Application of Current Measurement and Time Lapsed Multibeam Surveying to Investigation of a Banner Bank in the Bay of Fundy

Garret P. Duffy[1], John E. Hughes Clarke[1] and Russell Parrott[2]

(1) Ocean Mapping Group, Department of Geodesy and Geomatic Engineering, University of New Brunswick, Fredericton, New Brunswick, CANADA, E3B 5A3. E-mail: garret@omg.unb.ca.
(2) Geological Survey of Canada (Atlantic), 1 Challenger Drive, P.O. Box 1006, Dartmouth, Nova Scotia, CANADA, B2Y 4A2.

Abstract

Time lapsed multibeam surveys show that sand dunes on top of a headland associated sand bank (Banner Bank) are migrating swiftly at average rates of up to ~10 metres/month. Interpretation of depth averaged current vectors show a large eddy to be initiated on the ebb tide. Grab samples show that the sediment of the sand bank is composed of medium sand with a bimodal proximal facies consisting of granules and medium sand. Sediment transport vectors constructed on the basis of grain size parameters show that the muds to the west are an important source of sediment. Analysis of bottom currents reveals that there is no evidence for opposing residual bottom currents either side of the sand bank as reported in other studies of Banner Banks because the Banner Bank is not co-located with the centre of the residual eddy. Sedimentation is thought to be as a result of secondary centrifugal circulation arising from the small radius of curvature of the tidal eddy.

Multibeam Data

Six multibeam sonar surveys were carried out roughly a month apart from April 2002 to October 2002. Ocean Mapping Group's vessel *Heron* (**figure 1**) is equipped with a SIMRAD EM-3000 multibeam echosounder and was used to carry out the surveys of the Banner Bank outside Saint John, New Brunswick (**figures 2,3**). Differential GPS gave horizontal position (± 1 m) and a Canadian Hydrographic Service operated tide gauge at nearby Saint John gave tide data necessary to correct for depth variations due to tide.

Figure 1: Above: The CSL *Heron* (length: 10 m). Inset: A view of the EM-3000 multibeam sonar.

Survey lines were spaced 30 m apart which, in a water depth of 30 m, meant that the seafloor was effectively surveyed twice by the overlapping swaths (**figure 4**).

Resulting data was processed and cleaned with software developed with software developed at Ocean Mapping Group. Data from the 6 successive monthly surveys was then gridded up to form 1 metre resolution digital terrain models for bathymetric analysis.

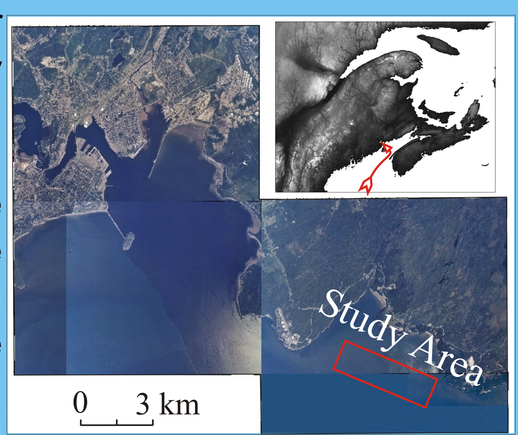

Figure 2: Aerial photograph mosaic of study are showing the nearby city of Saint John, New Brunswick.

