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Gamma-gamma Log and Its Correction

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Disclaimer

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ABSTRACT: Densities determined from the gamma-gamma log have been compared with the densities obtained from core measurement from Paleozoic to Mesozoic rocks in the Korean peninsula. The result of the comparison shows a significant difference between log density and core density, particularly from the rocks which have high gamma radioactivity. The effect of natural gamma rays in density determination has been corrected by subtracting the natural gamma response value from the conventional gamma-gamma value. A resultant coincidence is shown between the core and corrected log densities from both rocks of high gamma and non-radioactive rocks. In this study, the natural gamma response of gamma-gamma detector has been obtained in two ways: a natural gamma measurement by the gamma-gamma sonde with no gamma source, and a numerical calculation using the natural gamma response characteristics. The correction carried out by two different methods shows an equivalent result. Consequently, the natural gamma correction can be applied to the density log as a simple numerical method if we use a natural gamma detector mounted on the gamma-gamma sonde. This result also suggests the necessity for inserting a routine procedure of correction for the natural gamma effect in density determinations with gamma-gamma sondes that use a low-intensity gamma source

Introduction

Physical properties of rocks are of great concern to geophysicists, petrophysicists and geotechnical engineers. Density is one of the most important physical properties. Density can be measured by either gamma-gamma log (hereinafter "log density") or core density measurement (hereinafter "core density"). Core density measured either by saturation and buoyance technique or porosimeter adopts the basic relation between weight and volume of the specimen (Brown, 1981). While log density measured by the gamma-gamma method is based on the principle that the attenuation of gamma radiation as it passes through the borehole and surrounding rocks is proportional to the bulk density of rocks (Schlumbeger, 1991). The gamma-gamma logging is also made under the assumption that the gamma radiation registered by the detector mostly consists of the scattered gamma ray reaching the detector from an artificial gamma ray source.

Pickell and Heacock(1960) reported that natural radiation effects would become increasingly important as source strengths decay. But, many seem to be satisfied with their other suggestion that the effect of natural gamma radiation on the density log response is reportedly nil, and that logging companies take care to utilize a source of sufficiently high strength to dominate the influence of natural gamma radiation. It seems to be quite difficult to find specific comments on the correction for natural gamma effect even in these days when some companies have begun to use low level sources and highly sensitive detectors, particularly in groundwater and civil purpose logging.

This study has been made to show that the effect of natural gamma radiation needs to be corrected in density logging for groundwater or civil engineering purposes in radioactive rocks, and to find the efficient way to correct the natural gamma ray effect (hereinafter "natural gamma correction") in density determination with gamma-gamma log.

Natural Gamma Effect in Log Density Determination

The gamma-gamma log is based on the principle that the attenuation of gamma radiation as it passes through the borehole and surrounding rocks is proportional to the electron density of rocks(Tittman and Wahl, 1965; Keys, 1989; Schlumbeger, 1991).

$$Yobs = k / \rho e$$

where Vobs is gamma-gamma intensity observed, ρe is electron density index, and k is constant. Meanwhile, bulk density is shown as the function of electron density index:

$$\rho b = \rho e / (Mol.Wt / 2 Z)$$

or

$$\rho e = \rho b (Mol.Wt / 2 Z)$$

where ρb is bulk density, Mol.Wt is molecular weight, and Z is the number of electrons per molecule. If we assume that the bracketed value is close to unity, bulk density can be obtained from the observed gamma-gamma intensity using above equations:

$$\rho b = k / Yobs$$

The gamma-gamma logging is made on the assumption that the gamma radiation detected on the detector consists of the scattered gamma ray reaching the detector only from an artificial gamma ray source(Yags):

$$Yobs = Yags$$

If the gamma ray reaching the detector comprises a significant portion of gamma ray radiation emanating from natural gamma ray source(Yngs), the equation has to be expressed as follows:

$$Yobs = Yags + Yngs$$

Natural gamma correction can be defined by subtracting the natural gamma ray intensity(Yngs) which corresponds to the noise component in density determination from the observed total intensity(Yobs):

$$Yags = Yobs - Yngs$$

Density should be obtained from following equation:

