Exploring the Evolution of Seafloor Sand Dunes

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Scientia

EXPLORING THE EVOLUTION OF SEAFLOOR SAND DUNES

Marine sand is both a vital natural habitat and an essential resource. However, while desert dunes are comparatively easy to observe, their oceanic counterparts are still poorly understood. **Dr Xiaochuan Ma** and his colleagues at the Chinese Academy of Sciences in Qingdao are mapping the shifting sands of the seafloor and measuring their movement. By investigating how seafloor dunes respond to waves, tides, and typhoons, they can help decision-makers protect and manage this critical resource.

Shifting Seafloor Sands

Many of us might take sand for granted, but it plays a significant role in modern life. Sand is used to manufacture concrete and glass for the buildings we live in and the roads we travel on. The tech industry extracts silicon from sand to make computer chips. About 32 to 50 billion tonnes of sand, mostly from the seafloor, are used each year, making sand the most extracted material globally, even exceeding fossil fuels. Marine sand is also a vital natural habitat, with countless species depending upon the sandy seabed.

Seafloor sand is sculpted by ocean currents into dunes and ridges, similar to wind-blown desert dunes on land. These structures can pose a risk to ship navigation, especially in shallow waters. Understanding the dynamics of sand could help policymakers mitigate risks and manage this critical resource.

However, the origin and evolution of seafloor sand formations are still uncertain. In particular, more work is needed to examine the links between sand dunes and tidal flows, ocean surface waves, and extreme events such as typhoons. Understanding the activity of sand under these conditions will help scientists to predict the impacts of climate change on the seabed.

Dr Xiaochuan Ma and his colleagues at the Chinese Academy of Sciences are deploying numerous techniques to address these questions, from sampling and studying seafloor dunes to modelling sand transport. By integrating multiple methods, Dr Ma and his team can uncover the mysterious processes governing the rhythmic forms of these beautiful features.

Measuring Typhoon Impacts

Typhoons are among the most extreme weather events to affect China's coastline and continental shelf. The high wind speeds associated with typhoons can generate giant waves, posing a considerable risk to coastal communities and infrastructure. The effects are also felt offshore: ocean sediments are disturbed by the movement of the water, dispersing seafloor ecosystems.

However, the impacts on the seabed are poorly understood, partly due to the difficulty in gathering data during unpredictable storms. Where measurements are incomplete, mathematical modelling can fill in the gaps. Dr Ma and his colleagues modelled seafloor sediment transport processes during Typhoon Ketsana, the most devastating storm of 2009.

The researchers took sediment samples and produced echosounder maps of the seafloor in the Beibu Gulf, part of the South China Sea, before the typhoon. For three days while the storm passed, they also measured water speed and elevation using an instrument positioned 50 centimetres above the seabed.

Back in the lab, Dr Ma and his colleagues sieved the sediments to measure the size of the sand grains. They processed their grain size and water data using a mathematical model to predict sand transport during the typhoon. Using this model, they could identify when the conditions were suitable for bedload transport, where currents are strong enough to move sediments along the seafloor, or suspension, where sands are lifted into the water column.

The researchers predicted that ocean currents and waves during Typhoon Ketsana could have caused bedload transport, but that speeds were rarely high enough for suspension. The simulated bedload movement during

KEXUE research vessel operated by IOCAS.

the typhoon was about seven times higher than under pre-storm conditions. However, the results of this study are theoretical, as sediment transport was not directly observed during the typhoon.

To obtain more direct measurements, the team have pioneered long-term observations of sedimentary processes during storms. 'In-situ field observation directly provides convincing data and evidence, and is essential to understand the modern behaviours of sediment and small bedforms,' explains Dr Ma.

His team built a multi-sensor measurement platform that can be anchored to the seafloor with heavy lead bricks. The researchers used the platform, moored 440 kilometres south of the Yangtze River mouth in the East China Sea, to conduct a 49-day investigation of sediment flows during Typhoon Chan-hom in 2015. The instruments onboard the platform measured multiple variables, including the water temperature, suspended sediment concentration and ocean currents.

