

# TexAn: TEXTURAL ANALYSIS OF SIDESCAN SONAR IMAGERY AND GENERIC SEAFLOOR CHARACTERISATION

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*Abstract* - Geophysical and environmental seafloor surveys make an extensive use of sidescan sonar imagery. Most of it is still interpreted visually and qualitatively. We are presenting here a method of textural analysis, with supplements the interpreter with reliable quantitative results. The TexAn technique has been extensively ground-truthed in complex mid-ocean ridge terrains, using submersible and ROV observations, and in-situ sampling. The frequencies used so far range from 6.5 kHz to 500 kHz; all applications have been validated and ground-checked. Current applications cover very different environments, from mid-ocean ridges to continental margins and coastal waters. TexAn enables quantitative assessments of sidescan sonar imagery, at all stages of processing and in all conditions. TexAn also reveals details hitherto invisible to the human eye, however experienced.

## I. INTRODUCTION

The new generation of sidescan sonar systems delivers increasingly large volumes of data with a dramatic increase in the ground resolution of the instruments. For example, the sidescan sonar TOBI, developed at SOC, records several Gigabytes per day, with a ground-resolution of 6 metres (Flewellen et al., 1993). Other high-resolution sonars like the DSL-120 produce several Gigabytes per day, for a ground resolution of less than a metre (eg Blondel and Murton, 1997). For all this data to be used efficiently, information must be extracted with new techniques. This information should supply the interpreter with reliable quantitative material.

Presenting the datasets as mere images is not sufficient, and the new techniques must support the interpretation with quantitative arguments going as far as possible beyond the human capabilities. Every interpretation is based on the characterisation of seafloor units. However, although the physics of acoustic remote sensing remains the same, the appearance of the sidescan sonar images will vary widely according to the conditions of ensonification (tow-speed, grazing angle, altitude, gains, etc.) and to the frequency.

A few seafloor characterisation systems have tried to make the interpretation process more quantitative, investigating the content of individual echoes or of whole regions. These systems usually work at a specific stage of the acquisition process, with raw imagery. They are

hardware-based, and need to be calibrated with each new sonar and each new usage (new ship, or same ship in a different environment). Our approach is different, in that we aim for a system that can work at all stages of data acquisition and processing, and is not hardware-dependent.

## II. TEXTURAL ANALYSIS

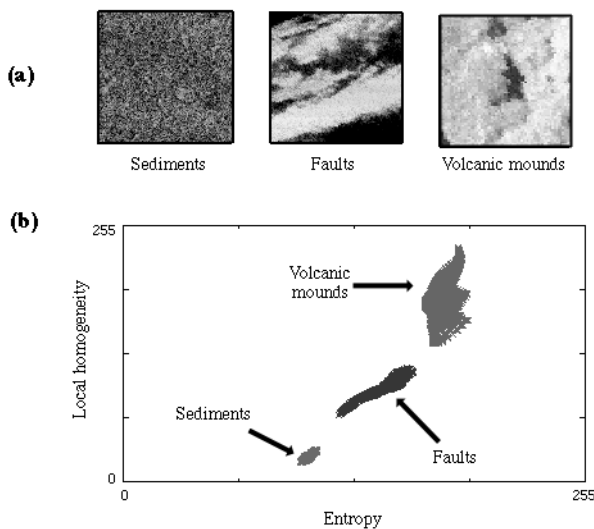
Remotely sensed images in general, and sidescan sonar images in particular, are mainly described by their tonal and textural properties. In the case of sonar images, the tone corresponds to the amount of energy backscattered by each point in the image and is expressed as grey levels. The backscattering is affected, in decreasing importance, by the geometry of the sensor-target system (relative angle of ensonification), the morphological characteristics of the surface (eg micro-scale roughness) and by its intrinsic nature (composition, density, relative importance of volume and surface reverberation). Most physical processes, and their surface manifestations, cannot however be described only with their tonal properties. Textural properties correspond to the spatial organisation of the grey levels within a neighbourhood. Textures can be intuitively described as smooth or rough, small-scale or large-scale, random or organised. Theoretical and experimental studies showed they are best quantified with stochastic methods, such as Grey-Level Co-occurrence Matrices (GLCMs) (eg Haralick et al., 1973; Blondel et al., 1993a).

