CORRELATION BETWEEN CORE LINEAR X-RAY AND WIRELINE BULK DENSITY IN TWO CLASTIC RESERVOIRS: AN EXAMPLE OF CORE-LOG INTEGRATION

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ABSTRACT

Linear X-ray measurements on core samples potentially provide a rapid means of obtaining a high resolution quantitative density profile. We tested this on slabbed core from two shoreface clastic reservoirs in the North Sea by comparing the linear X-ray results with wireline bulk density data over the same depth matched intervals. A linear X-ray scanner system produced inverted images on an electronic image intensifier. The digital images were composed of pixels of different grayscale. These grayscale values are referred to as "luminance" values. Low luminance values represent low penetrability of X-rays (i.e., high attenuation of X-rays, and therefore high density core) and are seen as dark pixels on the images, whilst high luminance values represent high penetrability of X-rays (low density core) and are seen as light pixels on the images. Luminance values were taken at high resolution along the slabbed core. The results were compared with the wireline bulk density data. A key result was that when the luminance data was averaged (by a simple smoothing technique) over the same vertical intervals that each wireline bulk density measurement was made (about 1 to 2 feet), the luminance and bulk density data showed a good correlation. Both the smoothed luminance and wireline bulk density exhibited similar profiles with depth in the intervals studied from the two clastic reservoirs, and crossplots quantitatively demonstrated the good correlations. As expected the correlations were worse if the luminance data was smoothed over an interval that did not correspond to the vertical interval of each wireline bulk density measurement. The strong correspondence between appropriately smoothed luminance and wireline bulk density data over identical intervals gives us confidence that the raw (unsmoothed) high resolution point luminance data offers a rapid, non-destructive means of obtaining a high resolution density profile on slabbed or whole core. The luminance data and X-ray images readily pin-pointed thin naturally cemented higher density dendritic barite filled fracture veins within the quartz sandstone that were not easily seen from standard visible light core images. Other features, such as thin clay laminae, were also better defined from the linear X-ray data than from visible light images.

INTRODUCTION

Some previous studies have indicated the potential of linear X-ray measurements for characterizing sedimentary structures [1,2] and high resolution density variations [3] in whole core and slabbed core samples. The latter study by Duncan et al [3] compared the grayscale of digital linear X-ray images (which they termed “luminance” values) of core with the wireline bulk density data from the same intervals. The present paper compares luminance data from the digital linear X-ray images on core with the corresponding wireline bulk density log data on sections of slabbed core from two different clastic reservoirs. We first compared raw single point luminance readings against the corresponding wireline bulk density log readings, and then compared smoothed luminance data that was averaged over the same vertical interval as each wireline bulk density log reading. The main purpose was to compare the luminance and wireline bulk density data over the same vertical scale of measurement, to see if this improves the correlations between the two types of measurement (compared to correlations between the wireline bulk density data and single point luminance measurements).

SAMPLES AND METHODS

Two clastic reservoir sections from the North Sea were studied: (i) a 24ft long quartz sandstone shoreface facies with barite filled fracture veins from Well 2, and (ii) a 36ft long quartz sandstone shoreface facies with clay laminae from Well 8, which also contained an upper small calcite dogger interval, and a lower micaceous sandstone. A linear X-ray scanner was used to create inverted images of the slabbed core on an electronic image intensifier. The images were picked up by a charge coupled device (CCD) camera and digitized. Point luminance values (the grayscale of the images at a particular point <0.1 inch in diameter) were taken directly from the digital X-ray images in real time during the scanning. Low luminance values representing low penetrability of X-rays (i.e., high attenuation of X-rays, and therefore high density core) were seen as dark pixels on the images, whilst high luminance values representing high penetrability of X-rays (low density core) were seen as light pixels on the images.

The luminance values were compared with the corresponding wireline bulk density values for the same sections after first depth matching the core against the log depths. The wireline bulk density log values were first compared to the nearest raw single point luminance values. We then compared the wireline bulk density log values with smoothed luminance data points that were averaged over vertical distances comparable to that of a typical wireline bulk density log reading.