$$\rho b = k / \{Yobs - Yngs\}$$

Comparison of Core Density with Log Density

As a way for confirming the natural gamma effect in log density determination, log and core densities were measured and compared in selected areas, whose geology consists of shale, sandstone, limestone, granite and metamorphic rocks. Core density was obtained by saturation and buoyancy technique based on ISRM suggested method (Brown, 1981). Log density was obtained after the standard procedure for data acquisition and correction, where only the natural gamma correction is excluded. The density logger used in the study measures the gamma ray intensity by three kinds of detectors with different spacings and corresponding depth of investigation. In this study Long Spaced Density (LSD) whose spacing is 48cm was used for the density calculation.

Fig. 1 shows an example of the comparison between log density and core density obtained from a borehole in a Cretaceous sedimentary basin as well as the comparison of gamma values between core and log data. The result shows significant discrepancies in density comparison, which are too large to be regarded as the result of different measuring methods and different volumes of investigation(Carmichael, 1983; Ellis, 1987). What is most notable is that a significant discrepancy occurs within the shale zone, which corresponds to the high gamma intensity rock.
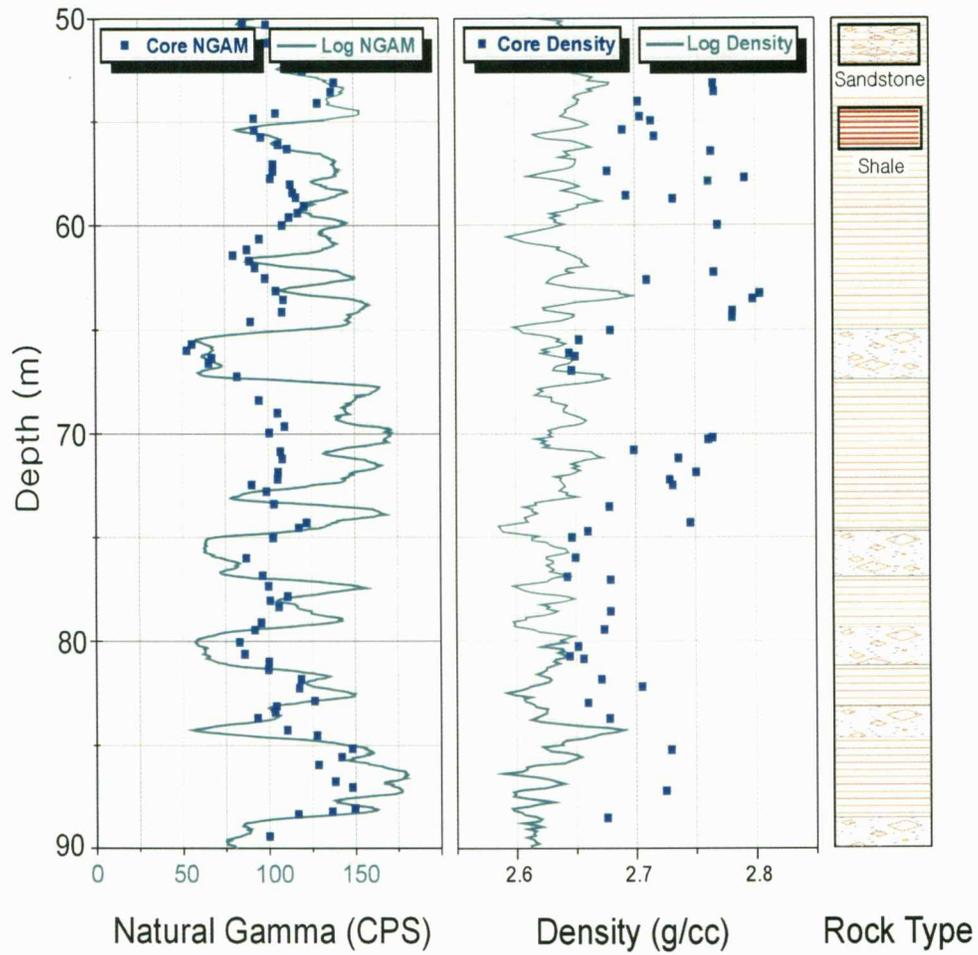
Fig. 1. Comparison between log and core data in terms of natural gamma intensity and density obtained in Cretaceous sedimentary basin. Density shows very poor correlation between core and log data while natural gamma shows fairly good correlation.