GLCMs address the average spatial relationships between pixels of a small region, by quantifying the relative frequency of occurrence of two grey levels at a specified distance and angle from each other. If the image is quantised on  $NG$  grey levels, each point of the image will be described with an  $NG \times NG$  matrix. Because they are difficult to manipulate and interpret, GLCMs are described by statistical measures, called indices. More than 25 are available from the current literature (eg Haralick et al., 1973; Blondel, 1996). Their usefulness for sonar images has been assessed in detail (eg Blondel et al., 1993a; Blondel, 1996; Blondel and Parson, 1998; Blondel and Robigou, submitted), and only two indices have been retained: entropy and homogeneity. They are used in a homegrown package called TexAn (Textural Analysis).

The entropy measures the lack of spatial organisation inside the region where the GLCM is computed. Entropy is high when all co-occurrence frequencies are equal, i.e. very low. This marks rougher textures. Conversely, entropy is

low when the texture is smoother and more homogeneous. Sedimentary facies will show low entropies, increasing with the number of heterogeneities (gravel patches, ripples, rocky outcrops). More complex structures such as slumps or turbidity channels will present higher entropies. In regions affected by volcanic activity, lava flows will exhibit entropies commensurate with their morphological roughness (low for sheet flows, higher for pillow or lobate flows). All geological features visible on sonar images are characterised by specific entropy signatures. Local-scale variations will also be enhanced by changes in entropy.

Homogeneity is directly proportional to the amount of local similarities inside the computation window. This parameter was specially modified to ensure its invariance through linear transformations of the grey levels (Blondel, 1996). If the Angle-Varying Gain or Time-Varying Gain are changed, or the image contrast is changed, but the seafloor remains the same, then the modified homogeneity parameter will remain the same. Homogeneity will be higher in regions of homogeneous backscatter or in regions with a few grey levels organised along at the scale of the computation window. Homogeneity should be able to quantify the differences between smooth sediments and faulted or deformed areas (including ripples or slumps), or between lava flow morphologies.



**Fig. 1. Only two indices are necessary to recognise the different types of geological environments. Homogeneity (negative) has been quantised on a logarithmic scale.**

Using sample TOBI images of 100 x 100 pixels, Fig. 1 shows how basic seafloor types can be separated with entropy and homogeneity alone. Sedimented areas correspond to lower entropies and to (negative) homogeneities of higher amplitudes. Sediment cover indeed appears on sonar images as smooth and with quite homogeneous textures. Faulted areas present a larger interval of homogeneity values, from low to mid-range, and higher entropies. The differences in homogeneity are related to the spatial organisation of local textures, the areas tectonised along preferential directions having higher

homogeneities than heavily tectonised zones where no pattern is discernible. The higher entropies are linked to faults and fissures. Finally, volcanic processes show low amplitudes of homogeneity, and higher entropies, explained by their greater roughness.

### III. MID-OCEAN RIDGES

Textural analysis with GLCMs was first tried on SeaMARC-II imagery (Reed and Hussong, 1989), but the results were hampered by the lack of ground information and the low resolution of the sonar. Our own studies used high-resolution sidescan data combined with extensive ground-truthing (Blondel et al., 1993a, b; Blondel and Robigou, submitted). The Endeavour Segment of the Juan de Fuca Ridge was imaged with DSL-120 (120 kHz, 1-m resolution), and a series of manned and unmanned submersible dives (eg Delaney et al., 1992; Robigou et al., 1993) complemented the acoustic images with visual inspection, generally at centrimetric scales. Some discrepancies arose in small areas when comparing Textural Analyses with geological maps. Later dives confirmed the results from TexAn, and enabled the resolution of features that had been overlooked during visual mapping: tilted blocks, changes in the slope of talus terrains. Classification accuracies ranged between 80% (for some of the smallest hydrothermal vents, at the limit of resolution of the sonar) and 100%. On a local scale, narrow fissures in complex terrains could be finely mapped. With GLCM-based textural analysis, it was possible to appraise the differences between similar-looking types of extrusive volcanics, or document the weathering and aging of hydrothermal sites (already known in some sites by visual observations from submersibles, and geochemical analysis of the fluids that the chimneys are actively venting). Thorough descriptions of the local geology, its acoustic appearance on DSL-120 sonar images, and the quantitative characterisation of the geological processes at play in this area can be found in several articles (eg Blondel et al., 1993a; Blondel and Robigou, submitted). These results enabled the fine-tuning of the TexAn technique, and paved the way for its application to other ground-truthed datasets.