RESULTS AND DISCUSSION

Figure 1 (top) shows linear X-ray images of the 24 foot section in Well 2. The black areas are barite (some barite filled fracture veins are particularly evident). The grey areas are quartz, and the “holes” are where core plugs have been taken. **Figure 1 (bottom)** shows linear X-ray images of a 12 foot section (of the 36 feet that was imaged) in Well 8. Inclined clay laminae can clearly be seen within the otherwise homogeneous quartz.

Figure 2 shows plots of wireline bulk density and luminance with depth for the 24 foot interval in Well 2. The top two plots are the wireline bulk density values (taken every half foot) and the raw high resolution luminance values (taken about every 3 inches). The raw luminance data exhibits far more variation than the wireline density profile, and reflects the higher resolution of the core X-ray measurements. The bottom two plots of **Figure 2** show smoothed luminance data that has been averaged vertically over 1 foot (5 point average) and 1.5 feet (7 point average) respectively. These smoothed luminance curves show a much closer correspondence to the wireline bulk density profile, since each smoothed luminance value represents an average over an approximately similar vertical interval to each wireline bulk density log reading. From these curves it appears that the luminance averaging over 1.5 feet (7 point average) is closest to the wireline bulk density profile.

A more quantitative test of the correlations of the Well 2 data is shown in the crossplots of **Figure 3**. The top crossplot is merely the wireline bulk density data plotted against each corresponding nearest single point raw luminance value. It is apparent that the regression coefficient is quite low with R^2 = 0.37. Significantly, however, when the wireline bulk density is plotted against the smoothed luminance data the correlations are much better. The regression coefficient R^2 = 0.58 for luminance data averaged vertically over 1 foot (5 point average, **Figure 3 middle**), and R^2 = 0.63 for luminance data averaged vertically over 1.5 feet (7 point average, **Figure 3 bottom**). All crossplots showed the expected inverse correlation of higher bulk density corresponding with lower luminance. We determined the regression coefficients for luminance data averaged vertically over several other spacings. For example, averaging over 2 feet vertically gave R^2 = 0.60. The maximum R^2 value was for the 1.5 feet vertical averaging shown in **Figure 3 bottom**. This might suggest that the wireline bulk density log was actually averaging vertically close to 1.5 feet.

Figure 4 shows plots of wireline bulk density and luminance with depth for the 36 foot interval in Well 8. The top two plots are the wireline bulk density values (taken every half foot) and the raw high resolution luminance values (taken in this case at very high resolution about every 0.8 inches). The higher resolution raw luminance data exhibits substantially more variation than the wireline density profile. The bottom two plots of **Figure 4** show smoothed luminance data that has been averaged vertically over 1 foot (17 point average in this case due to the high resolution of measurement) and 2 feet (31 point average) respectively. These smoothed luminance curves again show a fairly close correspondence to the wireline bulk density profile, since each smoothed luminance value represents an average over an approximately similar vertical interval to the wireline bulk density log.

Figure 5 shows crossplots of wireline bulk density versus luminance for Well 8. The top crossplot merely gives the wireline bulk density plotted against the nearest single point raw luminance value. The regression coefficient is quite low with R^2 = 0.43. Again significantly, however, when the wireline bulk density is plotted against the smoothed luminance data the correlations are much better. The regression coefficient R^2 = 0.64 for luminance data averaged vertically over 1 foot (17 point average, **Figure 5 middle**), and R^2 = 0.68 for luminance data averaged vertically over 2 feet (31 point average, **Figure 5 bottom**). We determined the regression coefficients for luminance data averaged vertically over several other spacings, and the maximum R^2 value was for the 2 feet vertical averaging shown in **Figure 3 bottom**. This might suggest that for Well 8 the wireline bulk density log may actually be averaging vertically close to 2 feet. However, all the R^2 values for luminance averaged vertically between 1.5 and 2 feet were very close (R^2 = 0.678 for 1.5 feet vertical averaging and R^2 = 0.683 for 2 feet vertical averaging, with intermediate R^2 values for averaging between 1.5 and 2 feet).

