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Magnetostratigraphy and paleopoles of the Kayenta Formation and the Tenney Canyon Tongue

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Key words: Pliensbachian magnetostratigraphy, Kayenta Formation, paleopole, J-1 cusp, North America apparent polar wander curve.

Abstract. The Kayenta Formation is the third in a series of stratigraphic units making up the Glen Canyon Group that were sampled along US Hwy 89 in southern Utah. The Kayenta is dominantly reversed polarity with a number of very short normal polarity intervals. Above the Kayenta and interbedded in the Navajo Sandstone is the Tenney Canyon Tongue of the Kayenta Formation. The lower half of the Tenney Canyon Tongue was also sampled and is dominantly normal polarity with three short reversed polarity intervals. The dominantly reversed magnetostratigraphy of the Kayenta appears to match that of Early Pliensbachian polarity interval "e-Pli R." The dominance of normal polarity of the Tenney Canyon Tongue suggests that the Tenney Canyon may have been deposited in the upper half of the Pliensbachian polarity interval "ePli-N." The suggested polarity matches indicate that the Kayenta and Tenney Canyon Tongue strata are 187–190 Ma in age. The paleopoles of the two units are statistically identical. The combined data of the Kayenta-Springdale-Whitmore Point show that the J-1 cusp terminated before the deposition of the Kayenta Formation. The North American continent/pole returned to its Late Triassic position during/after Springdale time, apparently along the same path used to reach the apex of the J-1 cusp.

INTRODUCTION

The age of the Kayenta Formation has been characterized as Late Hettangian to Pliensbachian based on sparse vertebrate fossils (Clark, Fastovsky, 1986). Padian (1989) concluded a Pliensbachian age for the Kayenta besed on the presence of *Scelidosaurus*. More recently, a study of the contained fish fauna led Milner *et al*. (2006) to conclude a Sinemurian to possible Pliensbachian age. However, as will be shown, the magnetostratigraphy indicates Early Pliensbachian ages for both the Kayenta Formation and the Tenney Canyon Tongue.

SAMPLING

The Kayenta Formation was sampled on the east side of Highway 89 (Fig. 1, site 3). The locality is 37.6°N, 112.5°W, just north of the Springdale Sandstone locality, but unlike the Springdale Sandstone and Whitmore Point strata, the sampled Kayenta exposures were a natural sloping outcrop. The entire 46 meters of the stratigraphic sequence were sampled by coring with a gasoline powered coring engine and oriented with a Brunton magnetic compass. The complete stratigraphic section was covered at a density of 0.2–0.3 m. Three hundred forty eight independently oriented cores were col-

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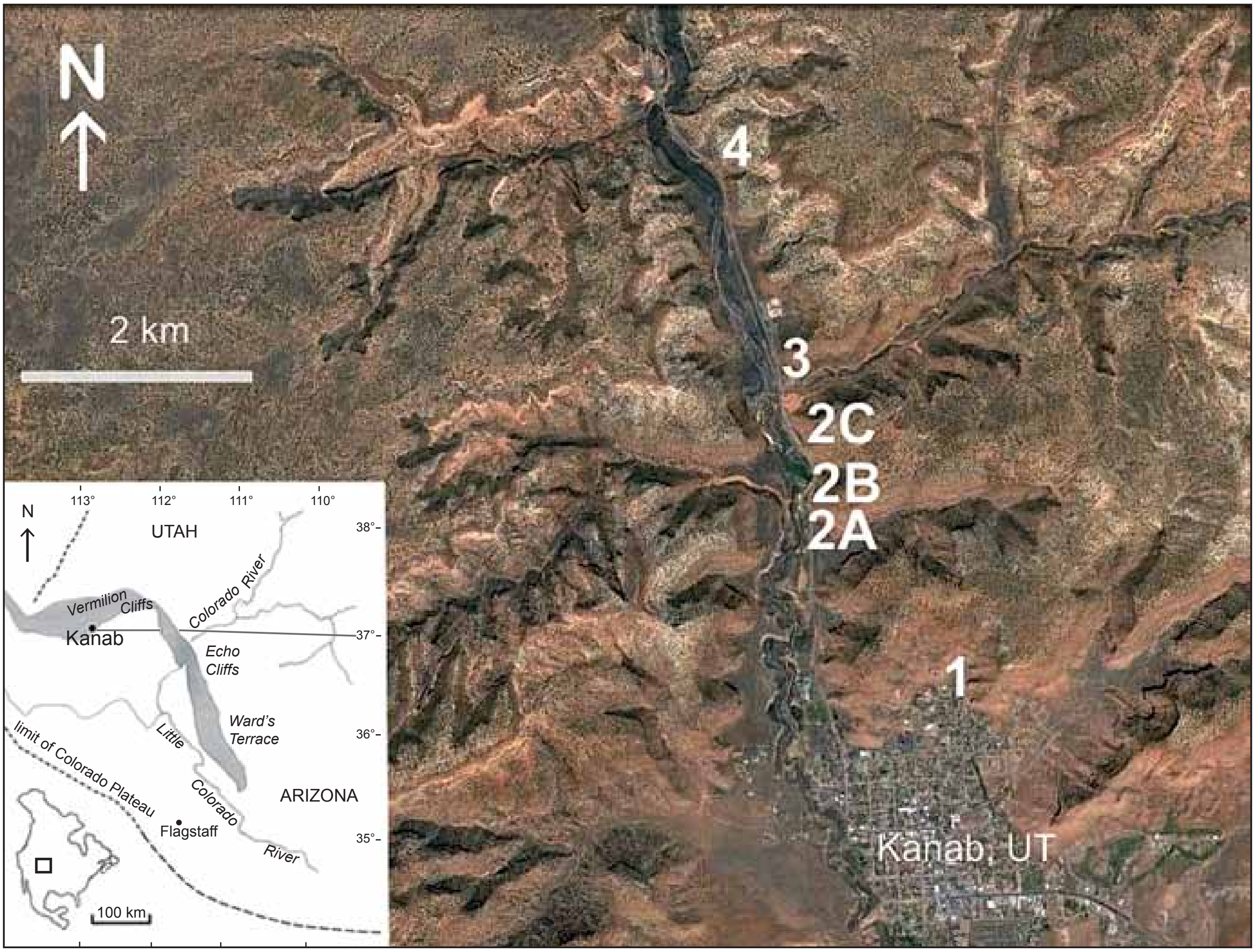

