated ridges separated by swales. The six lower ridges are in orthogonal alignment to the dominant wind direction (SW). The northern parabolic dunes and some of the western parabolic dunes are rotated 20°-30° to the west in comparison with these transverse dunes/foredunes. Both ridge systems are cut off at the northern and southern edge of this section (Figure 2). The sharpness of the cut indicates an erosional process such as channel avulsion or progressive channel shifting initiated by intense floods of nearby rivers/creeks flowing into the Tin Can Inlet or the Great Sandy Strait (e.g. Mary River). At the north-western edge a small spit (0.074 km^2) evolved some time after the erosion of the ridges (25°50′54″ – 25°51′1″S and 153°2′49″ – 153°3′24″E).

5.2 Holocene spit growth and development

Most of the Inskip Peninsula comprises an elongated strip of land featuring a well developed spit complex in the south-east that is composed of up to ten consecutive, shore parallel north–south orientated foredunes, with possible overwash fans. There is a large spit developed in the north (Figure 4). Two erosional

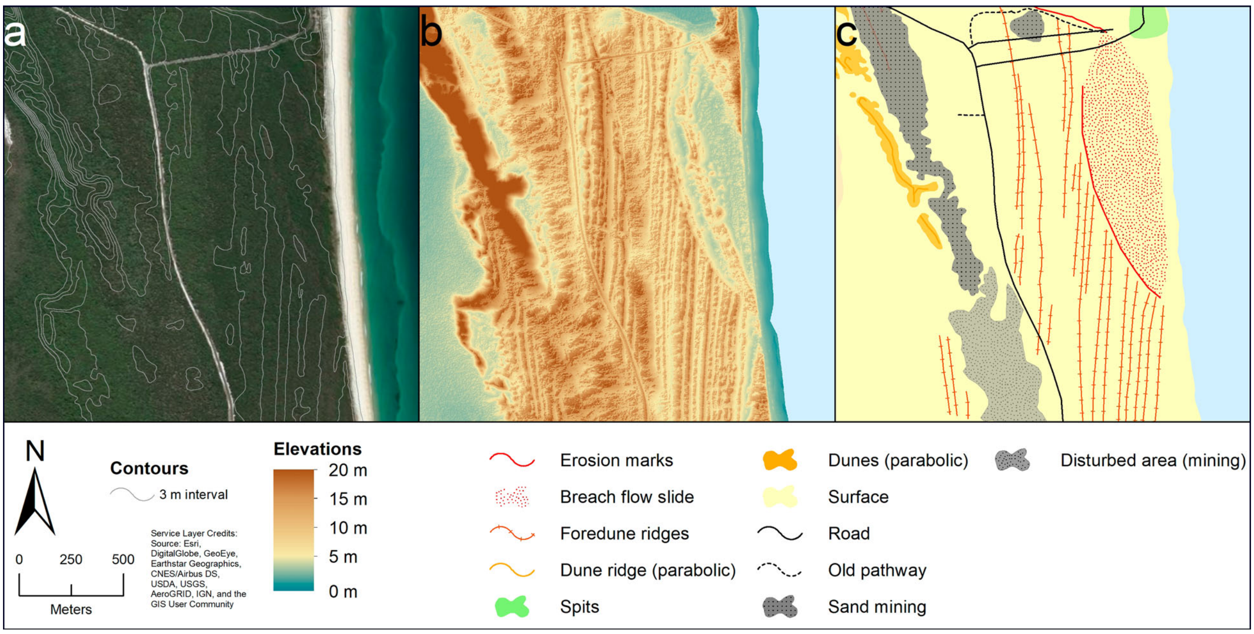

Figure 5. Foredunes and breach flow slide. (a) Satellite imagery with contours. (b) DEM imagery. (c) Mapped features.