Correction for the Natural Gamma Ray Effect in the Density Log

The basic approach for natural gamma correction is to use the natural gamma response value (LSDngs) measured by the LSD detector (Fig. 2). Corrected gamma-gamma intensity (LSDags) can be obtained by subtracting the LSDngs value (Fig. 2B) from the conventional gamma-gamma value (LSDobs) detected on the LSD detector with a gamma source as shown in Fig. 2A(hereinafter "source detach method"):

LSDags = LSDobs - LSDngs

Fig. 3 shows the corrected gamma-gamma curve (LSDags) as well as the conventional gamma response (LSDobs) and natural gamma response (LSDngs) values on the LSD detector. The LSDags curve that is free from natural gamma effect is shown as quite distinct from the LSDobs curve. Fig. 4 shows the density curves delineated before and after the natural gamma correction in Paleozoic sedimentary rocks comprising shale, sandstone and limestone. A fairly good match is revealed between core and log densities according to the natural gamma correction. The shaded area represents the density increase according to the natural gamma correction. This method has a benefit in the sense that it is simple and clear theoretically. However the bothersome extra work for data acquisition and processing procedure is pointed out as the disadvantage.

In order to avoid the additional effort anticipated in the above method, a numerical calculation method (hereinafter "numerical method") has been adopted in this study using natural gamma response characteristics. Fig. 5 shows the gamma response characteristics of the density logger used. Three kinds of natural gamma response curves (LSDngs, HRDngs, BRDngs) were obtained by the gamma-gamma detectors with no artificial gamma source in the same borehole. Although BRDngs values are too small to be shown in Fig. 5, all three kinds of gamma responses on the LSD channel show a good proportional relationship with the natural gamma values on the NGAM channel. Particularly higher sensitivity is revealed in the LSD channel since the sensitivity of detectors are designed to increase in proportion to the spacing between source and receiver. This environment is expected to be the cause of decrease of S/N ratio in gamma-gamma log which uses the LSD channel for the density calculation.

The proportionality between LSDngs values and NGAM values is shown well in Fig. 6 that was obtained from granite and sedimentary rocks. The correlation coefficient that is very close to unity suggests that natural gamma response value (LSDngs) acting on the density channel can be determined accurately from the NGAM value obtained from conventional density log according to a linear regression equation:

LSDngs = 7.4 + 0.38 NGAM

This is a sufficient background for the second approach to the natural gamma correction, which is to calculate the value of natural gamma intensity on a density detector. Virtually, the gamma ray correction
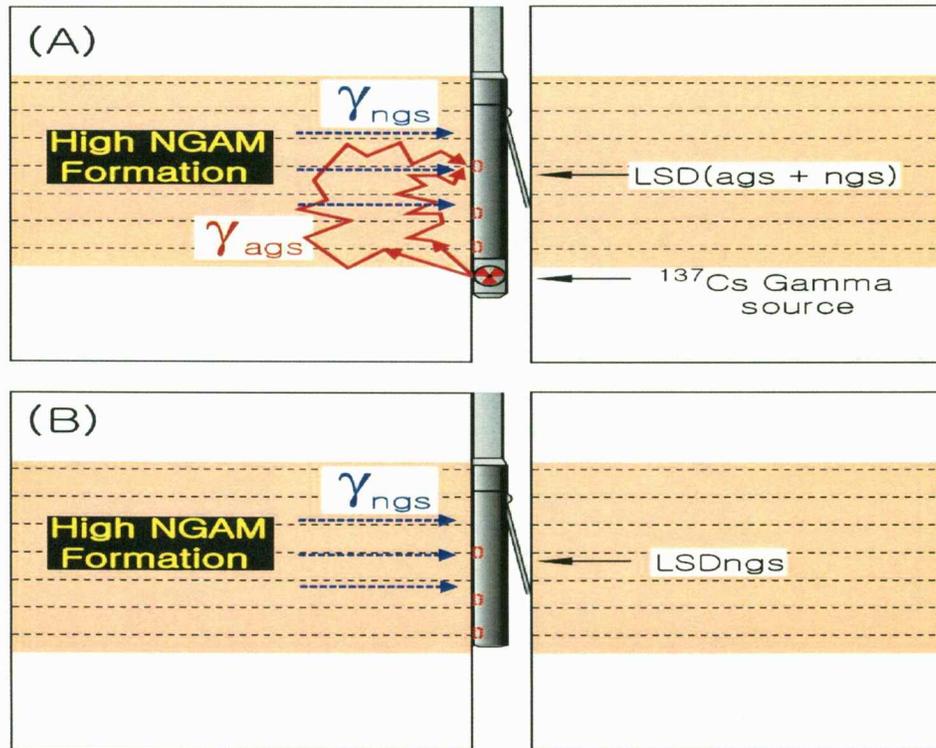
Fig. 2. Layout of gamma-gamma measurements with and without gamma source in high gamma formation. LSDags and LSDngs are detected together on LSD channel according to measurement with gamma source(A), while LSDngs is obtained by measurement without gamma source(B). LSDags is deduced by subtracting value measured at B from value measured at A according to following equation:

