The recognition of artefacts from acoustic and resistivity borehole imaging devices.

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Running title: Recognition of artefact images

Abstract

Image artefacts, that is, non-geological features present on acoustic or micro-resistivity borehole image logs are a fact of life. In poor quality image logs, they can constitute the bulk of the data-set although fortunately, such features generally constitute the minority of a data-set. The recognition of artefact features must form part of the log quality control process and should also form part of the interpretation process. By applying sound log quality control principles, these artefacts can be identified systematically and the remaining image data will be geologically related.

This paper provides an up-to-date summary of borehole image artefacts, their cause and recognition. It also, for the first time, considers artefacts arising from acoustic (ultrasonic) as well as micro-resistivity images. Four main artefact image categories related to data acquisition, borehole wall condition, post processing of data and measurement physics form the basis for the systematic identification procedure. These are discussed and developed herein.

Acoustic and micro-resistivity borehole image logs have become an invaluable and widely accepted source of information for sub-surface reservoir characterisation over the last decade. Interpreters are frequently presented with images that consist of confusing non-geological shapes that reduce the confidence of an interpretation. These non-geological features are commonly referred to as image artefacts. They are features that do not arise from *in-situ* geological lithology or which depart significantly from their physical nature on the borehole wall or which are not visible in core. In a poor quality image log they may represent the vast majority of the data present. Fortunately, artefacts generally represent a small proportion of the data-set although in general terms all data sets contain some artefacts. Fig. 1 illustrates a small section of micro-resistivity log showing no fewer than five artefact features present together.

The ability to recognise genuine formation features is an essential part of image log interpretation and therefore implies relevant geological experience and use of localised geological knowledge (Harker *et al.,* 1989). The need to recognise artefacts within an image data-set and to assess their effect on image quality is therefore key to any subsequent image interpretation. The recognition of these non-geological features must be an inherent part of the log quality control (LQC) procedure. By applying sound log quality control principles, artefacts can be recognised and identified systematically. This must be the first stage of any interpretation and should form part of an interpreters thought process during all stages of interpretation. The process of examining an image log for artefacts requires the interpreter to think of an image log in terms of the tool measurement principles, the nature of the borehole and how the images were generated.

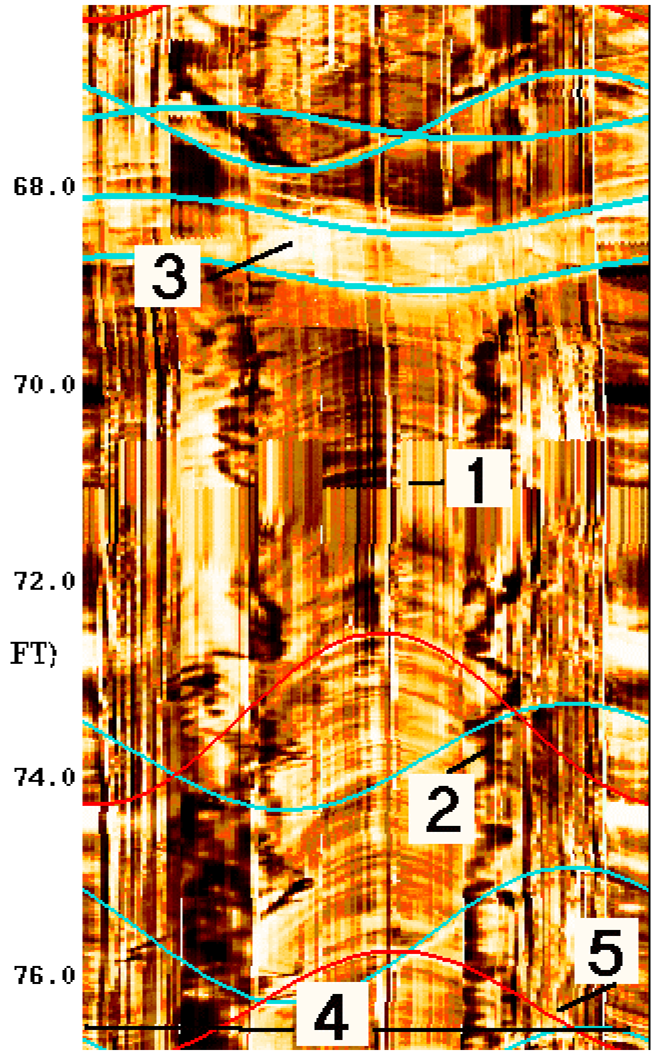


Fig. 1. A small section of micro-resistivity log showing no fewer than five artefacts features (labelled by arrows) 1./ tool speed irregularities, 2/ drilling induced fracturing, 3/ cementation mottling, 4/ incorrect image display (no pad-flap offset) 5/ vertical stripes indicate mud smear on button electrodes.

Previous independent work by both authors has attempted to classify artefact images. Bourke (1989) classifies artefact features observed in early micro-resistivity images whilst Lofts *et al.,* (1997) classify artefacts common in horizontal or highly deviated well bores. Bourke (1989) provides a comprehensive guide to log quality control.

The previous classification of artefacts by Bourke (1989) and adopted by Lofts *et al.,* (1997), forms the basis of this contribution although it is extended to account for modern image logs. This paper considers artefacts arising from both acoustic (ultrasonic) as well as micro-resistivity image logs and provides an up-to-date catalogue of artefacts and an indication of their cause in the context of the adopted systematic approach. Examples are drawn from image logs acquired with currently available image-logging tools.

Micro-resistivity image technology

The most commonly observed artefacts of micro-resistivity images are attributed to the pad technology of the tool and to the complex pathway taken by the passive electrical current of these devices. See Ekstrom *et al*. (1987), Bourke *et al.* (1989) and Safinya *et al.* (1991) for detailed accounts of the technology. Micro-resistivity devices, with various arrangements of pads, commonly suffer from *tool sticking,* differences in friction between pad and the borehole wall (*mud smear, washout, tool stand-off*), and *offsets* between pads. These produce the most common micro-resistivity artefacts. In addition, micro-resistivity tools are generally conductivity 'seeking' devices where electrical current will tend to flow towards the most conductive lithology/fluid present, Williams (1996). This produces very complex current pathways and also accounts for a number of common artefacts such as current 'halo' effects and proximity effects (described later).

Acoustic (ultrasonic) image log technology

Ultrasonic imaging was primarily introduced for use with oil-based drilling fluids. This involves firing a high frequency (250 or 500 kHz) ultrasonic pulse from a rotating transducer towards the borehole wall and simultaneously measuring the amplitude and transit time of the returned pulse (Faraguna *et al.* 1989; Hayman *et al.*1994). The pulse is fired between 140 and 250 times per revolution of the transducer depending on the tool design. Consequently, this device is particularly sensitive to the condition of the borehole wall and the acoustic impedance of the fluid in the borehole, resulting in artefacts such as hole spiralling, and stabiliser grooving and rugosity effects which are described in Tables 1 and 2.

Artefact Classification

Four main artefact image types have previously been recognised, these include:

- Acquisition artefacts

These are features arising from the acquisition of the image data. These can be subdivided into artefacts associated with the *drilling* process and artefacts associated with the *logging* process.

Drilling related features: result from perturbations that accompany the drilling of a borehole such as tool orbiting and drill-bit slide, or during maintenance of the borehole such as wiper trips and reeming, or features that merely represent manifestations of the drilling process such as bit-at-rest and side-track windows. Separate features are described in Table 1 & 2.

Logging related features: can be attributed to physical problems associated with tool malfunction, such as tool eccentralisation, mud smearing, or 'dead' button or pads, excessive tool rotation, decreased signal-noise ratio. They may also result from changes in formation properties that cause tool speed irregularities, or from extremes-of-condition, such as very resistive formations like evaporites.

- Borehole wall artefacts

These are non-geological features developed on the borehole wall through drilling, well clean-up or logging operations. Whilst relating to acquisition they are not exclusive to it. They commonly include washouts, rugosity, key seating, mudcake effects, tools marks and drilling induced fracturing. Borehole wall conditions are the greatest cause of artefacts in acoustic images due to the sensitivity of the measurement.

- Processing artefacts

These arise as a consequence of subsequent data processing and image generation post acquisition. Examples of this class of artefact include the incorrect use of normalisation parameters, the incorrect distribution of colour scales in the process of displaying the images, or incorrect speed correction.