CONCLUSIONS

1. The results from the two clastic reservoirs studied showed an inverse correlation between the grayscale of linear X-ray images (the "luminance") on core and the wireline bulk density. As the bulk density increases the luminance decreases.
2. The best correlations between luminance and wireline bulk density occurred when the smoothed (i.e., averaged) luminance vertical interval was between 1 and 2 feet, which we believe closely corresponded to the vertical interval over which the wireline bulk density log averages each reading.
3. The good correlation between wireline bulk density and luminance that is averaged over the same vertical interval gives us confidence that the raw point luminance values taken at small scale vertical spacings are giving an accurate profile of the high resolution density variations.
4. The linear X-ray images and luminance values readily picked out higher density barite filled fracture veins in one of the reservoirs, and clay laminae in the other reservoir, that were much more difficult to see from visual observations alone.

ACKNOWLEDGEMENTS

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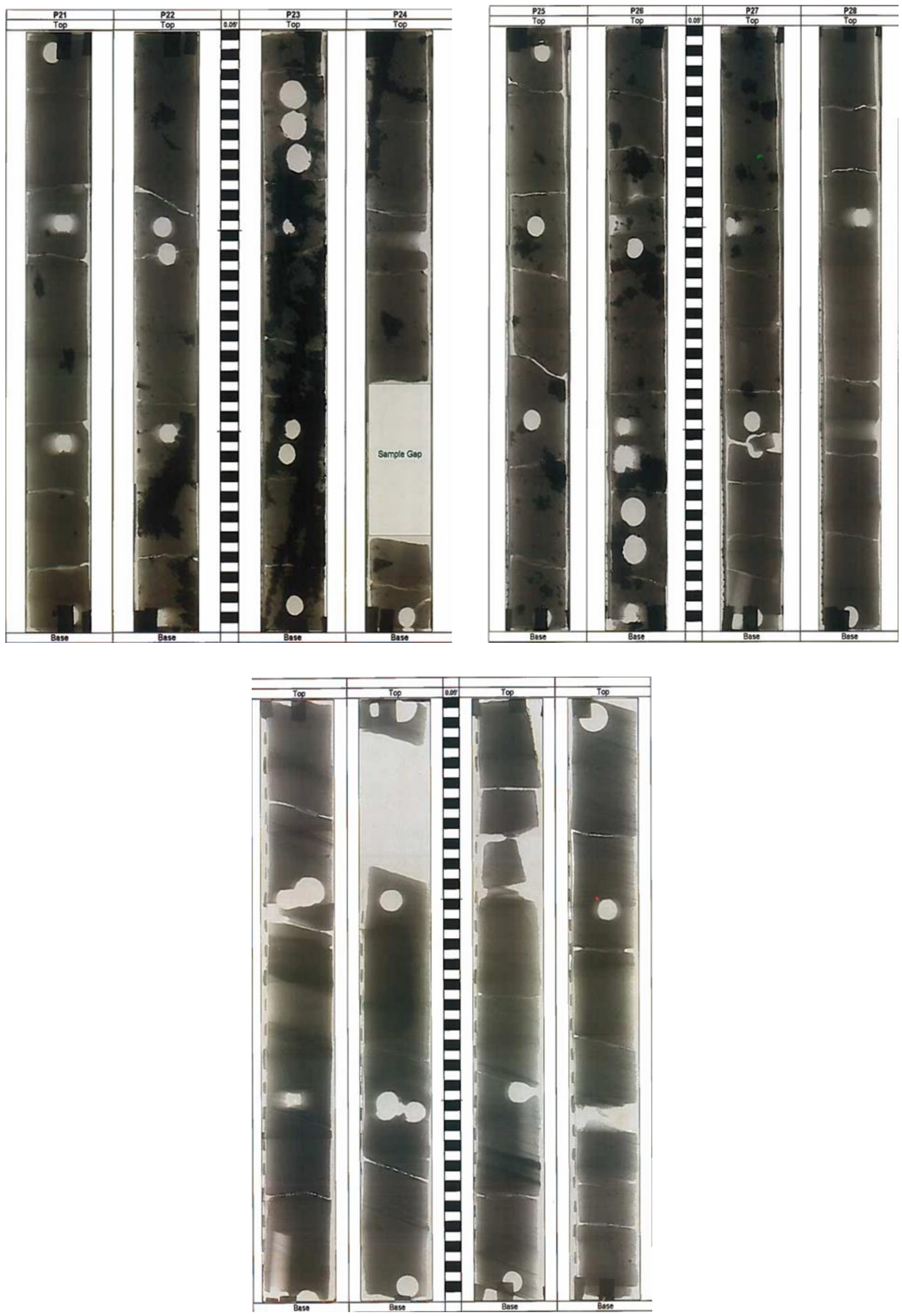