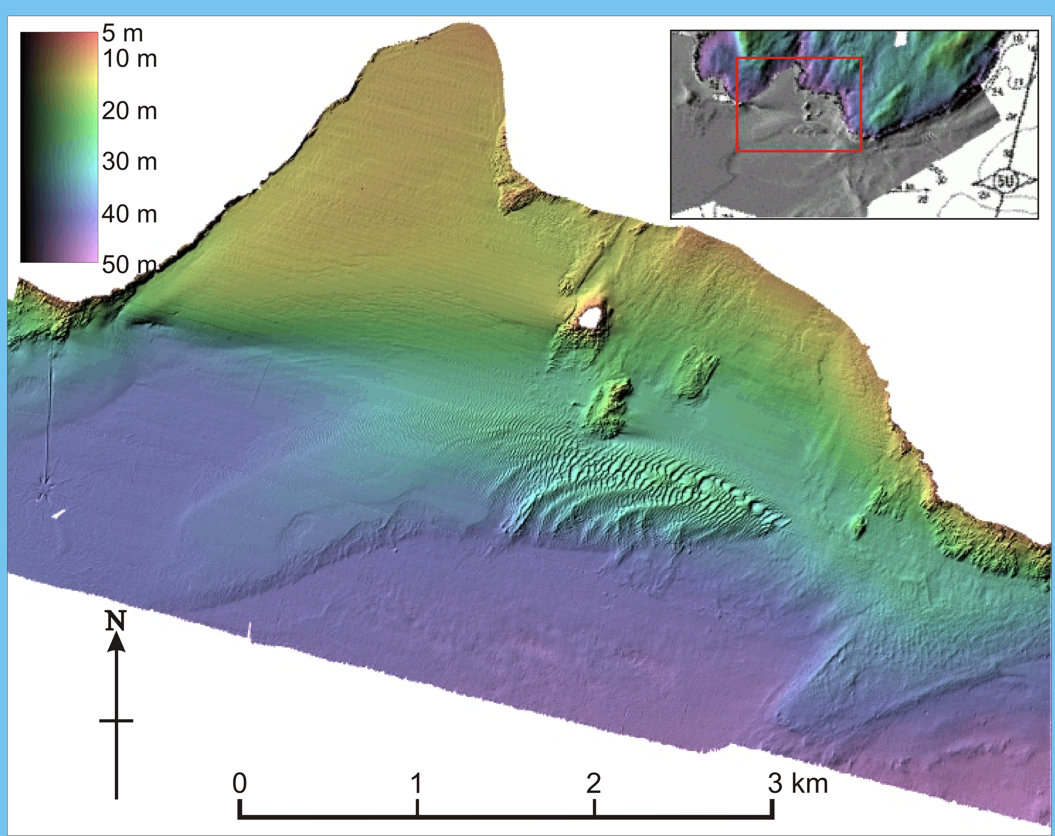

Figure 3: Bathymetric map of the Mispec Bay Banner Bank. Inset shows relationship of the Banner Bank with the headland, Cape Spencer.

Migration Detection

When the 6 consecutive surveys were viewed in a movie, it was very evident that the large sand dunes in the shallowest part of the sand bank had migrated the most over the period of investigation. The lunate megaripples just off the tip of the sand bank close to the headland migrated 50 m over the 5 month epoch of observation. Whilst the movie was a useful method to interrogate the datasets, it was difficult to get a quantitative estimate of migration. To this end, cross-correlation code was developed and executed on sun-illuminated versions of the digital terrain models. Sample output vectors calculated by cross-correlating June and July's surveys are displayed in **figure 5**.

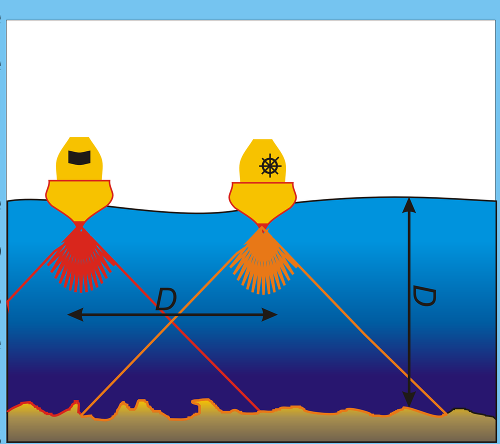

Figure 4: Schematic diagram showing overlapping sonar swaths between adjacent survey lines giving 200% sonar coverage of the seabed when the survey line spacing equals the water depth.