- Measurement 'derived' artefacts

These are features which arise from the interaction of the physics of the measuring device and the actual geological feature. They have a different appearance on images than they would visually appear if seen on the outside of a core or in the borehole wall. These effects are predominantly seen on micro-resistivity images because of the complex nature of the flow of electrical current throughout a rock formation. This gives rise to effects such as halos, aureoles, cementation mottling and effects close to the borehole wall although not actually touching (termed here 'proximal' features).

Additional classification

In addition to using artefact categories to systematically identification, artefacts can also be graded on a scale of severity. Such a scale would range from an artefact which masks a small part of an image (e.g. drilling induced fracturing), where interpretation is mildly impaired, to extreme cases where the image is totally obscured by the artefact and geological data exists (e.g. woodgrain texture or hole-orbiting). Extreme disruption of the image occurs more commonly in acoustic images (Bourke 1998, this volume).

An interval may contain more than one artefact image. Fig. 1 illustrates a small section of micro-resistivity log displaying no less than five artefact features. This is also seen in the acoustic image in Fig. 2 where two artefacts occur together (right image), diagonal hole spiralling and an artefact resembling 'woodgrain' (see Table 2 for a description). The presence of multiple artefacts is usually additive and may reduce the quality of the image and confidence of the subsequent interpretation.

Due to the inherent differences in the acquisition technology between micro-resistivity and acoustic devices, different artefacts may be exclusive to one image technology. This is illustrated in Fig. 2 which shows an acoustic image (right) and micro-resistivity image (left) over the same section of lithology. Hole spiralling has severely reduced the quality of the acoustic image log whereas the micro-resistivity image shows no adverse effect or artefact. The acoustic image demonstrates two of the most common acoustic image artefact features, hole spiralling (due to borehole wall morphology) and 'woodgrain' (due to excessive mud weight, see Table 2).

A summary of the artefacts recognised in these four categories is summarised in Table 1.
Table 2 illustrates the most common artefacts and includes a brief description and their effect and severity on micro-resistivity and acoustic image interpretation.

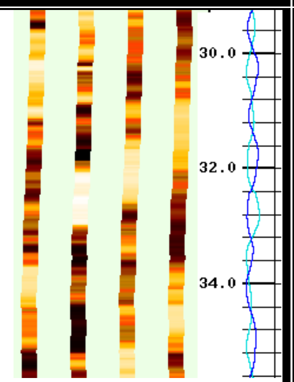
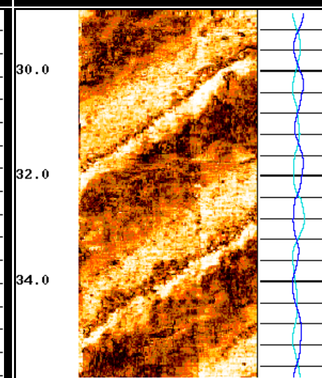
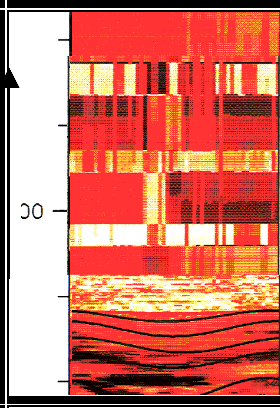
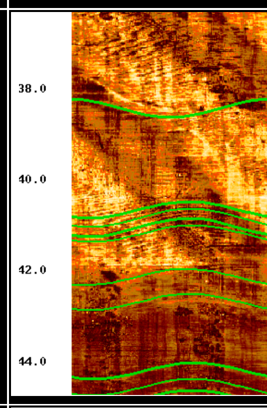
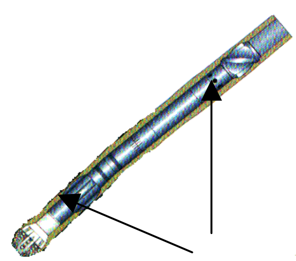
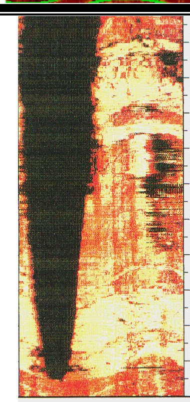
Artefact Category	Artefact	Description	Micro-resistivity – Occurrence and severity	Acoustic - Occurrence and severity	Comments
1a Acquisition - Drilling	Tool Orbiting	Borehole is 'roller coasting' (bit whirl)	Common/mild	Common/severe	Affects acoustic images most
	Drill bit slide	Driller allows drill bit to slide, not rotate	Common in RAB tools only	N/A	Only relevant to the LWD RAB tool
	Side-track window	Window left when side tracking	Rare/Severe	Rare/Severe	Will effect all images
	'Bit/stabiliser at rest'	Bit/stabiliser marks on borehole wall	Common/Mild	Common/Mild	Common when pipe conveyed
	Wiper –trip/reeming	Cleaning hole allows scratching	Rare/No effect	Common/Mild to severe	Affects acoustic images only
	Debris material in hole	Old drill bits and BHA equipment lodged in borehole wall	Uncommon		
1b Acquisition - Logging	Eccentralisation/stand-off	Tool not centred in borehole, dark/light images	Common/no real effect	Common/Severe	Severe when pipe conveyed
	Mud smear	Mud buildup on electrodes, missing button data	Common/Mild-severe	N/A	Affects electrical images only
	Tool Speed – Stuck Zones	Yo-yo effect of logging tool due to speed variations	Common/Mild to severe	Common/Mild to severe	Worse when pipe conveyed
	Tool Speed – Sticky zones	Logging tool catches on a ledge, dark image patches	Common /Severe	Common/Severe	Interpretation is often impossible
	Button or flap 'death'	Electrical fault on button/flap, missing button data	Possible/Mild to severe	N/A	Affects electrical images only
	Faulty inclinometry data	Faulty magnetometer or accelerometer device	Common/Severe on subsequent dips	Common/Severe on subsequent dips	QC of inclinometer is always advised.
	Excessive tool rotation	Tool rotates >1 rotation per 30 ft.	Common/Mild to severe	Common/Mild to severe	Accuracy of dip estimation reduced
	Noise: '60 Hertz'	Acquisition current interference, diagonal stripes	N/A	Common/Mild to severe	Common in acoustic images
	'Woodgrain 1'	Sampling inaccuracy resembling woodgrain	N/A	Can be common/Severe	Common in acoustic images
	'Honeycomb'	Gain correction inaccuracy – honeycomb pattern	N/A	Common/Mild-severe	Common in acoustic images
	Signal Loss - Spotty image	Degradation in signal/noise - spotty image	When mud lubricants added (up to 8%) /Mild to severe	Common in washouts or heavy muds/Severe	Variety of causes. Common in acoustic images with heavy muds
	Extremes of condition- 'Speckling'	Dynamic range of tool exceeded (very high/low acoustic impedance/resistivity lithologies.	Possible in some high resistivity lithologies as speckling/Severe	Rare/Severe	Variety of causes. Effect is generally severe
2. Borehole Wall Artefacts	Washout	Enlargement of hole diameter	De-focusing of image/Severe	Dark image/Severe	Will effect all images
	Rugose hole	Pitted borehole wall	Rare/Mild	Common/Mild to severe	Generally affects acoustic images only
	Key-seat Furrow	Ovalisation due to bit wear on underside of wellbore	Noticeable in deviated wells/Mild	Common in deviated wells/ Mild to severe	Will effect all images, can be filtered out
	Spiral Hole	Borehole wall is grooved due to bit	Common/Mild	Common/severe	Effects acoustic tools most
	Mudcake	Build up of mudcake generally over permeable lithologies	Common/Mild to severe	Common/Can be severe	Obliterates acoustic image interpretation
	Tool Marks:				
	Stabiliser grooving	Logging stabilisers scratch borehole wall	Not noticeable	Common without care/Mild severe	Acoustic tools most sensitive
	Sampling tool marks	Round marks made by probe & packer sampling tools	Rare but possible/Mild	Rare but possible/Mild	Easily identified at regular spacings
	Sidewall core samples	Marks made by sidewall corer	Rare but possible/Mild	Rare but possible/Mild	Easily identified as round
	Cable 'slap'	Marking of wireline cable on borehole wall	Uncommon/No affect	Uncommon/Mild	Effects acoustic tools most
	Drilling induced fractures	Zigzag fractures parallel to well bore axis	Common/Mild	Common/Mild	Useful for in *situ-stress* determination
	Drilling induced breakout	Broad parallel grooves separated by 180 degrees	Common but rarely identified/Mild	Easily detected/Mild	Useful for in *situ-stress* determination
3. Processing Artefacts	Incorrect hole diameter	Wrong assignment of diameter produces erroneous dips	Uncommon/Severe	Uncommon/Severe	Wrong apparent dip is calculated
	Incorrect colour assignment	Saturated images – concealment of detail in images. Apportioning the data into unequal bins for display	Possible/Locally severe	Possible/Locally severe	Will effect all images
	Incorrect gain correction	Under saturated/over saturated images	Possible/mild-severe	Possible/mild	Will effect all images
	Unsuitable image based speed correction	Poor 'button-to-button' speed correction results in 'Tiger striped' images	Possible/Severe	N/A	Relevant to Schlumberger tools only
	Unsuitable accelerometer based speed correction	Causes 'saw-tooth' patterns on images and pad-to-pad or pad-to-flap offsets.	Common/ Mild to severe	N/A	Common in electrical tools
	Window length	Normalisation window produces multiples of high contrast layers	Rare/Mild to severe	Rare/Mild to severe	Refer to Bourke (1989)
	Multiple-pass image offsets	Depth mismatch between logging runs. Correct with depth matching	Rare/Mild	Rare/Mild	Refer to Bourke (1989)
4. Measurement Derived Artefacts	Current Gather Effects:				
	Halo effects - Conductive	Light rim of a conductive feature due to current draw	Common in heterogeneous rocks	N/A	Common in electrical tools
	Halo effects - Resistive	Dark rim of a resistive feature due to current drain	Common in heterogeneous rocks	N/A	Common in electrical tools
	Cement mottling	Mottling fabric caused by highly resistive cements	Common in fractured rocks	N/A	Common in electrical tools
	Proximity effects:				
	Fracture aureoles	Light patches at the apex of fracture sinusoids	Common in fractured rocks	N/A	Common in electrical tools
	Proximal features	Imaging of features close to the borehole wall	Common in heterogeneous rocks	N/A	Common in electrical tools
	'Woodgrain 2'	Multiple effect, resembling woodgrain 1	N/A	Common in heavy mud/Severe	Common in acoustic images
	Residual Hydrocarbon Effects	Blotchy image caused by gas/oil saturation	Common - Distorts resistivity map	Rare/ Severe	Care when using thresholding techniques