The image presented here (Figure 2) was acquired with a high-frequency sonar (TOBI, 30-kHz, 6-m resolution) and also includes a large range of seafloor types. It was fully processed for geometric and radiometric distortions (LeBas et al., 1995). Located on the Mid-Atlantic Ridge at 37°02'N, this portion of TOBI imagery shows a ridge offset, where volcanic activity is still present, but less important than tectonic and sedimentary processes. The image illustrates two types of artefacts: the pair of white lines symmetrically disposed at the edges of the swath, resulting from reflection from the sea surface, and fuzzy dark lines at the sonar's nadir, inherent to sonar data acquisition. TOBI imagery shows significant sediment deposition on the eastern part of the ridge offset, and fault scarps (oriented roughly ENE) in the middle of the offset. Some of them may be covered by a thin layer of sediments. Neo-volcanic activity is mainly located at the Western end of the discontinuity.

Entropy and homogeneity have been computed for all points in the image. New texture measurements are interpreted as belonging to one geological process or the other according to a classification algorithm called Measurement-Space Guided clustering, which labels each cell in the measurement space. Comparison with other classification algorithms proved it was the most robust and adapted to sonar images. A particular advantage of this algorithm is that it is not biased by the statistical predominance of some regions (e.g. sediments, covering large areas of seafloor, whose textures are very close to hydrothermal deposits, covering only a few pixels).

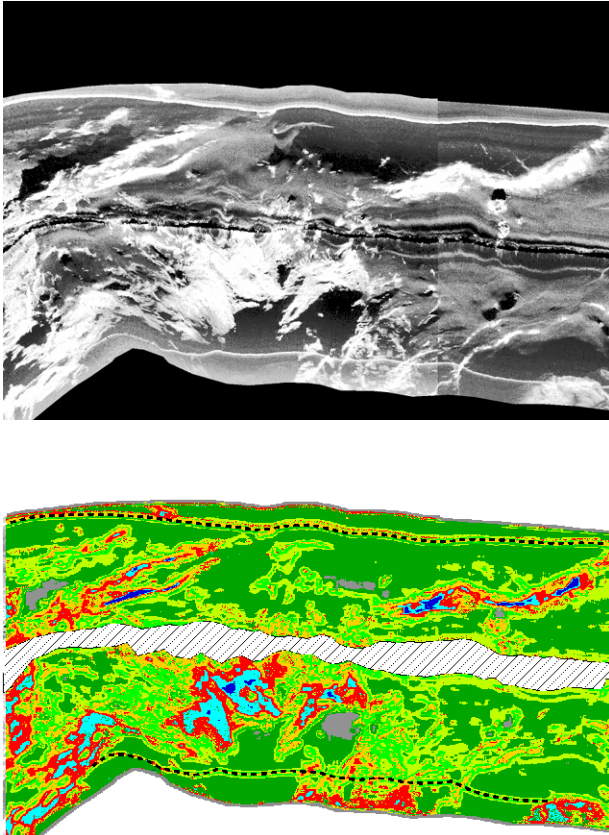


Fig. 2. TOBI imagery (top) and resulting classification with TexAn (bottom). The swath width is 6 km. The hashed pattern masks the nadir, and the black dotted line indicates the sea surface reflection. Sediments are represented in dark green, perturbed sediments in light green. Fault scarps and tectonic activity in general are in light and dark blue. Neo-volcanic activity is in red or yellow, depending on the degree of alteration.

The results from textural analysis show the dominance of sediments, covering 60% of this image. TexAn distinguishes between smooth sediments, perturbed sediments (with somewhat rougher textures), and the light sediment cover above the earlier volcanic products. Most of the areas classified as faulted and deformed correspond to fault scarps. Regions classified as "volcanic" are concentrated at the northern tip of the FAMOUS segment. Some regions inside the discontinuity are also classified as "volcanic". They are mainly located at the bottom of fault scarps, and the corresponding full-resolution backscatter

imagery indeed shows highly-reflective lava flows. Comparison between TOBI imagery and textural analysis results (Fig. 2) verifies the accuracy of the classification. TexAn recognises correctly the different artefacts and fares better than some other methods tried on the same dataset. Misclassification only occurs in some of the very dark regions interpreted as shadows. Histogram stretching of the corresponding TOBI imagery reveals that these shadows are not uniformly black, and that some lowly-contrasted patterns are visible. These minute variations from the darkest grey levels may be due to unprocessed noise from the sonar electronics at low levels.