From examining the migration vectors, it is evident that the bedforms in

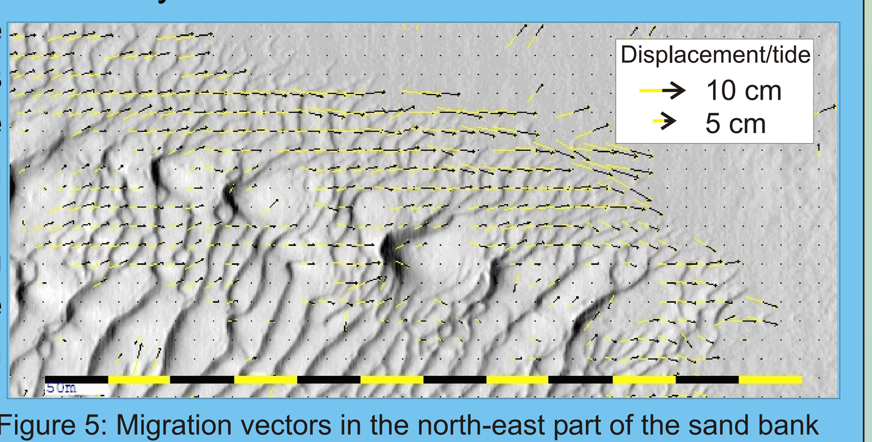

Figure 5: Migration vectors in the north-east part of the sand bank calculated by cross-correlating the DTM's from June and July 2002. Note increasing migration (8-10 cm/tide) at the periphery of the sand bank.

figure 5 are migrating towards the periphery of the sand bank where they disappear when the suspension threshold for the sediment is exceeded. The migration direction of the sand dunes is roughly towards the headland indicating that flood currents are dominant for sediment transport over the sand bank.

Current Data

Three current measurement surveys were carried out over the M2 tidal cycle for this study: two in October 2002 and one in September 2003. Tide ranges for the three measurement cycles

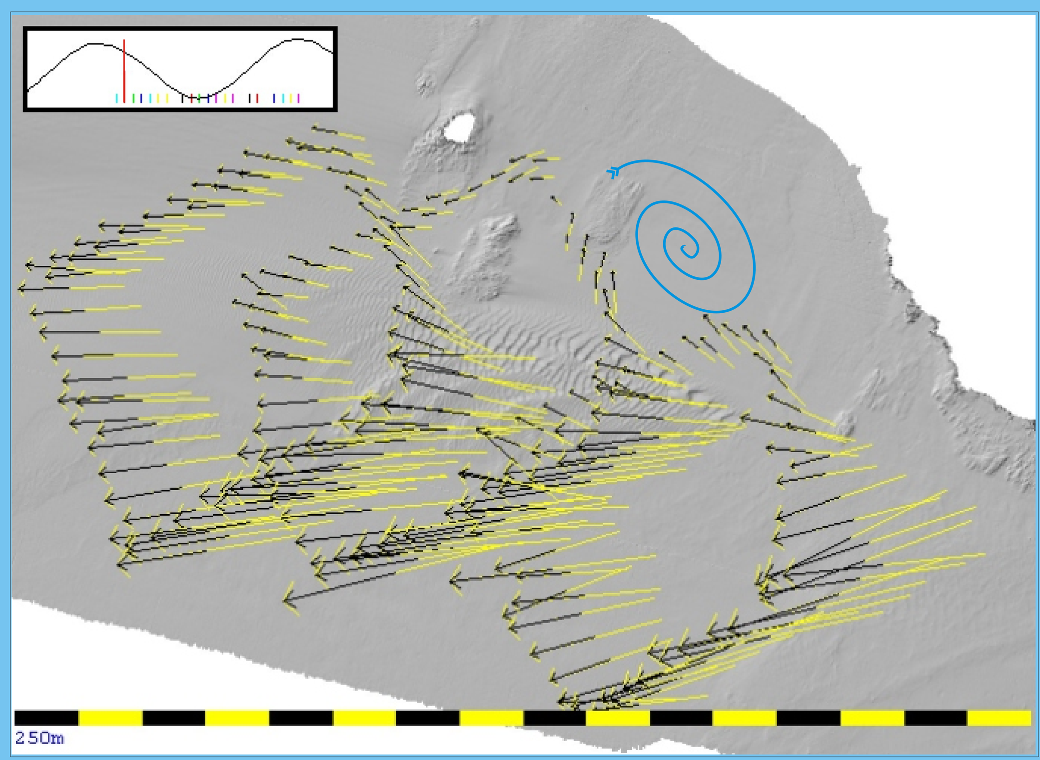

Figure 6: Flow vectors depicting current field 2 hours after Slack High Water. Incipient eddy is seen in the lee of the headland. Max/Mean current speeds: 1.8/0.6 m/s (depth averaged).