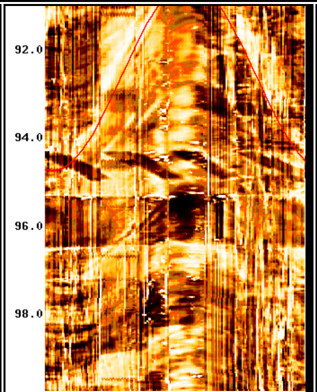
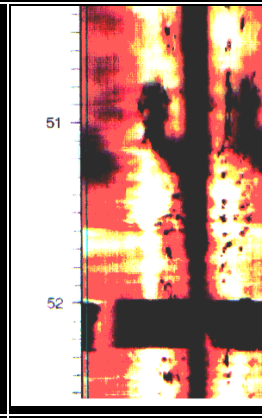
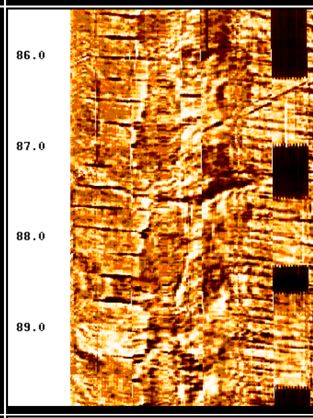
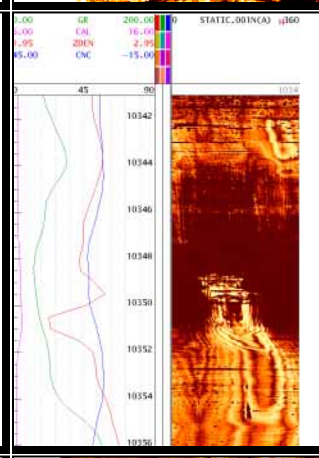
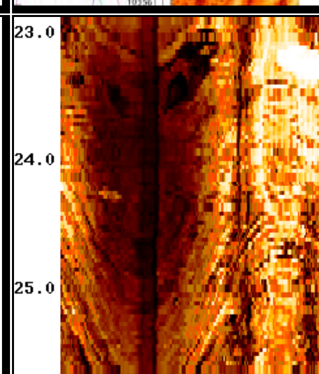
Table 1. *Summary of the most common micro-resistivity and acoustic artefacts observed on borehole image logs.*
A brief description and indication of the effect and severity of each artefact on both micro-resistivity and acoustic images.
An explanation of tool mnemonics is given in Appendix 1.

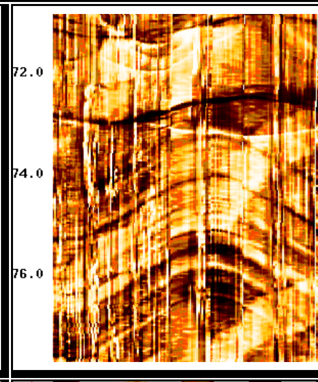
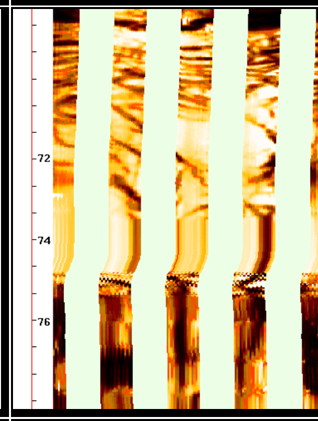
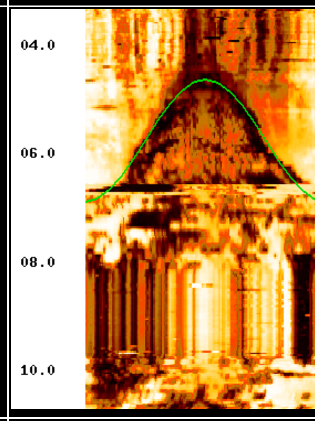
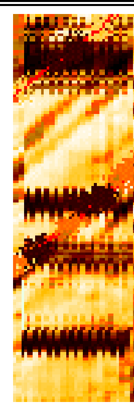
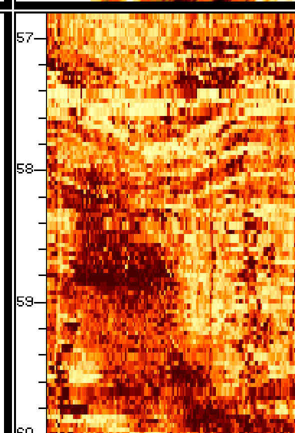
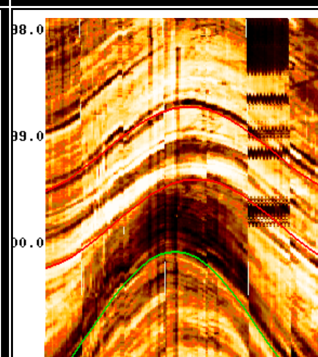
Table 2-1 Acquisition Drilling.

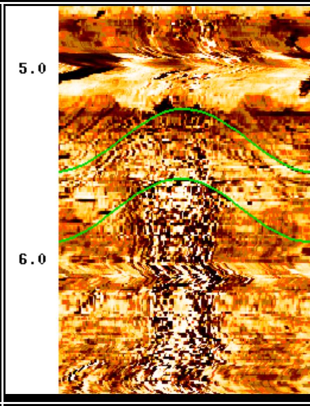
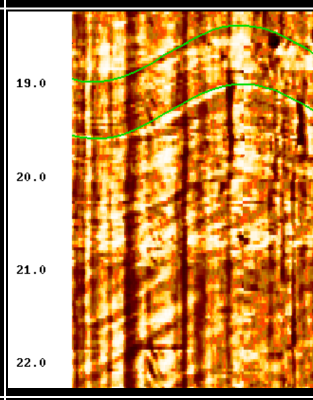
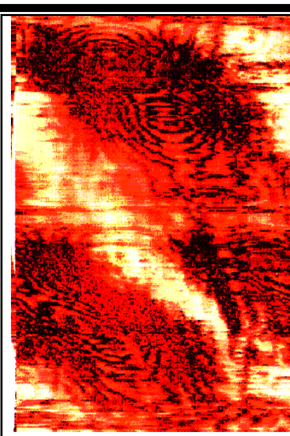
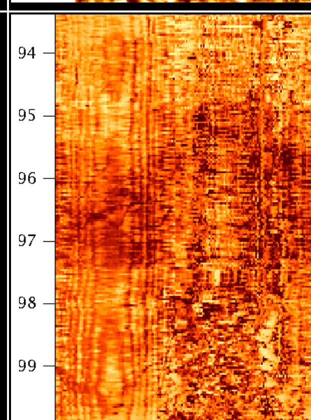
Description of the most common micro-resistivity and acoustic artefacts observed on borehole image logs.