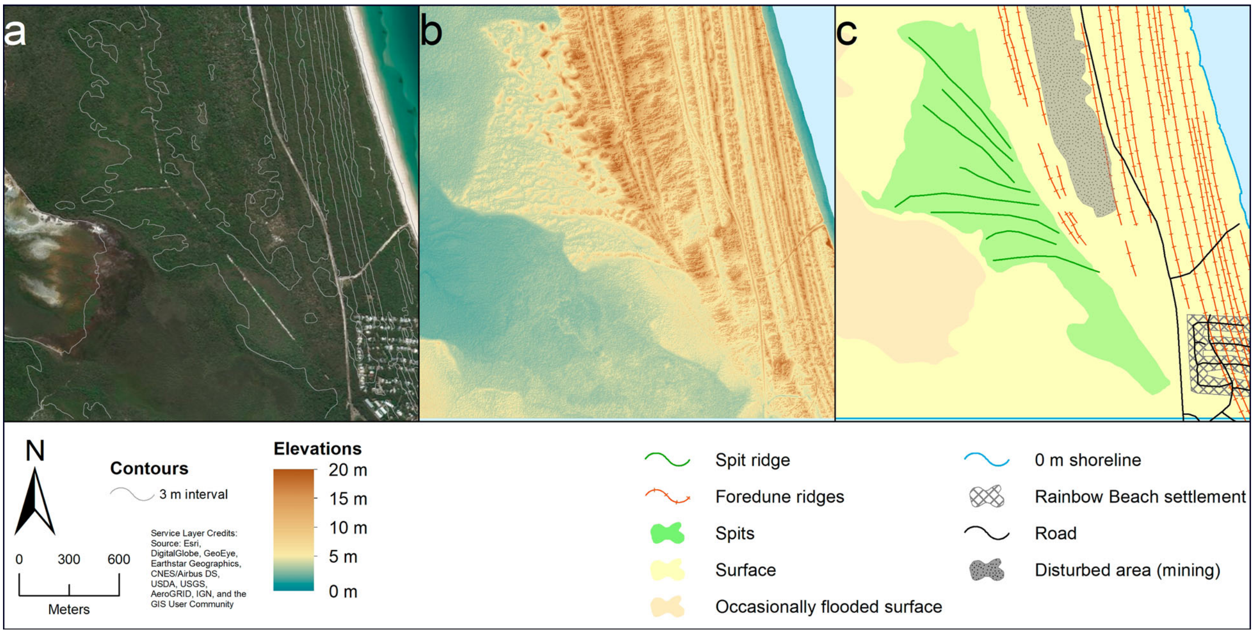

Figure 6. Southern spit complex. (a) Satellite imagery with contours. (b) DEM imagery. (c) Mapped features.

cuts are present in the northern part (Figures 3–5), representing a major erosional event which eroded the northern spit area for a length of 1360 m (25° 49′28″ – 25°49′40″S and 153°3′32″ – 153°4′16″E) and a minor breach flow slide or retrogressive flow slide (Figure 5) covering an area of 0,3 km^2, capping ten foredune ridges in the north-east (25°49′40″ – 25° 50′21″S and 153°4′12″ – 153°4′26″E). Foredunes are shore parallel, vegetated ridges separated by swales in the backshore zone of beaches (Hesp, 1984). The foredunes in this part of the peninsula are up to 7 m high and 15–50 m wide. They display typical ridge-swale morphology and their northern ends are eroded by the present day shoreline, due to both short-term storm events and longer-term shifts in the wave climate (McSweeney & Shulmeister, 2018). Their lengths vary between ~4700 m and ~100 m. The ridge successions are divided into two, north–south orientated groups (25°49′35″ – 25°53′48″S and 153°3′50″ – 153°5′21″E), separated by an area (~1.1 km^2) with features with very ambiguous morphologies (25°50′16″ – 25° 52′51″S and 153°3′52″ – 153°4′33″E). Spits are narrow coastal landforms tied to coast at one end formed by longshore sediment transport (Cooper, 2007). The spit complex in the south-east (0.77 km^2) could be the relict of a former spit complex, which is the foundation of the present day peninsula (Figure 6) and the basement of the foredunes (25°52′13″ – 25°