Figure 1. Top: Linear X-ray images of the 24 foot section in Well 2. The black areas are barite (particularly evident in the barite filled fracture veins of the 3rd section from the left). The grey areas are quartz, and the "holes" are where core plugs have been taken. **Bottom:** Linear X-ray images of a 12 foot section in Well 8 (a further 24 feet was also imaged, but not shown here due to available space). Inclined clay laminae can be seen (e.g., towards the base of the 3rd section from the left).

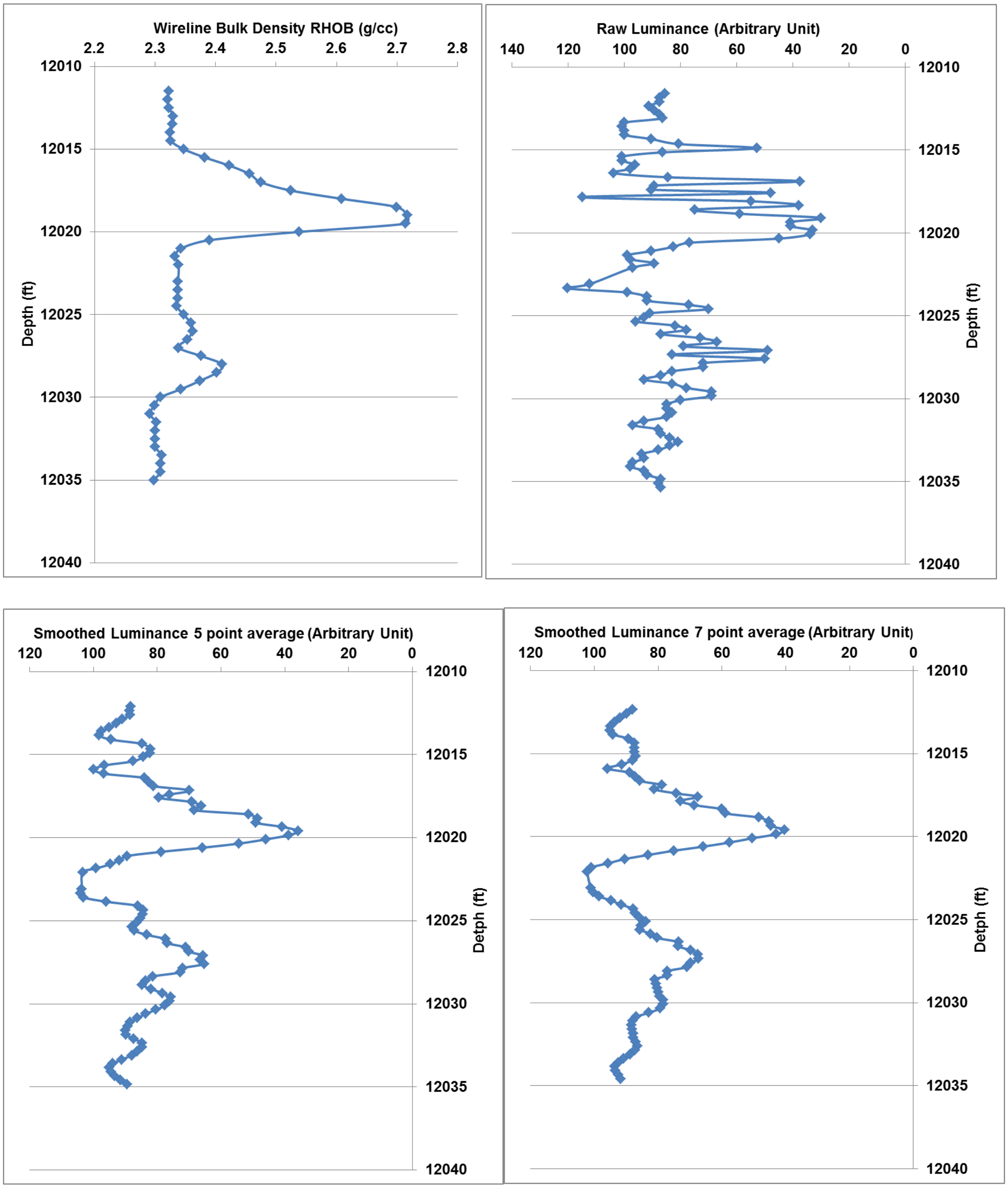

Figure 2. Plots with depth for Well 2. **Top left:** Wireline bulk density. The high value at 12,018-12,020 ft is due to the barite filled