were 8, 7 and 6.5 metres. The typical maximum and minimum tide ranges in this area are 8.5 and 5.5 metres. An RDI instruments Workhorse Acoustic Doppler Current Profiler (ADCP) pole

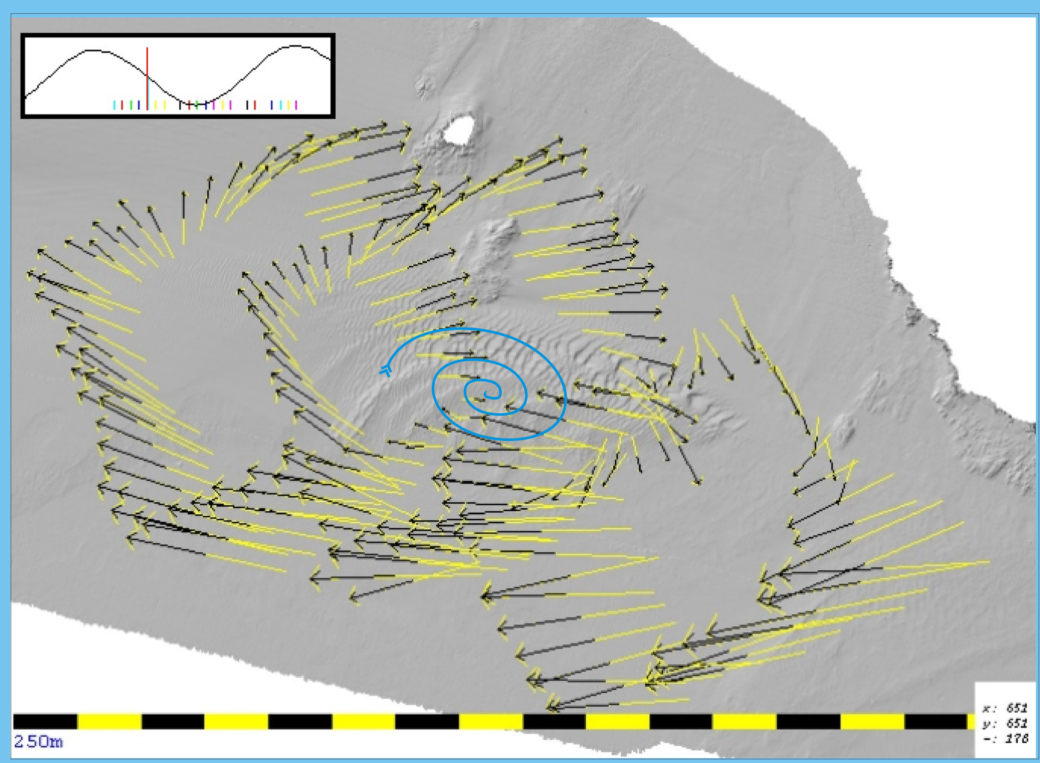

Figure 7: Current field 3.5 hrs after Slack HW. Tidal eddy has been advected SSW and is now circulating about the sand bank. Max/Mean currents: 1.3/0.5 m/s.

mounted on *Heron* was used to collect the data.