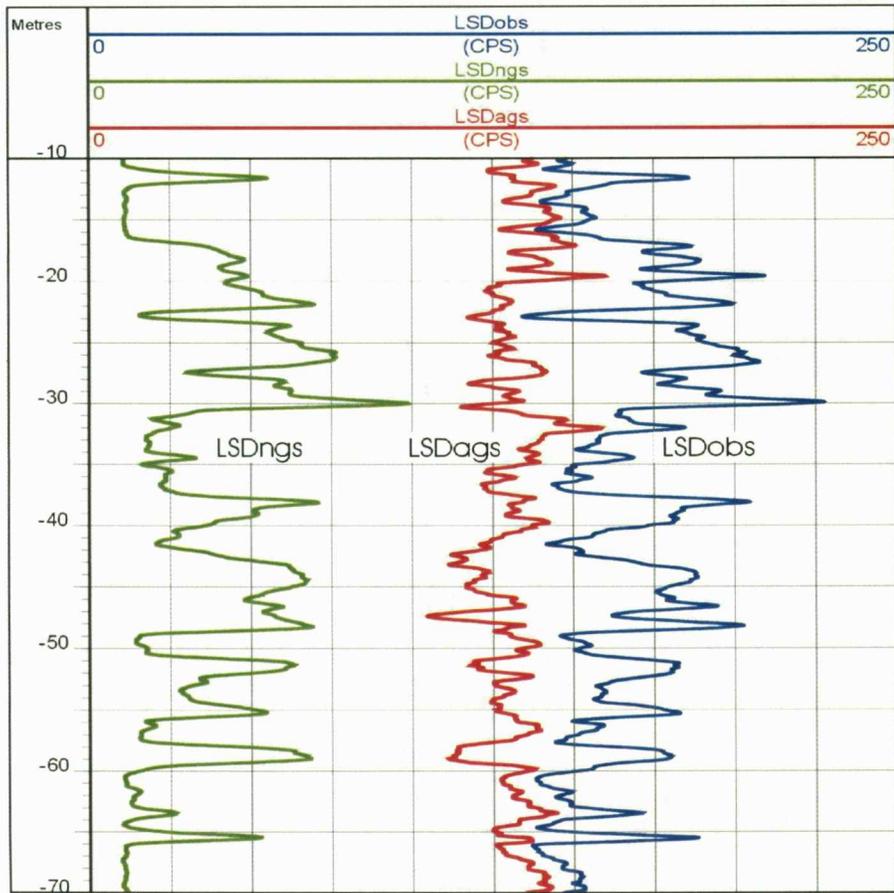 LSDags = LSD(ags + ngs) − LSDngs

Fig. 3. Comparison of gamma-gamma curves obtained before(LSDobs) and after(LSDags) natural gamma correction. LSDngs curve is also shown for comparison.
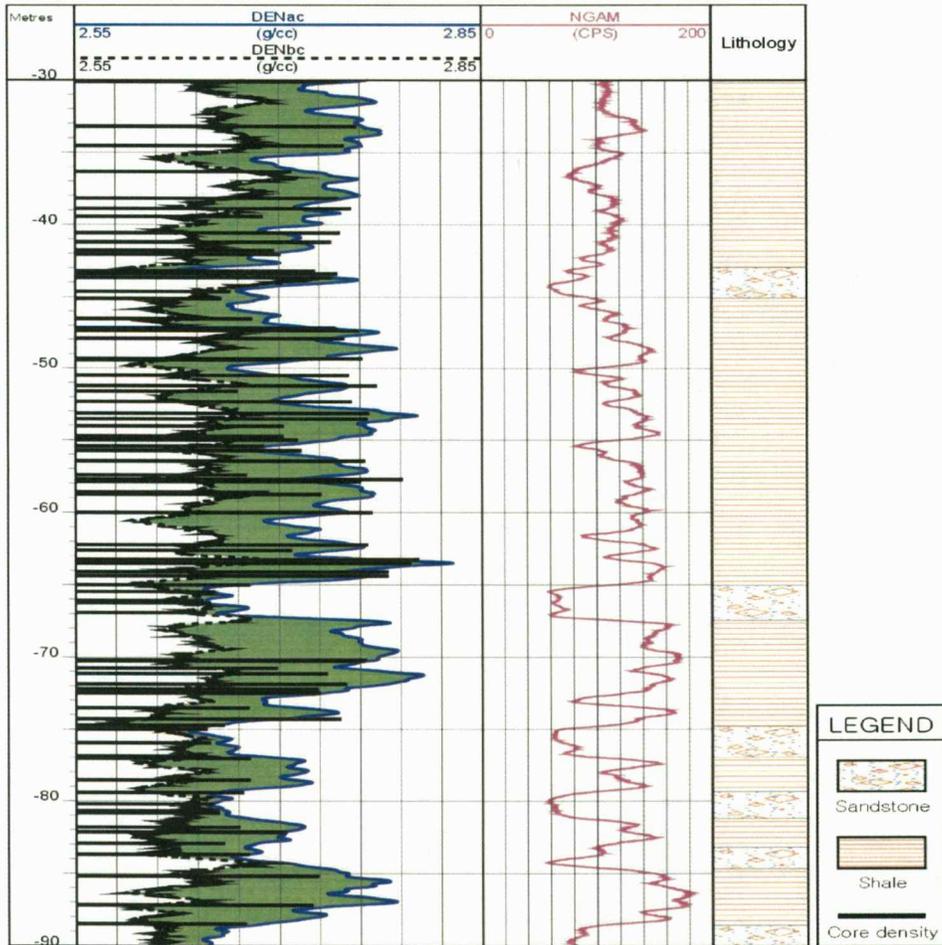