Micro-resistivity images are illustrated on the left hand side, acoustic images to the right. An indication of the depth units and bit size is given in brackets after the main text in each box. An explanation of tool mnemonics is given in Appendix 1.

Artefact	Cause - description	Micro-resistivity	Acoustic
1. Acquisition - Drilling Tool Orbiting	Borehole is 'roller coasting' (effect caused by certain bit-stabiliser configurations). Affects acoustic tools most severely, often obscuring interpretation. Generally, effect is minimal on resistivity images where it rarely completely impairs interpretation. Left: OBDT false images showing diagonal tool orbiting. Calipers in blue/cyan. (ft). Right: UBI amplitude image showing severe orbiting of borehole, eradicating any useful information. Calipers in blue/cyan. (ft). Box below right: hole orbiting stops with coring @xx42 ft.		
Drill bit slide	Driller allows drill bit to slide, not rotate. Only relevant to LWD (logging while drilling) tools. Left: RAB tool showing a severe slide interval. This results in data under-sampling and a smear of the button data in the top half of the image (above xx01). This occurs when the drill bit slides rather than rotates during drilling. Only relevant to LWD tools. (scale ft, horizontal). Right: Described in 'Tool orbiting' (above).		
Side-track window	Hole in borehole wall produced when side-tracking. Severe in all imaging tools as this is a physical gap in the borehole wall. Often seen as a conical shape in images up to 20ft in length. Left: See 'Bit-at-rest' artefact (below). Right: Horizontal well (20 ft section) showing UBI acoustic image over a side-track window. Note, interpretation is still possible on the right side. (ft).		

‘Bit-at-rest’	Bit/stabiliser imprints produced during drilling. Effect is mild in all images. Consists of a horizontal mark across the image (impression of the bit, left @xx96 ft) and a set of diagonal marks immediately above (impression of the near-bit-stabiliser, (left at xx95 ft). Right: Artefact in an acoustic image. Bit mark at xx52 ft, stabiliser at xx51 ft. (ft, both deviated). Above Left: Bit-stabiliser configuration that can be responsible for ‘Bit-at-rest’ artefact. Note, the near-bit-stabiliser that produces the diagonal mark.		
Wiper-trip & Reeming	Processes used to clean the borehole or during coring produce a scratching of the borehole wall. Mild effect in micro-resistivity images and it rarely impairs interpretation. Mild to severe in acoustic tools because these respond much more to the borehole wall. Right: Semi-horizontal to diagonal regular scratch marks caused by the reeming of the borehole wall on a microresistivity device. (one pad is also malfunctioning as shown by the black areas to the right of the image. (ft, deviated, bit size - 6 in).	Mild effect on micro-resistivity images.	
Debris material in borehole	Material from drilling that is lodged in borehole wall. Right: Acoustic image showing a disused drill-bit that is lodged in the borehole wall shown by density spike (red curve) and a high amplitude acoustic (light area) image half way down the diagram surrounded by a low amplitude area (dark image)		
Acquisition - Logging Eccentralisation/stand-off	Logging tool is not centred in the borehole. This causes one side of the image to be too near the borehole wall, and one side too far away. Effect is mild on micro-resistivity images because these are pad devices that touch the borehole wall, unless the hole diameter exceeds the operational diameter of the tool. On acoustic images however, it is often severe (especially the transit-time image) as these are centred devices (held centrally by stabilisers/stand-offs). Common with pipe-conveyed logging. Right: Acoustic amplitude image showing a broad vertical darkening down the left side of the image and a light strip down the far-right side. (NB there is also a very dark vertical strip, this is a stabiliser mark). This is caused by the eccentralisation in this horizontal borehole. Tool is falling to the low-side of the hole which is the lighter side of this image, to the far-right and is confirmed by a broad ‘key-seat’ to the right. (ft, bit size – 8in, referenced to north).		

Mud smear	Mud build-up on electrode buttons, missing button data causes a vertical striping. Effect is mild to severe on micro-resistivity images depending on mud used, tool speed and tool type. Left: Mud smear on separate buttons of a FMI micro-resistivity device causing vertical striping. Buttons become smeared then clean by themselves due to pad friction with the borehole wall. The effect does not severely inhibit interpretation in this example. (m, deviated, bit size 6 in).		Not applicable to acoustic tools as they do not have electrodes.
Tool Speed Irregularities 1) Stuck Zones	Erratic breaks in an image resulting in a compression/expansion of the image over a small interval. Caused by sudden differences in tool speed and the yo-yo effect of wireline cable. Interpretation is often impaired. Refer also to Bourke (1989), Fig. 3a. Left: 4 pad micro-resistivity device with a tool stick and resulting data expansion over the base of the image (below xx75 ft) and compression just above at xx74 ft. Right: Acoustic image with expansion at the base (xx8-10 ft) and compression at xx7 ft.		
Tool Speed Irregularities 2) Sticky zones	Logging tool has suffered minor sticking possibly visualised as a minor tool juddering. Often the appearance of 'saw tooth' on micro-resistivity images. Interpretation is not often impaired. Left: single pad of a micro-resistivity device with a saw-tooth appearance, common within sticky zones. (vertical extent 200 mm). Right: Acoustic image over a 'sticky' interval where the tool motion is erratic or 'jerky' but has not caused a severe stick. The results are blocky patches across the image at xx57.4 ft, xx58.3 ft and xx59.4-59.9ft.		
Button or flap 'death'	Electrical fault on micro-resistivity devices usually a single button or complete pad, resulting in missing button data and interrupted image. Mild-severe to severe affect on interpretation. Right: One single pad of an 8 pad-flap FMI micro-resistivity device is malfunctioning as shown by the interrupted image on the right of the image above xx00.0 ft. Interpretation is not inhibited in this example. (ft, vertical, bit size 6 in.).		Not applicable to acoustic devices as these are centred devices.

Faulty inclinometry data	Either one or all of the 3 accelerometer or magnetometers are faulty which give an incorrect orientation of the images. Resulting dip magnitude and azimuth will therefore be in error. Effect is severe on subsequent interpretations and thorough checks of inclinometry data should always be made before interpretation. The artefact is common at the top of logging runs where the inclinometer enters the pipe ahead of the image tool (which causes the magnetometers to malfunction due to the magnetic effect of the casing). The result is incorrectly displayed image data over an interval generally related to the length of the tool. Right: Acoustic amplitude image showing zigzag patterns especially at xx5.0 m and just below xx6.0m although other minor rotation disruptions are present in between. These are caused by magnetometers that are malfunctioning. The subsequent dips azimuth and magnitude are likely to be affected.	
Excessive tool rotation	Logging tool rotates at a speed greater than the acquisition system can sample data. Results in an under-sampling of the inclinometry data. Generally a problem when the tool rotates >1 rotation per 30 ft (10 m). The result is commonly reduction of the precision and accuracy of the dip magnitude. This artefact is common with a mild to severe effect on interpretation in both micro-resistivity and acoustic images.	Notable by a fast rotation of the orientation Pad 1 Azimuth and Relative baring curves. Not often noticeable on images at high display scales (<1:20)
Noise: '60 Hertz'	Acquisition current noise - operating frequency interference, resulting in diagonal stripes across images. Can be common/ with a mild-severe effect in all tools. Right: acoustic image (UBI) with clear right-to-left diagonal stripes. Generally visible at low EMEX voltage. Can be successfully filtered. Interpretation is still possible although there is also a vertical stripping attributed to stabiliser grooves scarring the borehole.	
Processing Noise: 'Woodgrain'	Processing noise resembling woodgrain texture. Only applicable to acoustic images. This artefact can be common with severe results often inhibiting interpretation (right). Caused by systematic errors in acquisition peak interpolation. This can be ameliorated by filtering. A similar artefact is caused by an interference multiple effect (similar to a fresnel effect), see derived image artefacts. Left: 'Woodgrain' effect occurring within a hole spiral from a STAR2 tool. Common in heavy muds. (4 ft, vertical). Right: woodgrain texture clear to the left of the UBI image, caused by peak interpolation errors. (ft, deviated, 12.25 in. bit size). 	