They found that during the storm, water temperature decreased by about 0.8°C and currents reached 1.5 metres per second. The suspended sediment concentrations during Typhoon Chan-hom were 50 times higher than before the storm; most of the sediments came from the re-suspension of seafloor sand. Typhoon Chan-hom, lasting only a few days, was responsible for 89% of the south-westward sediment transport during the whole 49-day study period. Using direct observations, Dr Ma and his colleagues confirmed that typhoons play a significant role in moving seafloor sediments.

Understanding Ocean Dunes

Crescent-shaped dunes, called barchans, are typical of inland deserts, where the wind sculpts their characteristic shape. But barchan dunes also form underwater on sandy continental shelves due to ocean tides, waves and currents. While the formation of desert barchans has been well-researched, few studies have been conducted on their seafloor counterparts.

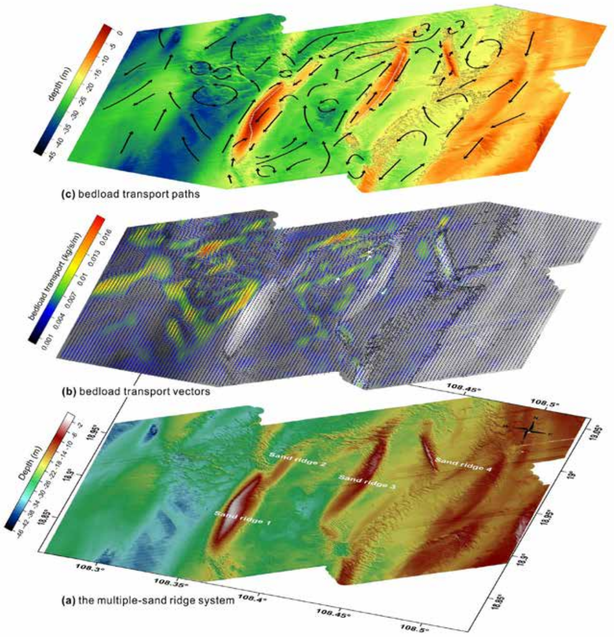
Dr Ma and his colleagues measured the shape and movement of barchans in the Beibu Gulf. In 2007 and 2009, the scientists used an echosounder to map part of the Gulf. They also measured ocean currents and collected sediment samples. When compared, the maps revealed that the individual barchans shifted along the seabed by up to 43 metres in two years.

The researchers studied the shape of the dunes, finding that they were wider and more asymmetric than desert barchans. They also discovered that smaller barchan dunes formed by breaking off from larger ones during typhoons. 'Their morphology is mainly controlled by finite water depth, daily reverse currents, sand supply changes and dune interaction,' explains Dr Ma.

By combining seafloor maps and ocean current measurements with mathematical modelling, the scientists were able to estimate sediment transport directions. The team tested this method on a region of the Beibu Gulf characterised by large sand ridges. They found that small dunes mainly migrated northwards on the west sides of the large ridges and southwards on the east sides, suggesting opposite directions of bedload transport. Transport generally occurred along the ridges rather than across them.

While mathematical modelling and seafloor surveying reveal present sediment transport, scientists can

Sediment sampling on the RV under the moonlight.



Bedload transport pathways in the multi-sand-ridge system in the northwest South China Sea.

analyse the history of dune formation by looking inside the dunes. Dr Ma and his colleagues studied the sediments inside two typical dunes to determine past changes in the tidal environment. The researchers used high-resolution seismic surveys, in which artificially generated shockwaves are reflected or refracted from the different sand layers to build up a picture of the subsurface.

The older, underlying sand layers sloped to the south. In comparison, the newer top layers dipped to the north, indicating a reversal of the sand transport direction. The sediment layers were shortened in the troughs adjacent to the dunes, indicating erosion.

By combining multiple techniques, Dr Ma and his colleagues are building an accurate picture of dune evolution in the Beibu Gulf. 'It is interesting because there are rare records of sediment transport changes in a shelf during small sea level fluctuations,' says Dr Ma.