Fig. 4. Density curves delineated before (dotted) and after(solid) natural gamma correction in Cretaceous sedimentary rocks. Shaded area represents amount of density increase according to natural gamma correction.
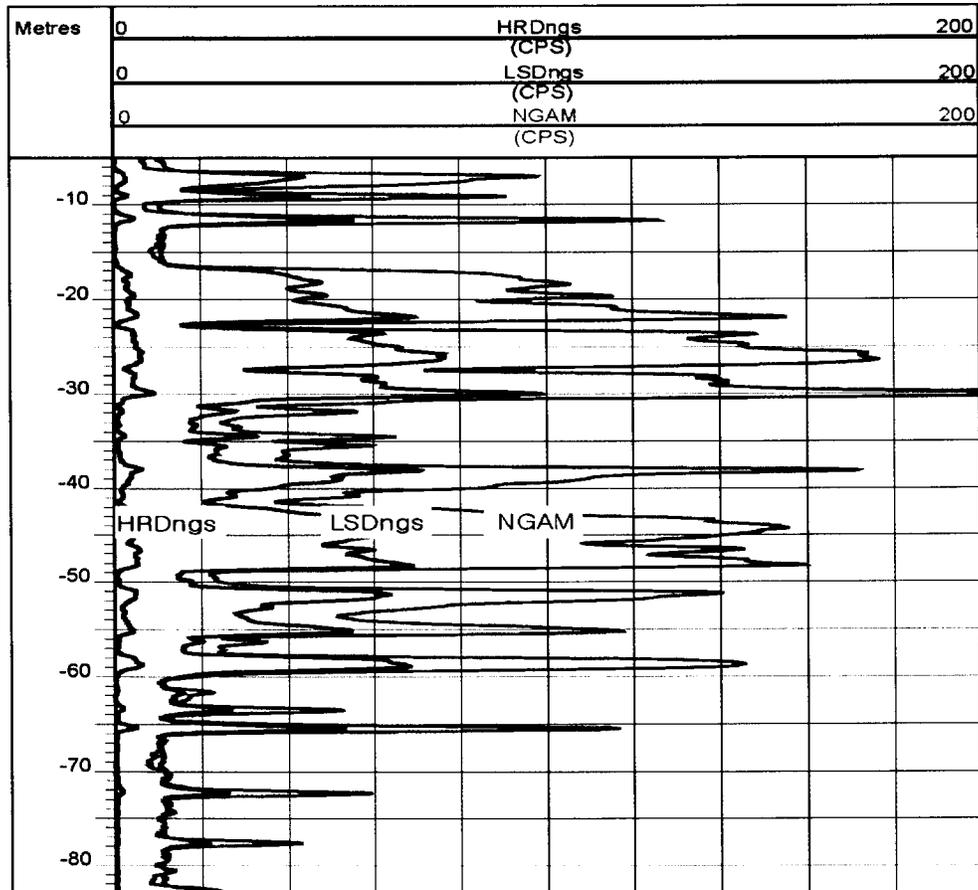
Metres	0	HRDngs	200
		(CPS)	
	0	LSDngs	200
		(CPS)	
	0	NGAM	200
		(CPS)	