fracture veins. **Top right:** Raw high resolution luminance values (at approximately 3 inch vertical spacing). **Bottom left:** Smoothed luminance 5 point average (averaged over 1 foot vertically). **Bottom right:** Smoothed luminance 7 point average (averaged over 1.5 feet vertically).

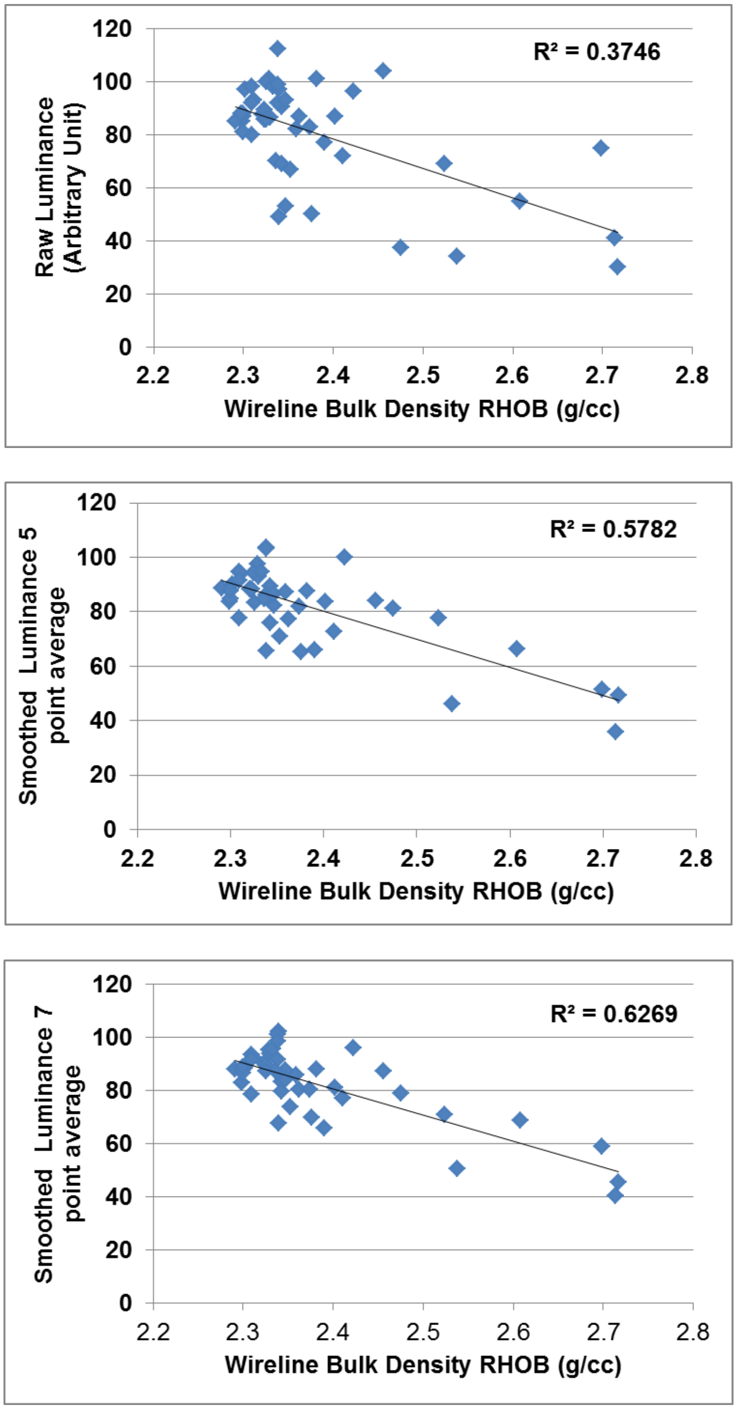

Figure 3. Crossplots for Well 2 of wireline bulk density versus (i) **Top:** Raw single point luminance at the nearest depths to the corresponding wireline bulk density readings, (ii) **Middle:** Smoothed luminance 5 point average (averaged over 1 foot vertically), and (iii) **Bottom:** Smoothed luminance 7 point average (averaged over 1.5 feet vertically).