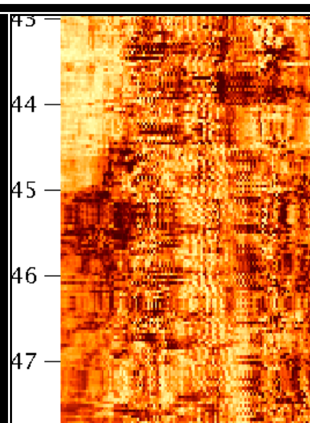
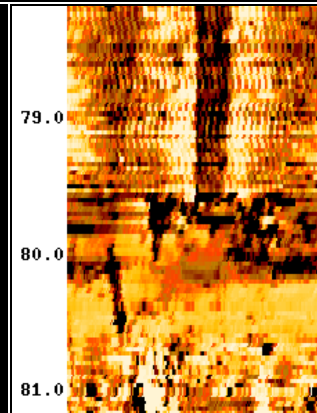
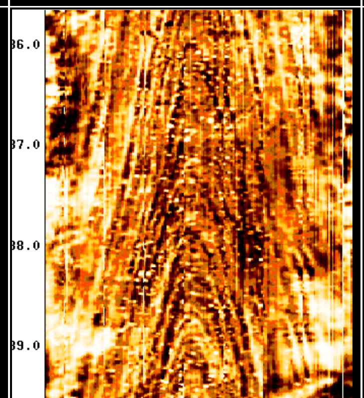
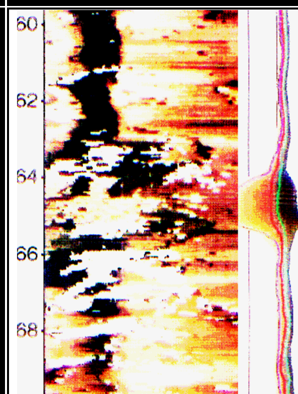
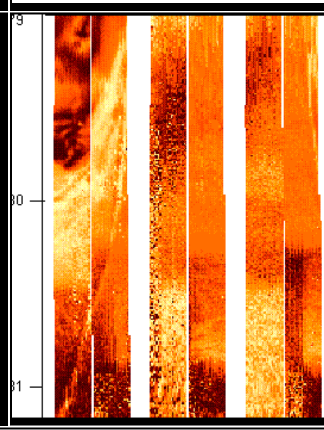
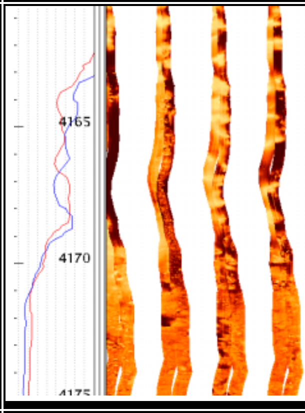
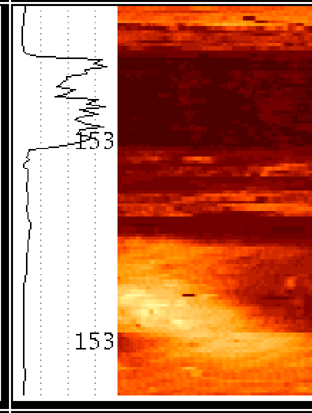
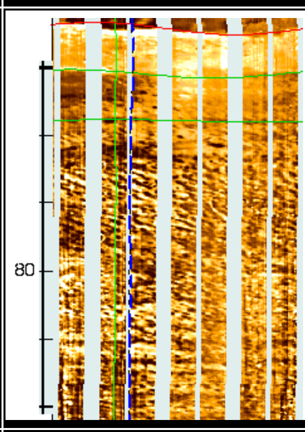
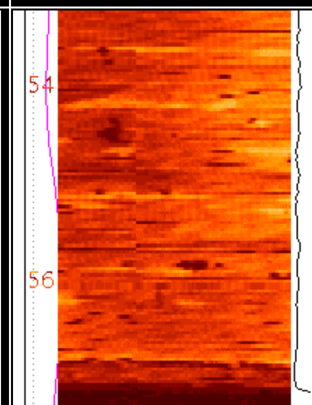
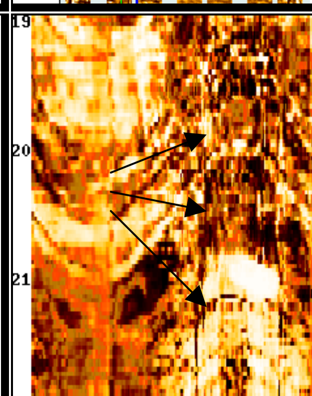
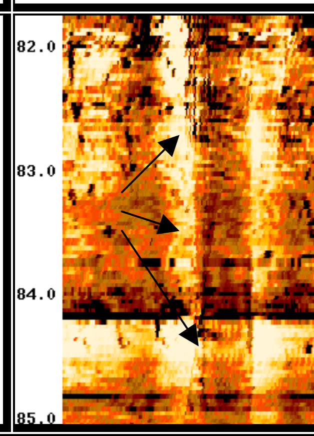
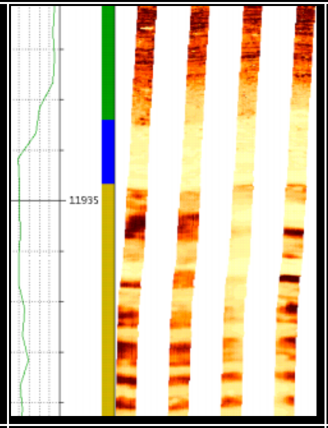
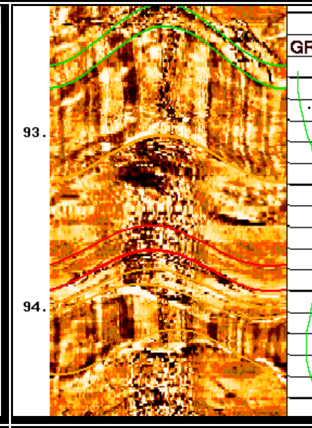
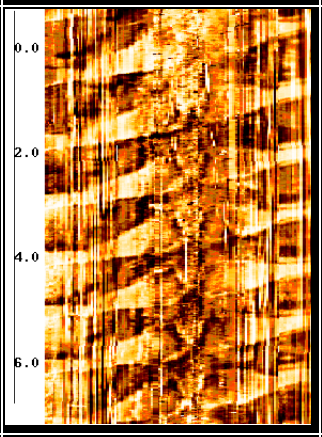
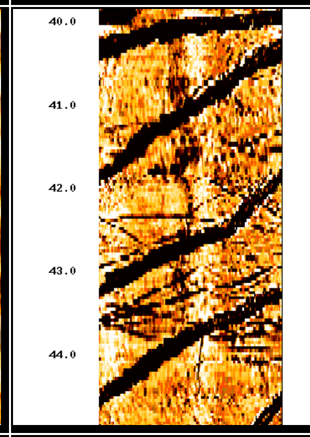
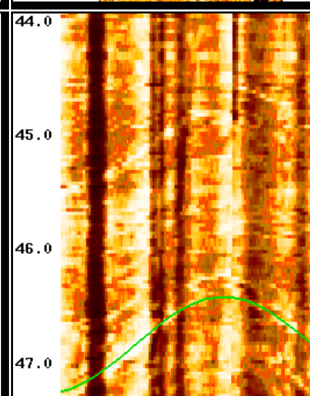
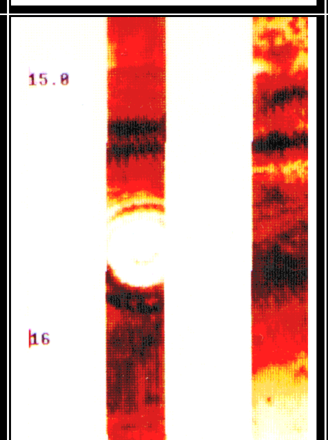
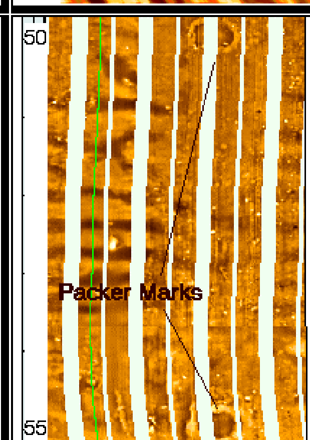
Processing Noise 'Honey-comb'	Regular horizontal comb pattern on the amplitude of acoustic images. Caused by errors in calculation of the amplitude gain during acquisition. The tool changes its gain on each sample, each gain is corrected based on statistics from the previous sample – if correction is miscalculated it results in honeycomb pattern. Can be common with mild-severe effect. N/A in micro-resistivity devices Left: amplitude image with honeycomb texture noticeable to right of image. Interpretation is impaired (ft). Right: honeycomb texture stops below xx79.5 ft.		
Signal Loss	Degradation in signal/noise ratio. Seen in all devices for various reasons. Rare but can be mild to severe in effect. Left: 8 pad-flap micro-resistivity device showing a spotted texture attributable to oil based mud lubricant additives (up to 8%) in water based mud. The effect does not inhibit interpretation in this example. (ft). Right: More common in acoustic tools are the white patches on travel time image representing areas where returned travel time (TT) falls outside of the measurement window. See dispersion (right side) of TT at xx65 ft. Common in washouts. (ft).		
Extremes of condition	Dynamic range of tool exceeded. Common in high resistive lithologies as a crystalline like speckling on an resistivity image. Left: 'Crystalline speckling' in a very highly resistive lithology (evaporite) where the micro-resistivity tool has reached its maximum dynamic range. Lithology at top left is a shale. (ft).		Not applicable to acoustic images

Table 2-2 Borehole Wall artefacts

Description of the most common micro-resistivity and acoustic artefacts observed on borehole image logs.