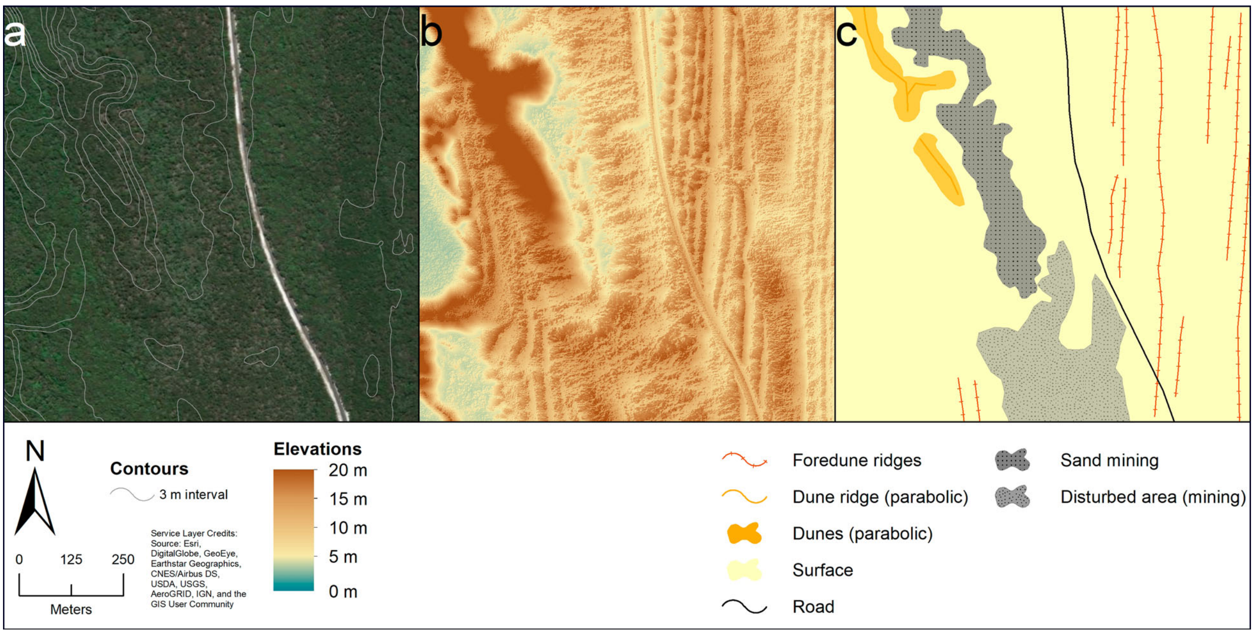

Figure 7. Sand mining areas. (a) Satellite imagery with contours. (b) DEM imagery. (c) Mapped features.

53′25″S and 153°3′44″ – 153°4′44″E). The spit at the northern end of the peninsula (1.4 km^2) is one of the youngest landscapes of the Inskip Peninsula (Figure 4) and its recurved tip is a result of wave and tidal interactions (25°48′28″ – 25°49′41″S and 153°2′38″ – 153° 4′26″E).

5.3 Anthropogenic influences

In the central part of the Inskip Peninsula pre-existing landforms were heavily altered or destroyed by intense sand mining activities, deforestation and road constructions (Figure 7). Although heavy minerals were only mined in a small area (~0.25 km^2) in the north of the field area (25°49′28,″ – 25°50′21″S and 153° 3′33″- 153°4′6″E), the mining associated impacts are clearly visible in the remote sensed data. An approximately 250 m wide strip of undistinguishable surface features stretches from the southern to the northern end (25°50′16″ – 25°52′51″S and 153°3′52″ – 153° 4′33″E) and this is very likely the result of deforestation, intense usage by heavy transport vehicles as well as dredging and levelling actions.

6. Conclusion

The overall patterns of late Pleistocene/Holocene climate fluctuations and sea level changes, and the corresponding sedimentation trends are manifested in the orientation and geomorphological characteristics of the depositional and erosional features across the Inskip Peninsula. The landform features can be divided into two distinct groups: one group, of likely Pleistocene age, comprises of relative high parabolic dunes and lake foredunes; while the second group, of clearly Holocene age, consists of coastal foredunes, spits and erosional areas.

This map will provide a basis for future sedimentological and geochronological/age-correlation work of dune fields in this region and contributes to ongoing studies of the southern Queensland coast.

Software

ESRI ArcMap 10.5 was used to visualise the remote sensed imagery, process the DEM, generate contours, map distinct landscape features and create the final map layout.

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Disclosure statement

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