Current data were vertically averaged through the water column and through the bottom 10 metres of the water column. Then data from the three adcp tidal cycles were spatially binned into a 75 m grid and stacked together into common phases of the tide (in 30 lunar minute increments) enabling the three

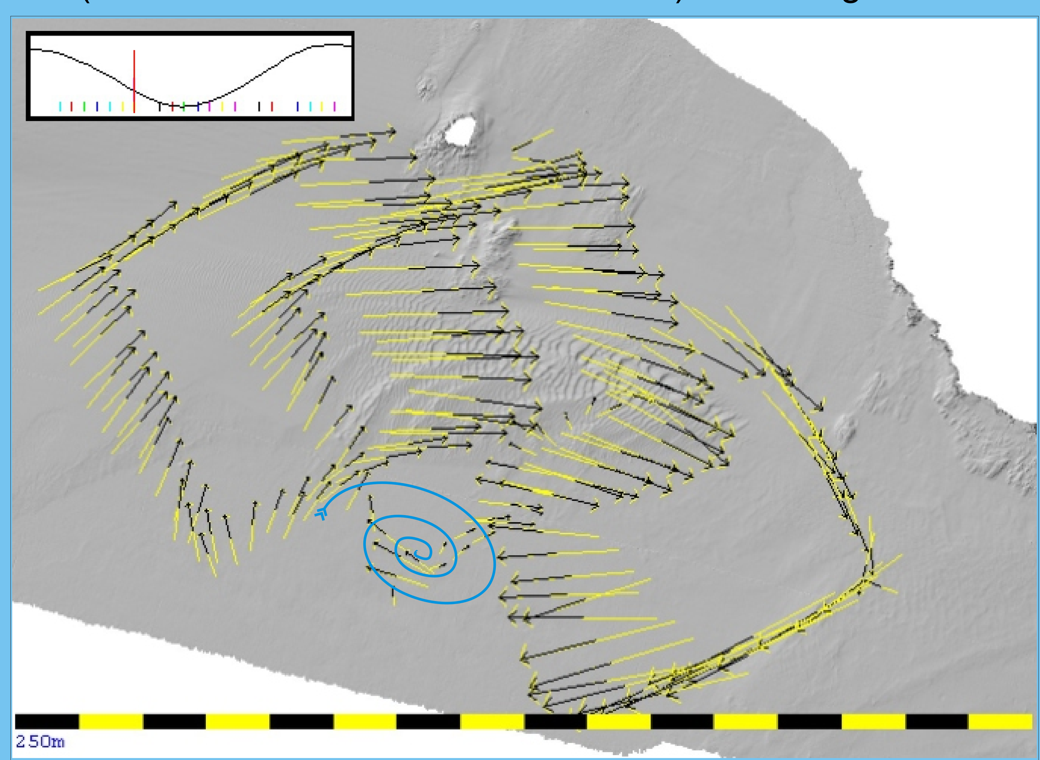

Figure 8: Current field 5 hours after Slack HW. Superimposition of eddy circulation has induced reversal of the current field over the sand bank causing apparent "flood" currents to dominate over the sand bank. Max/mean currents: 1.0/0.5 m/s.

measurement cycles to be simultaneously interpreted in a movie.

The tidal eddy is clearly seen to be initiated in the lee of the headland on the ebb tide and subsequently advected across the

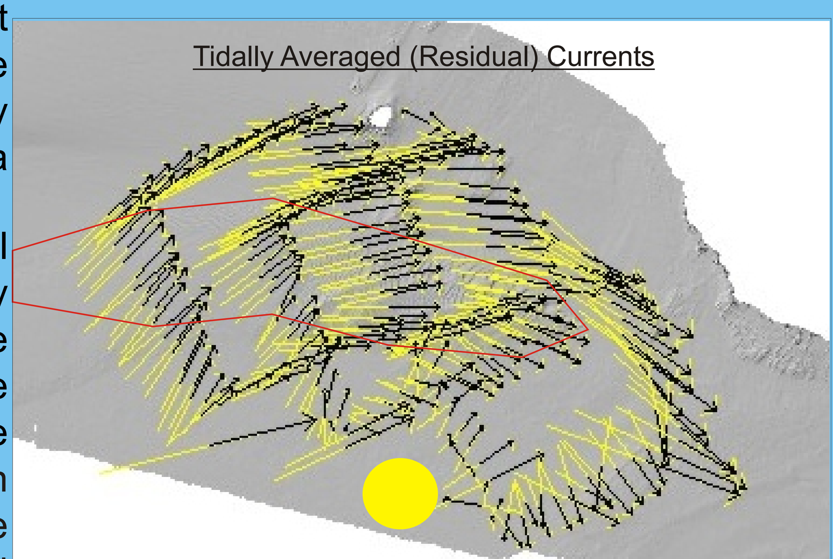

Figure 9: Tidally averaged currents showing the 'residual eddy' with the sand bank (outlined in red) located off centre (yellow circle). The currents depicted are averaged over the bottom 10 m and have an average velocity of 25 cm/s