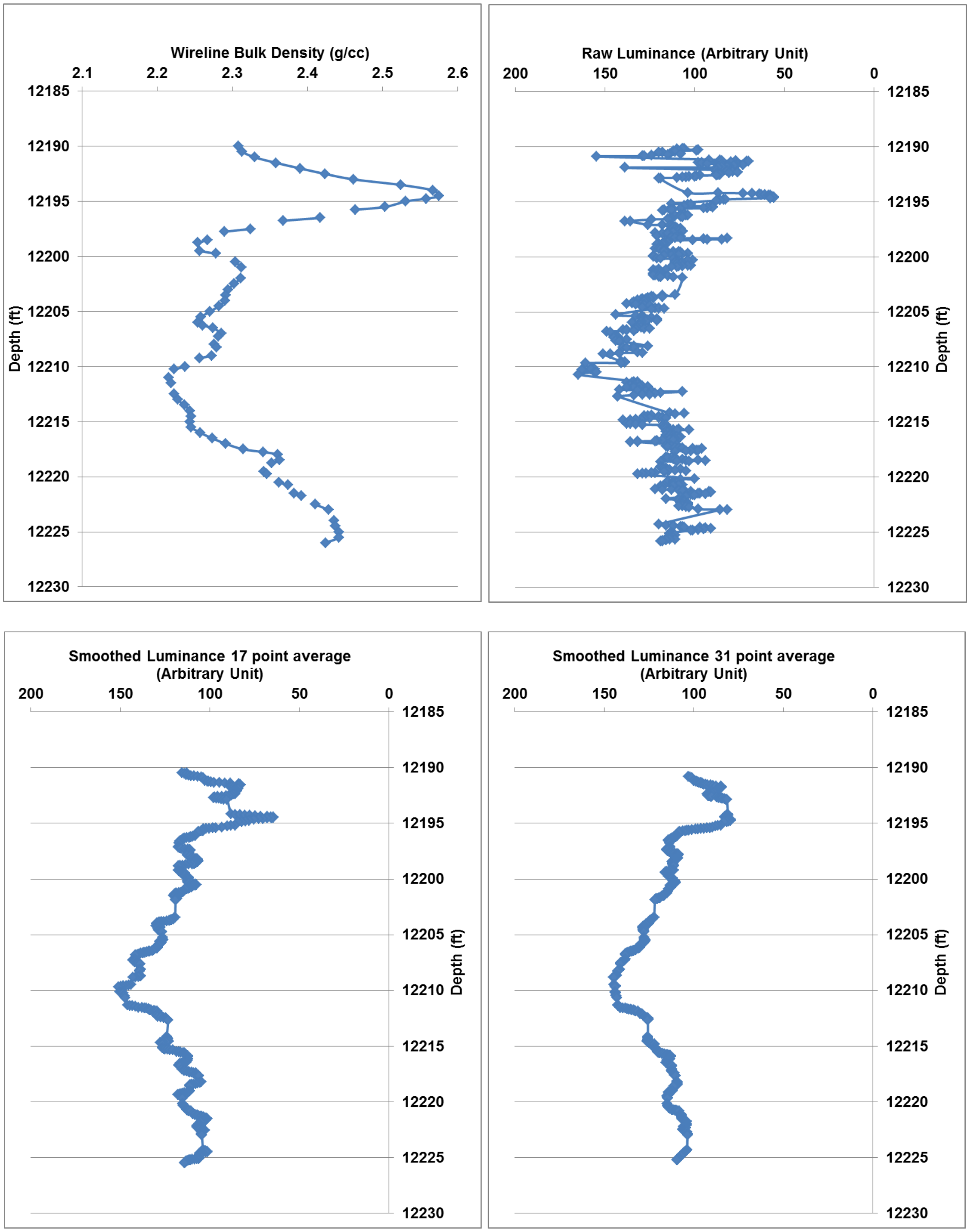

Figure 4. Plots with depth for Well 8. **Top left:** Wireline bulk density. The high value at 12,195 ft is due to a calcite dogger. **Top right:** Raw high resolution luminance values (at approximately 0.8 inch vertical spacing). **Bottom left:** Smoothed luminance 17 point average (averaged over 1 foot vertically). **Bottom right:** Smoothed luminance 31 point average (averaged over 2 feet vertically).