Micro-resistivity images are illustrated on the left hand side, acoustic images to the right. An indication of the depth units and bit size is given in brackets after the main text in each box. An explanation of tool mnemonics is given in Appendix 1.

Artefacts	Cause - description	Micro-resistivity	Acoustic
2. Borehole Wall artefacts Washout	Enlargement of the borehole hole diameter and corresponding de-focusing of image and giving a patchy image. Severe effect on all image logs. Left: Micro-resistivity image and calipers (left in blue/red increasing to right) showing de-focusing of the image as a washout is encountered above 4170 m. Interpretation is inhibited above. Right: dark area on an acoustic log and associated caliper deflection (left) indicate a large washout at xx153 ft.		
Rugose hole	Pitted borehole wall. Common on acoustic logs with a mild to severe effect on interpretation. Rarely noticeable on micro-resistivity images. Left: Extremely massive, homogeneous sand with Darcy permeability showing a hatchy texture, probably rugosity. (ft). Right: Acoustic image showing dark and light patches with a corresponding erratic caliper (black curve right side is the caliper, increasing to the right). This corresponds to rugosity of the borehole wall. (ft, 8. In. bit size).		
'Key-seat Furrow	Ovalisation due to bit wear on underside of the wellbore. Noticeable in deviated wells with often only mild effects as a broad vertical stripe. Left: micro-resistivity FMI image showing a broad vertical key-seat furrow towards the right hand side. (ft, 6.25 in. bit size), Right: Vertical key-seat furrow in an acoustic CBIL image. More visible just right of centre (see arrows). (ft, 8.5 in. bit size).		

Mudcake Build-up	Build up of mudcake generally over permeable lithologies. Effect can be mild to severe, often inhibiting interpretation. Left: Micro-resistivity FMS image showing a transition from a shale above 11935 ft to a permeable sand below. A mud cake has formed over the sand giving a blur to the image and masking bedding. Gamma-ray to left (increasing to the right). Right: Acoustic UBI image showing mudcake buildup and latter stabiliser scratching over sand layers in a sand-shale sequence. These are indicative of mudcake build-up in sands. Gamma-ray to right. (ft)		
Spiral Hole	Borehole wall is grooved due to scratching by the bit. Often leaves a diagonal mark similar to hole orbiting. Common effect in all logs, although more severe on acoustic images. Left: Horizontal FMI showing regular diagonal marks representing catching of the bit which is scratching the borehole wall. Button smear is also seen as vertical marks on this image. (ft, 6 in. bit size). Right: Black diagonal marks on a acoustic tool are scratch marks that are filled with drilling mud appear as low acoustic impedance. (ft, 6in. bit size). From Lofts *et al.* (1997).		
Tool Marks: A/ Stabiliser grooving	Vertical striping on the borehole wall caused by scratching of the logging tool stabilisers. Acoustic tools are highly sensitive to the borehole wall condition as is seen here. Right: Light and dark vertical stripes in an acoustic CBIL image. Often only partially obscure interpretation. Bedding can in fact be identified below xx46 ft shown as a green sinusoid.	Rarely noticeable in micro-resistivity images.	
B/ Sampling tool probe & packer marks	Marks made by probe/packer sampling tools. Seen in all tools as distinctive rounded marks left in mudcake or soft lithologies like the massive sand on the right. Commonly mistaken for cementation nodules. Effects are rarely serious on interpretation. Left: Resistivity image of two pads of an FMS tool showing an RFT probe/packer on mudcake. (ft, unknown bit size). Right: Two probe/packer marks on a micro-resistivity FMI image in a soft massive sand lithology. (ft, 8.5 in. bit size).		

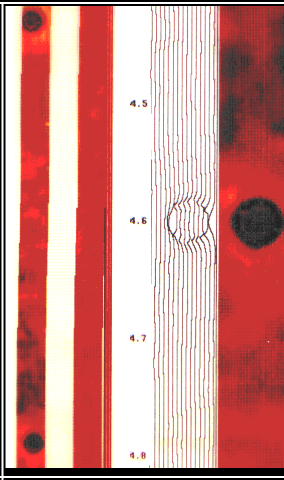
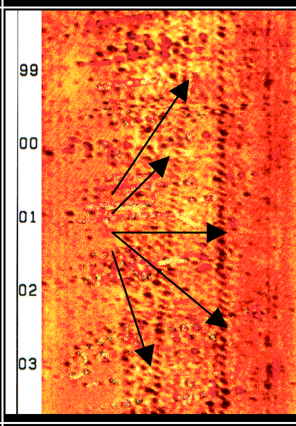
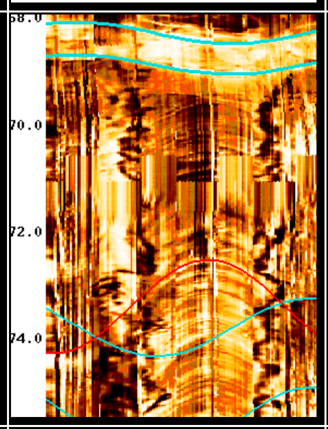
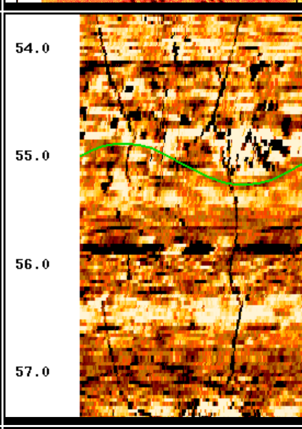
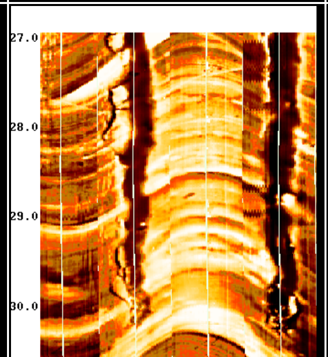
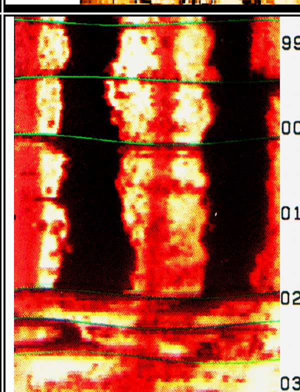
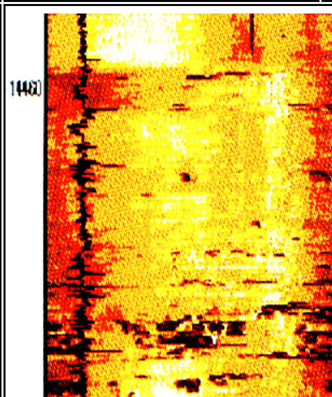
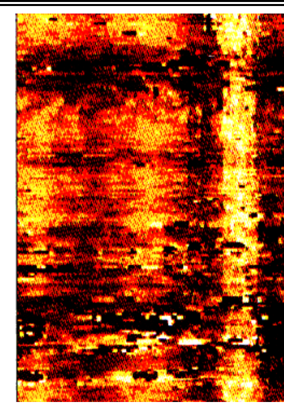
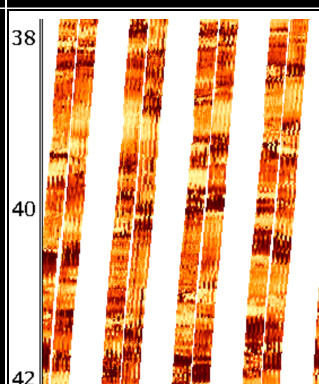
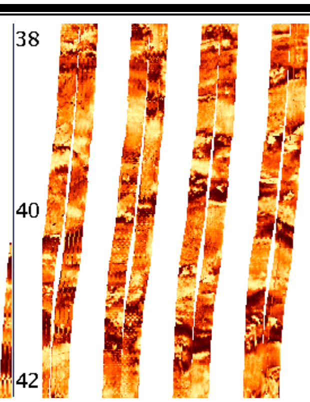
C/ Sidewall core sample points	Marks made by a mechanical sidewall corer device. Usually seen as dark spots where mud fluid replaces the sample that has been extracted. Left: Spilt image showing two sidewall core samples (left) and a zoom showing a single core sample and resistivity profile over that core sample (right). These are easily identified as they are symmetrically round shapes. (ft) unknown bit size.		Possible in acoustic images, similar in appearance to micro-resistivity images
Cable 'slap'	Marking of wireline cable on borehole wall. A very subtle artefact and relatively uncommon. Most noticeable in acoustic images. Right: acoustic CBIL image showing two marks made by the cable 'slapping' the borehole wall, one almost vertical and one slightly diagonal in the centre of the image (see arrows). (ft, 8.5 in. bit size).	Not common in micro-resistivity images.	
Drilling induced fractures	In general, zigzag fractures parallel to well bore axis. Caused by drilling process and indicates the predominant in-situ stress direction (sigma 1). Easily identified and useful in situ-stress determination. Left: Micro-resistivity FMI image showing two parallel zigzagging vertical fractures in a deviated well bore. Image also suffers from some mud smear on various buttons especially to the left. (ft 6.25 in. bit size). Right: Hairline zigzag fractures very clearly visible in an acoustic image parallel to the borehole axis. (ft, 8.5 in. bit size).		
Drilling induced breakout	Broad parallel grooves separated by 180 deg and parallel to borehole axis. Caused by shear failure fractures orthogonal to the main in-situ stress direction and therefore useful in situ-stress determination. Generally, they do not fully inhibit interpretation. Left: Micro-resistivity image showing the broad breakout features which are dark as they are filled with conductive drilling mud. (ft, 6.25 in. bit size). Right: Acoustic image showing breakouts as wide dark area which abruptly terminate at xx02 ft as the lithology changes.		