shallowest part of the sand bank in a south-south-westerly direction (**figures 6,7,8**). The tidal eddy has a substantial effect on the residual current field with a large *residual* eddy resolved when the tidal currents are averaged over the tidal cycle (**figure 9**). The sand bank is noticeably off-centre relative to the 'eye' of the residual eddy. This is contrary to Pingree (1978) which hypothesises that the location of a Banner Bank is due to the residual current field, this from work done on the Shambles Banner Bank at Start Bay, Devon. Dyer and Huntley (1999), Signell (1991) and Imasato (1983) have also questioned the importance of residual eddies to sediment transport and instead attributed sediment deposition to curvature of the primary current field causing a 'centrifugal secondary flow' converging towards the centre of curvature at the bed.

Grain Size Data

A Shipek grab was employed to sample the sediments of the field area in September 2003. The samples were sieved through sieves with aperture sizes ranging from 37.5 mm down to 75 micron. Statistical quantities (mean, standard deviation, skewness and kurtosis) were calculated using cumulative curves and the central moment method. The muddier samples collected in the western part of the study area were measured using the settling rate method.

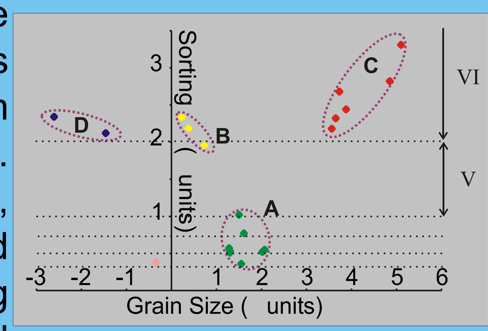

Figure 10: Plot of grain size (fining to the right) against sorting showing the 4 interpreted sedimentary facies. Roman numerals show degrees of sorting from Very Well Sorted (*I*) to V. Poorly Sorted (*VI*).

Analysis of the sediment samples revealed that the study area is spatially highly variable indicating that contrasting sediment transport conditions exist. Four distinct sedimentary facies were identified on a plot of grain size against sorting (**figure 10**).

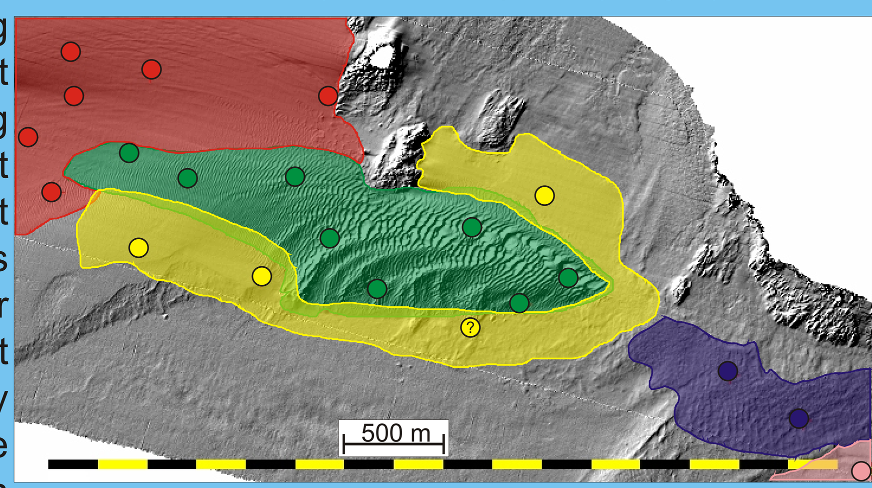

Figure 11: Map showing distribution of sedimentary facies around the study area. Colours match colours in grain size plot. '?' denotes visual classification of sample.