Fig. 5. Comparison of natural gamma responses on LSD channel(LSDngs), HRD channel(HRDngs) and on NGAM chennel(NGAM). Natural gamma response on BRD channel(LSDbrd) is too small to be shown in this figure.
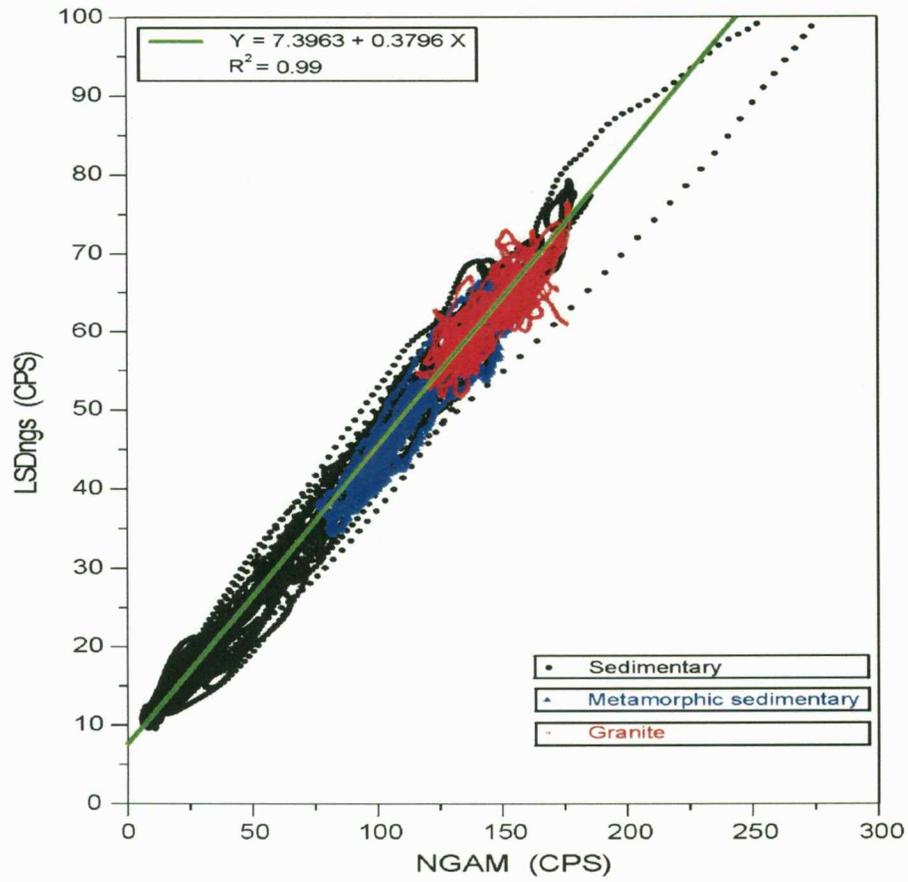
Fig. 6. Cross-plot result of LSDngs and NGAM values obtained from sedimentary, granite and metamorphic rocks in Korean peninsula. Correlation coefficient close to unity suggests that LSDngs can be determined accurately with numerical method.