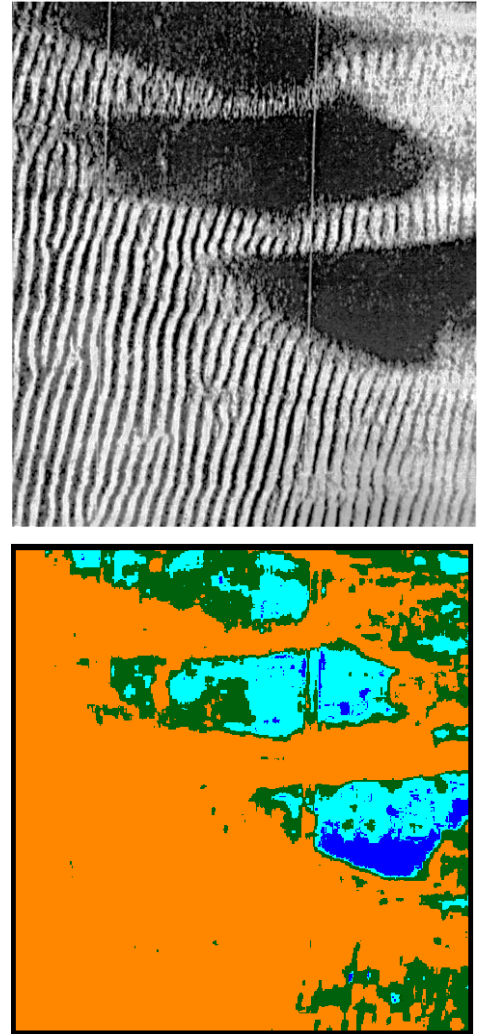


Fig. 3: 100-kHz sidescan image showing wave ripples in medium-grained sand with intervening patches of mud. The image is ensonified from the right, at an altitude of 6 m above the seafloor, and covers an area nearly 30 m wide. The bottom image shows the TexAn classification.

#### IV. COASTAL AREAS

Textural Analysis has also been applied to high-resolution sonar imagery from shallower regions, in particular continental margins and coastal waters. One of

the many examples is shown in Fig. 3. It was acquired with a 100-kHz sonar (Klein 590), in a water depth of 18 m in the North Sea. Only very limited processing was performed after the acquisition. The image can be divided into two major elements: dark homogeneous patches of low backscatter and linear parallel backscatter variations. On the basis of their characteristics, and with subsequent ground-truthing (Hühnerbach, pers. comm.), these areas are respectively interpreted as patches of mud, and wave-driven ripples in medium-grained sand (Milkert and Hühnerbach, *in* Blondel and Murton, 1997).

TexAn maps out exactly the different regions of mud (blue) and sand ripples (orange), but goes further by detecting other textural variations (Figure 3). Some areas of the sand ripples are less distinct: the ripples may be smaller, or made from a different material. They appear as texturally different, and are represented here in green. They are located mainly at the proximity of the mud patches, supporting the idea of ripples decreasing in height as the geological setting changes. Similarly, the dark mud patches are in fact composed of distinct regions, shown in dark and light blue. The darker tones delimit homogeneous areas where the textures are smoother. Logically, they are located away from the regions mapped in green, where ripples are destroyed or much smaller.

The artefacts visible on the image (sub-vertical lines) appear only as slight variations in the textures, but do not influence the final results, nor the geological interpretation.

## V. DETECTION OF "HIDDEN" STRUCTURES

Image analysis with TexAn is concerned with local texture variations. Many applications are now focusing on object detection, reflecting the needs of the military (eg mine detection), the industry (eg gas pockmarks or mineral nodule mapping) and simply the need to recognise small features on the seafloor quickly and easily. In terrains characterised by a homogeneous texture, a human interpreter will not always recognise structures presenting acoustic targets very similar to their surroundings. But GLCM-based analysis quantifies more detailed statistics than are accessible to the human perception (Julesz, 1973) and should therefore prove useful.

The image presented in Fig. 4 has been acquired with TOBI. It shows a flat portion of the seafloor, heavily sedimented, in an inactive portion of the Mid-Atlantic Ridge. The image has a homogeneous texture, and a vague shape is visible near its centre. Conventional statistical analyses cannot separate it from its background, trace its outline, or even verify it is indeed a distinct feature. Histogram equalisation provides some enhancement, but conventional image processing techniques (edge detection, mathematical morphology, bandpass filtering) do not.