Internal Solitary Waves

Internal solitary waves, or ISWs, are waves in the interior of the ocean. They form and propagate because the sea is composed of layers with different densities. ISWs often originate in the deep ocean and break when they reach the continental shelf, where the water depth suddenly shallows. Their behaviour could shape the continental slope between the shelf and the deep sea. 'The role that obliquely incident internal waves play in sediment and seabed shaping was elusive before,' says Dr Ma.

To find out how ISWs shape the seabed, his team travelled to the northern South China Sea, where the continental slope is subjected to some of the world's largest ISWs. The researchers deployed temperature and pressure sensors and an acoustic Doppler current profiler, which measures water speeds using sound waves scattered back from particles in the sea. They also mapped the depths of the seafloor, revealing large-scale ripples called sand waves.

The researchers detected strong ISWs and internal ocean tides, which occur as surface tides move ocean water up or down the sloping seafloor. They identified two types of sand waves. Type 1, with crests perpendicular to the ISWs, are most likely formed by wave propagation. Type 2 sand waves only form on steeper slopes, which are most affected by tides. 'This study sheds light on the roles of internal tides and ISWs in shaping the seabed, especially oblique ISWs near the shelf break,' says Dr Ma. A second, later bathymetric survey of the sand waves revealed they are mobile, moving along the seafloor by almost a metre per year.

By combining seafloor surveying, sediment sampling and mathematical modelling, Dr Ma and his colleagues continue to shed light on the hidden shifting sands of the seafloor. Their work could have profound implications for the management of this precious resource. 'Tools including gauge stations, in-situ measurements and acoustic technologies are aiding sand resource management,' says Dr Ma.

In the future, further efforts to understand the physical mechanisms of sand transport depend on more advanced numerical models, along with more measurements. 'More field observations are required, and a dataset about the world's subaqueous sand waves and dunes is urgently needed,' says Dr Ma.

Meet the researcher

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Dr Xiaochuan Ma gained his PhD in Marine Geology from the Chinese Academy of Sciences (CAS), Qingdao. Since 2013, he has worked as a professor in the CAS Key Lab of Marine Geology and Environment. In 2018–2019, he visited the Woods Hole Oceanographic Institution, USA, as a guest investigator. Dr Ma's research focuses on the dynamics of sediment transport from the coastline to the deep ocean, the origins of features such as sand dunes and seamounts, and the effects of storms on the seabed. His work uses a wide array of techniques, from mathematical modelling to conducting research cruises. Dr Ma has published numerous articles in peer-reviewed journals and presented his research at international conferences. At CAS, he supervises postgraduate students and doctoral candidates in addition to his research activities.

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FURTHER READING

X Ma, J Yan, Y Song, X Liu, J Zhang, PA Traykovski, Morphology and maintenance of steep dunes near dune asymmetry T transitional areas on the shallow shelf (Beibu Gulf, northwest South China Sea), Marine Geology, 2019, 412, 37–52.

H Zhang, X Ma, L Zhuang, J Yan, Sand waves near the shelf break of the northern South China Sea: morphology and recent mobility, Geo-Marine Letters, 2019, 39, 19–36.

J Lu, J Jiang, A Li, X Ma, Impact of Typhoon Chan-hom on the marine environment and sediment T dynamics on the inner shelf of the East China Sea: In-situ seafloor observations, Marine Geology, 2018, 406, 72–83.

X Ma, J Li, J Yan, Tide-induced bedload transport pathways in a multiple-sand-ridge system offshore of Hainan Island in the Beibu Gulf, northwest South China Sea, Earth Surface Processes and Landforms, 2018, 43, 2738–2753.

X Ma, J Yan, Y Hou, F Lin, X Zheng, Footprints of obliquely incident internal solitary waves and internal tides near the shelf break in the northern South China Sea, Journal of Geophysical Research: Oceans, 2016, 121, 8706¬–8719.

X Ma, J Yan, F Fan, Morphology of submarine barchans and sediment transport in barchans fields off the Dongfang coast in Beibu Gulf, Geomorphology, 2014, 213, 213–224.

X Ma, J Yan, F Fan, P Yao, Response of bedload transport, submarine topography, and dune internal structures to typhoon processes off Dongfang coast in the Beibu Gulf, Acta Oceanologica Sinica, 2013, 32, 27–40.