Table 2-3 Processing Artefacts

Description of the most common micro-resistivity and acoustic artefacts observed on borehole image logs.

Micro-resistivity images are illustrated on the left hand side, acoustic images to the right. An indication of the depth units and bit size is given in brackets after the main text in each box. An explanation of tool mnemonics is given in Appendix 1.

Artefact	Cause - description	Micro-resistivity	Acoustic
3. Processing Artefacts Incorrect hole diameter	Wrong assignment of borehole diameter in processing produces an incorrect calculation of apparent dip. The resulting true dip is therefore in error.	Effect not noticeable but can be severe.	Effect not noticeable but can be severe.
Normalisation window length artefacts	Distinctive colour tones caused by an extremely high/low resistivity feature which skews the histogram such that the background colour is modified for a distance corresponding to the window length for normalisation.	Not common in modern images. Refer to Bourke (1989), Fig. 10a, b and c.	Not common in modern images
Multiple pass image offsets	Depth mismatch between two logging passes over the same interval. Easily corrected with modern depth matching.	Not common in modern images Refer to Bourke (1989), Fig. 12.	Not common in modern images Refer to Bourke (1989).
Incorrect colour assignment	Results from the skew of the image histogram by an anomalous high or low resistivity/amplitude image. Saturated looking images – concealment of detail.	Not common in modern images	Not common in modern images
Incorrect gain correction	Wrong gain correction is applied during processing of images. Resulting in under saturated/over saturated images. Can appear in all logs. Left/right: Static acoustic images showing a raw uncorrected image that is saturated (left image) and one that has had a proper gain correction applied (right image). More detail is visible and the image is not so washed out. (ft, 8.5 in. bit size).		
Faulty button correction	'Tiger striped' images that appear fuzzy. This results from the incorrect processing and correction for the faulty electrodes. Generally only occurs if there is a faulty acquisition circuitry. Left: FMI tool with an inferior correction applied. Right: Same image with correct processing applied.		

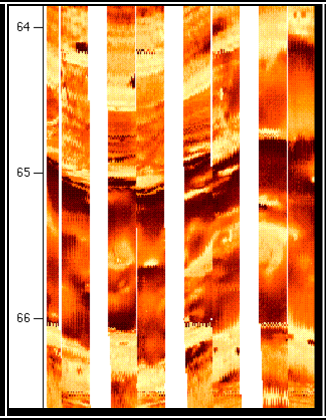
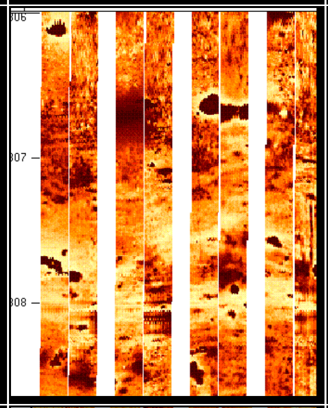
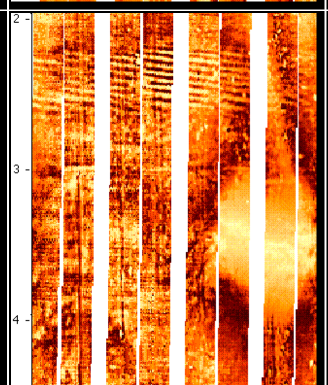
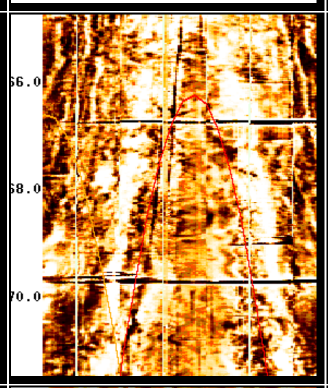
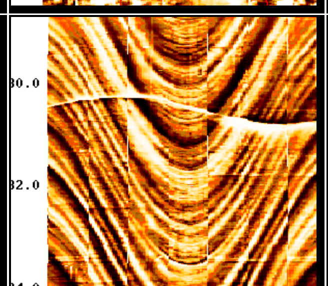
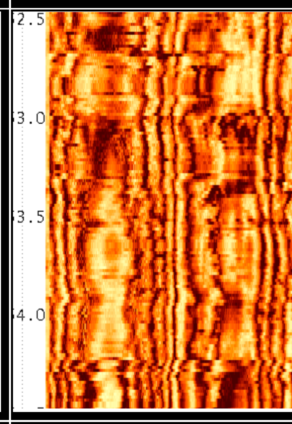
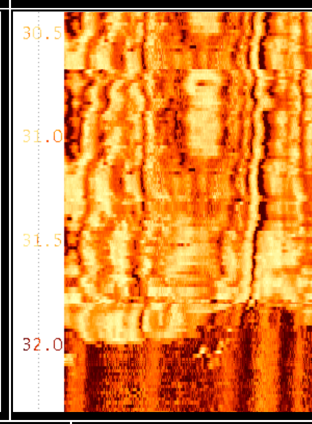
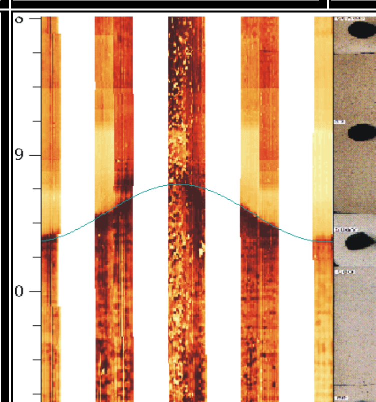
Pad-flap or button offsets	Incorrect speed correction applied. Offset of the pad to the flap in pad-flap micro-resistivity tools or buttons on different rows of a pad device. Refer also to Bourke 1989. Left: Large pad-flap mismatch on an FMI tool as a result of incorrect speed correction. (ft, bit size 8.5”)		Not applicable to acoustic tools.

Table 2-4 Derived Artefacts

Description of the most common micro-resistivity and acoustic artefacts observed on borehole image logs.

Micro-resistivity images are illustrated on the left hand side, acoustic images to the right. An indication of the depth units and bit size is given in brackets after the main text in each box. An explanation of tool mnemonics is given in Appendix 1.