All the samples taken on the sand bank fall into Facies A (moderately well sorted medium sand and fine sand (**figure 11**). Facies B encompasses samples taken proximal to the sand bank and is noticeably bimodal with equal parts granules (3 mm) and medium sand (0.3 mm). Facies C is made up of very poorly sorted silts and muds. Facies D comprises 2 samples and is poorly sorted gravel.

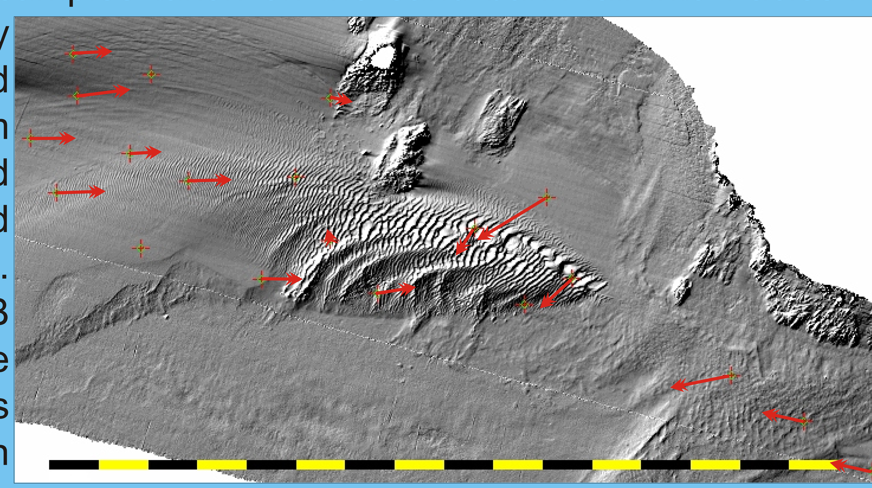

Figure 12: Sediment transport vectors calculated by comparing grain size, sorting and skewness of a sample with nearby samples. Note predominant sediment transport direction from the west towards the headland.

Sediment transport vectors were constructed on the basis of Gao (1992), comparing spatial trends in sorting, grain size and skewness, and indicate sediment transport direction onto the sand bank from the silts of Facies C to the west by flood currents and from Facies D to the east (**figure 12**) by ebb currents accelerating around the headland.

Conclusion

Numerous data sources point to the very dynamic seabed conditions in the vicinity of Cape Spencer. Cross-correlation of successive monthly DTM's has shown that migration of the dunes on the Banner Bank is uniformly toward the headland, reflecting the dominance of flood currents. On the falling tide, a tidal eddy causes bedload convergence which is subsequently mobilised by the flood dominated current regime. The migration rates are greatest in the shallowest part of the Banner Bank, downstream of which they are seen to vanish where the suspension threshold for medium sand is exceeded and the grain size becomes too coarse for bedform development. Previous models of Banner Banks only allow for sedimentation originating from the seabed around the headland. These data show that sediment supply from the opposite direction is important also.

References

Dyer, K.R. and Huntley, D.A. (1999), *The Origin, Classification and Modeling of Sand Banks and Ridges*, Cont. Sh. Res., **19**, 1285-1330.

Gao, S. and Collins, M., (1992), *Net Sediment Transport Patterns inferred from Grain-Size Trends, based upon Definition of "Transport Vectors",* Sedimentary Geology, **80**, 47-60.

Imasato, N. (1983), *What is Tide-Induced Residual Current?*, J. Phy. Oc., **13**, 1307-1317.

Pingree, R.D. (1978), *The Formation of the Shambles and Other Banks by Tidal Stirring of the Seas,* J. Mar. Biol. Ass. U.K., **58**, 211-226.

Signell, R.P. and Harris, C.K. (2000), *Modeling Sand Bank Formation around Tidal Headlands,* in Estuarine and Coastal Modeling, 6th Int. Conf. ASCE. Spaulding, M.L. and Blumberg, A.F. (Ed.).

Ocean Mapping Group
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