that has been done by the numerical method shows nearly the same result as the result done by the source detach method. Fig. 7 is suggested to show that the two methods give the same result. Correspondingly, the numerical method is regarded as more efficient as compared to the source detach method, particularly in its being relative ease of application.
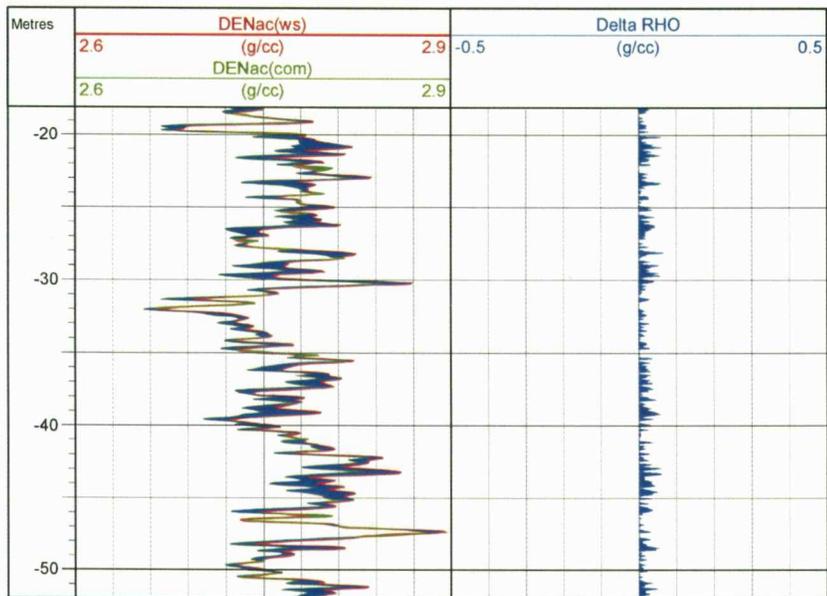

Figure 7. Comparison of density curves deduced from two kinds of correction methods.
It is shown that difference between two density curves is negligible.

Conclusions

The need for correction of the natural gamma effect in the density log is expected to become increasingly important, particularly with the trend of decrease in gamma source strength and corresponding increase in sensitivity of detectors. The need for correction was confirmed from the significant difference in density response between well log and core measurement done on Paleozoic to Mesozoic granite and sedimentary rocks in the Korean peninsula.

Two kinds of natural gamma correction have been adopted: correction based on the result of measurements with and without a gamma source, and correction based on a numerical calculation using the natural gamma response characteristics. The natural gamma response characteristics are deduced from the comparison between the natural gamma detector and the gamma-gamma detector in the density sonde. This study shows that natural gamma effect can be corrected accurately without troublesome extra work in field and laboratory by applying the numerical method. According to the natural gamma correction in log density, a fairly good correlation has been obtained between core and log densities.

The result strongly suggests the need of inserting a procedure for natural gamma correction in the routine calibration procedure in density log since we are frequently facing the need of natural gamma correction due to the decrease in gamma source strength and its corresponding increase in sensitivity of detectors nowadays.

Acknowledgement

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