Artefact	Cause - description	Micro-resistivity	Acoustic
4/ Derived Artefacts. Current Gather Effects: Halo effects - Conductive	Light rim or 'halo' surrounding a conductive feature. This results from the flow of current toward the most conductive pathway. This 'current gather' leaves a resistive rim where current is lacking around such a feature. Left: Current gather seen around pyrite nodules, which are extremely good conductors of electrical current. The best example is a dark nodule at xx06.5 ft. (ft, bit size 8.5 in.).		Not applicable to acoustic tools.
Halo effects - Resistive	Dark rim or 'halo' surrounding a resistive feature (light). This results from the drain of current away from the most resistive areas to the more conductive pathway. This 'current gather' leaves a conductive rim where current is gathering around such a feature. Left: Large resistive cemented nodule (light colour) surrounded immediately by a dark halo indicating current gather.		Not applicable to acoustic tools.
Cement mottling	Mottling fabric caused by highly resistive cements. Again this is an effect caused by current gather. In the case of cements, they are generally resistive and result in a mottle fabric as current drains to a more conductive area. Left: White 'mottled' area following the outside of the red sinusoid is to current gather over a resistive bedding horizon. (Horizontal well with shallow bedding makes bedding surfaces here very steep sinusoids). (ft, bit size 8.5 in.).		Not applicable to acoustic tools.
Proximity effects. Fracture aureoles	Light patches at the apex of fracture sinusoids. Due to the depth of investigation (approx. 0.5-1 in.) the fracture is detected by the tool before the fracture plane is encountered in the borehole wall. Refer to Bourke (1989), Fig 5b. Left: Resistive fracture (shallow sinusoid) with a light aureole at the apex of the sinusoid..		Not applicable to acoustic tools.

Proximity features	Patchy texture caused by current gather/around resistive and conductive features (such as nodules) proximal to the borehole wall but not actually touching. Refer to Williams (1996). Left: Benthic shells in a mudstone showing dark blotchy texture which is attributed to proximal features not actually touching the borehole wall and not seen in core at this depth.		Not applicable to acoustic tools.
Woodgrain 2	Processing noise resembling woodgrain texture. Explained as a multiple or interference effect which occurs in heavy muds and within heavy mudcake intervals. With reflections from tool housing. Only applicable to acoustic images. This artefact can be common with severe results often inhibiting interpretation (right). Left: Woodgrain effect in a heavy mudcake on a CBIL image. (ft, 8.5 in. bit size) Right: Woodgrain effect commences where heavy mudcake starts in a permeable zone above xx32 ft. (ft, 8.5 in. bit size)		
Residual (remaining) Hydrocarbon	Imaged oil-water contact (at xx9.75 ft) in a sandstone lithology. Within the oil zone the resistivity image is highly resistive (bright yellow) and within the water zone the sandstone has a normal resistivity profile. Core is displayed on right side showing no change in lithology and confirming oil stain. (ft)		

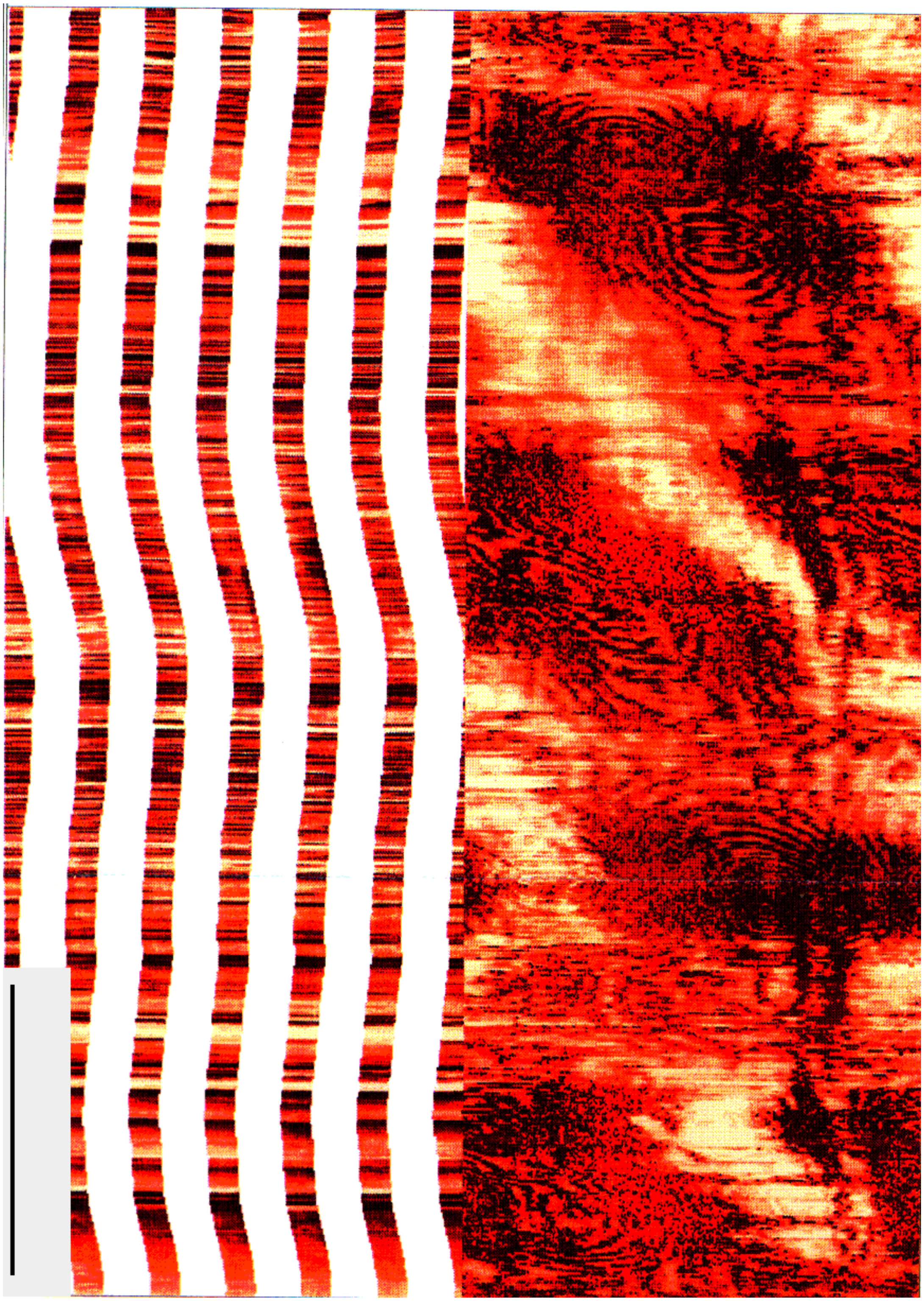


Fig. 2. A 5 ft vertical section of ultrasonic (right) and micro-resistivity images (left). This indicates the sensitivity of the acoustic image to the borehole wall condition which in this case is hole spiralled, whereas the micro-resistivity image shows no adverse effect or artefact. The acoustic image itself demonstrates two of the most common artefact features seen an acoustic image, hole spiralling and 'woodgrain' artefacts.

Conclusions and Recommendations

- Systematic recognition of artefacts is the first stage in log quality control prior to any interpretation. Artefacts should be related to the acquisition practice so that they can be effectively filtered out with greater confidence during interpretation. The ability of the interpreter to recognise and disregard artefacts (effectively blank them out) should significantly enhance confidence and accuracy of the geological interpretation.
- When two or more artefacts are present they are generally additive in lowering the confidence of an image interpretation.
- Micro-resistivity images are most affected by either pad contact problems or the complexities of current flow within rocks.
- Acoustic (ultrasonic) image logs are highly sensitive to borehole conditions and drilling mud properties. These are the most common causes of artefacts observed on acoustic image logs.
- As tool design and processing improve further, some artefact types will doubtless disappear but new ones may be created.
- As interpreters become more familiar with the causes this information can be related back to the acquisition companies for modification of tool design and acquisition practices.

Acknowledgements are given to those oil companies who have contributed artefacts in the preparation of this paper but who wish to remain anonymous.

Appendix 1

Glossary of tool mnemonics and terms

CBIL – Circumferential Borehole Imaging Log (Western Atlas)

FMS - Formation MicroScanner (Schlumberger)
FMI - Fullbore Formation MicroImager (Schlumberger)
OBDT - Oil Based Dipmeter Tool (Schlumberger)
RAB – Resistivity at Bit Tool (Schlumberger)
RFT - Repeat Formation Tester (Schlumberger)
STAR2 –Simultaneous Acoustic & Resistivity Borehole Imager (Western Atlas)

EMEX – variable emitter-exciter current/voltage used by Schlumberger's passive imaging devices (FMS and FMI) to maximise signal-noise.

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