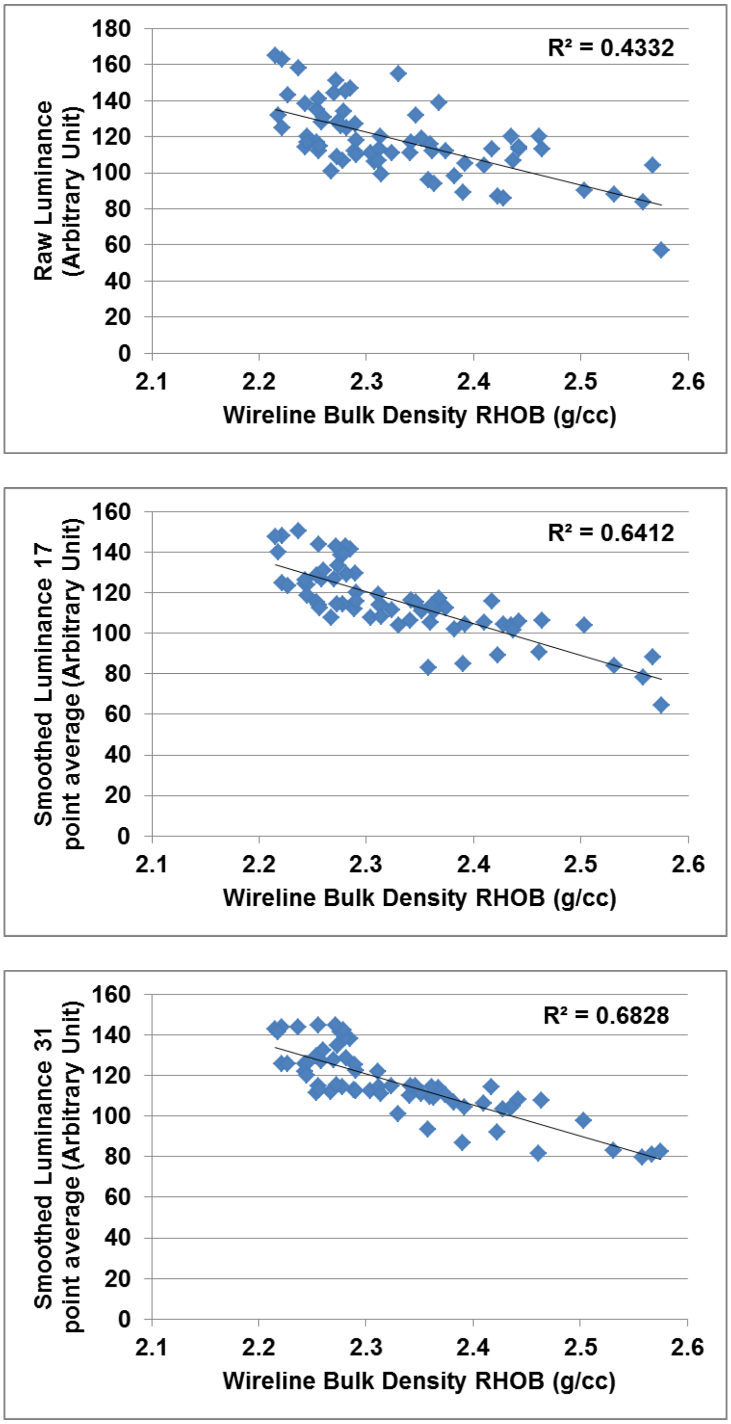

Figure 5. Crossplots for Well 8 of wireline bulk density versus (i) **Top:** Raw single point luminance at the nearest depths to the corresponding wireline bulk density readings, (ii) **Middle:** Smoothed luminance 17 point average (averaged over 1 foot vertically), and (iii) **Bottom:** Smoothed luminance 31 point average (averaged over 2 feet vertically).