Entropy and homogeneity were computed for this image and have values in the range associated to sedimented areas. They are highly correlated (around 85%), which is characteristic of sedimented areas. But the higher entropies are localised in one region of the graph only. The subsequent classification shows the complete outline of

what was thought of as a discrete object, with dimensions of approximately 460 x 210 metres. Its outline is accurately defined at a 1-pixel resolution. From the shape of the object and its dimension, we interpret it as an area of differential sediment compaction. This is confirmed by medium-resolution bathymetry, which shows at the same place a localised denivellation of gentle slopes, 25 to 50 metres below the surrounding seafloor. This structure was not detectable visually on the sidescan sonar imagery, and only faint traces of it were visible. Textural Analysis allows a clear recognition of the structure. This result is clearly of interest for the geological interpretation of this region and the assessment of its evolution with time.

Current applications of this technique for object detection are centred on other geological problems, with the recognition of hydrothermal sites in high-resolution imagery (eg Blondel, 1996; Blondel and Robigou, submitted) and the regional geology of the Mid-Atlantic Ridge south of the Azores. Many other applications of this technique can be envisaged: retrieval of buried objects or objects with a low acoustic signature, survey of wreck sites and real-time mapping of obstacles or targets.

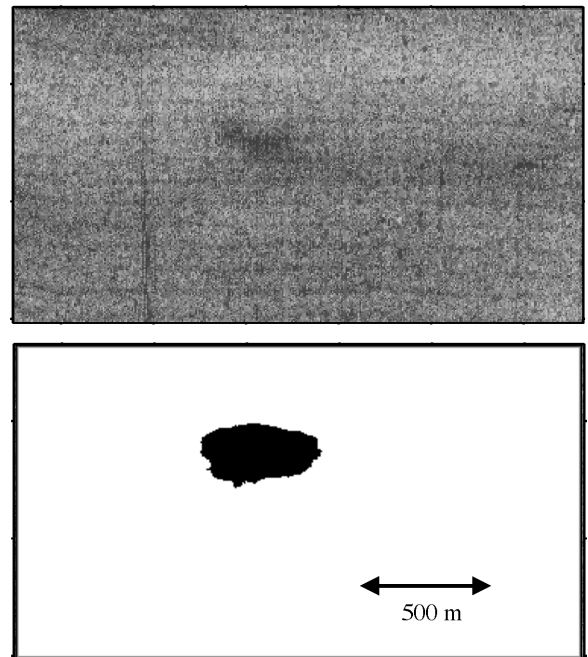


Fig. 4. TOBI imagery of pelagic sediments close to the Mid-Atlantic Ridge (top). Textural analysis reveals an elongated feature (bottom), also visible on bathymetry, and interpreted as an area of differential sediment compaction.

## VI. CONCLUSION

This short paper presented only a few of the applications of the TexAn technique. TexAn is now used with sidescan sonar imagery acquired at frequencies ranging from 6.5 kHz to 500 kHz, and with ground resolutions ranging from 0.1 m to 60 m. The classification algorithm has been extensively ground-truthed in complex mid-ocean ridge terrains, using submersible and ROV observations, and in-

situ sampling. Well-documented test areas provide good calibration which we can use for extrapolation to new areas of seafloor and increasingly complex combinations of surface processes.

The applications presented here showed different levels of analysis (regional for TOBI, local for Klein-590) and of processing (fully processed for TOBI, nearly raw imagery for Klein-590). Suitably tuned, TexAn can detect structures overlaid by sediments or with subtle acoustic differences. The last case presented the potential of TexAn for revealing details hitherto invisible to the human eye: minute variations in the textures, attributable to geological processes, concealed objects (e.g. mines) or shallow subsurface structures.

TexAn is hardware-independent, and can be used at any stage of processing (or non-processing). Contrary to some seafloor characterisation techniques, TexAn does not lose the original information. It is always possible to come back to the original sonar data, and reprocess/reinterpret it. This technique makes most of the user's experience, and the envisaged use of Artificial Intelligence techniques will help build self-learning, self-adapting systems.

The current applications of TexAn aim at broadening the range of frequencies and environments in which the software can be used, and building up the knowledge base for applications of TexAn in similar settings. The exact variation of the results with the input parameters has also been assessed statistically. The technique is now used routinely in some geological applications, and proves able to perform generic seafloor characterisation.

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