Fig. 1. Location map, showing the Kayenta sampling sites of this study

The Kayenta sample locality at Site 3; the Tenney Canyon Tongue was sampled in a roadcut at Site 4. Other localities are: 1 – Whitmore Point Member, and 2a – through 2c – Springdale Sandstone). Grey shading on inset map is outcrop area of Moenave Formation

lected in the Kayenta Formation through the 46.65 m of section; 125 samples were thermally demagnetized to 645°C, 25 of which were subsequently heated up through 670°C.

In addition to the Kayenta, the Tenney Canyon "tongue", a Kayenta-like lithology within the body of the lower Navajo Sandstone, was sampled a few miles further north on US Highway 89 (Fig. 1, site 4). The Tenney Canyon Tongue is a sequence of red-brown sandstone-siltstone enclosed within the lower part of the light colored Navajo Sandstone. Forty-six samples were collected from the lower half of the Tenney Canyon Tongue, spanning approximately 14 m. The upper part of the Tenney Canyon Tongue exposure comprises an additional 15 or more meters that were not sampled for lack of time.

MAGNETIC CHARACTERISTICS

The quality of the Kayenta data is much poorer than that of the other sampled formations of the Glen Canyon Group, primarily due to the fact that a natural exposure was sampled (*cf.* Steiner, 2014a, b – this volume). The magnetization of the Kayenta samples includes appreciable secondary magnetization from the present or recent geomagnetic fields. The samples are dominantly of reversed polarity below 580°C, but a number of stratigraphically separated intervals display short Jurassic normal polarity. All samples show unblocking temperatures below 580°C, as well as magnetizations held at higher temperatures of 610–640°C. The polarity of the lower temperature magnetization may change upon heating higher.

Magnetite probably holds the lower temperature magnetization, whereas the higher temperature remanence is probably held by hematite.

The Tenney Canyon Tongue had much less secondary magnetization than the Kayenta, undoubtedly because it was collected from a road cut exposure. The Tenney Canyon remanence is dominantly of normal polarity and is held at temperatures between 400–450°C and 600–610°C.

DATA

KAYENTA FORMATION

The natural remanent magnetization (NRM) of the Kayenta Formation forms half of a great circle between the present day field and a reversed polarity direction having a declination of about 190° (Fig. 2A). One hundred and twenty-five core samples from the Kayenta Formation were studied with thermal demagnetization, carried out in 18 or more steps from 150°C to either 645°C or as high as 670°C. Sample directions were calculated from lines fit to the data, using the method of Kirschvink (1980).

In the lower two meters of the section, nearly all samples contain a pronounced overprint of the recent geomagnetic field direction, and demagnetization only partially removed that secondary magnetization. This is also the portion of the outcrop with the least relief, that is, a gentle slope up to the main exposure. Once the more vertical portion of the outcrop was reached, directions better reflected the Jurassic geomagnetic field direction. However, appreciable secondary magnetization persists in many samples, even after demagnetization up through either 645°C to 670°C.

Stereographic projection of all demagnetized results is shown in Figure 3A. In summary, samples from twenty-two intervals display reversed polarity up to 580°C, and then display Early Jurassic normal polarity at higher temperatures, typically at 645°C. Generally these samples display Jurassic normal polarity at only one demagnetization temperature, and return to reversed or intermediate directions in high temperature steps.

Overall, the Kayenta Formation largely recorded reversed polarity, but 9 to 11 short intervals present short normal polarity intervals (Fig. 4). Among the demagnetized samples, 9 intervals display clear normal polarity and two additional intervals also may record normal polarity, but have larger uncertainties. These normal polarity intervals were obvious in NRM directions as well as demagnetized directions.

TENNEY CANYON TONGUE

A pilot group of Tenney Canyon samples was demagnetized from 150°C through 670°C, and the rest were demagnetized from 150° to 630°C. The NRM of the Tenney

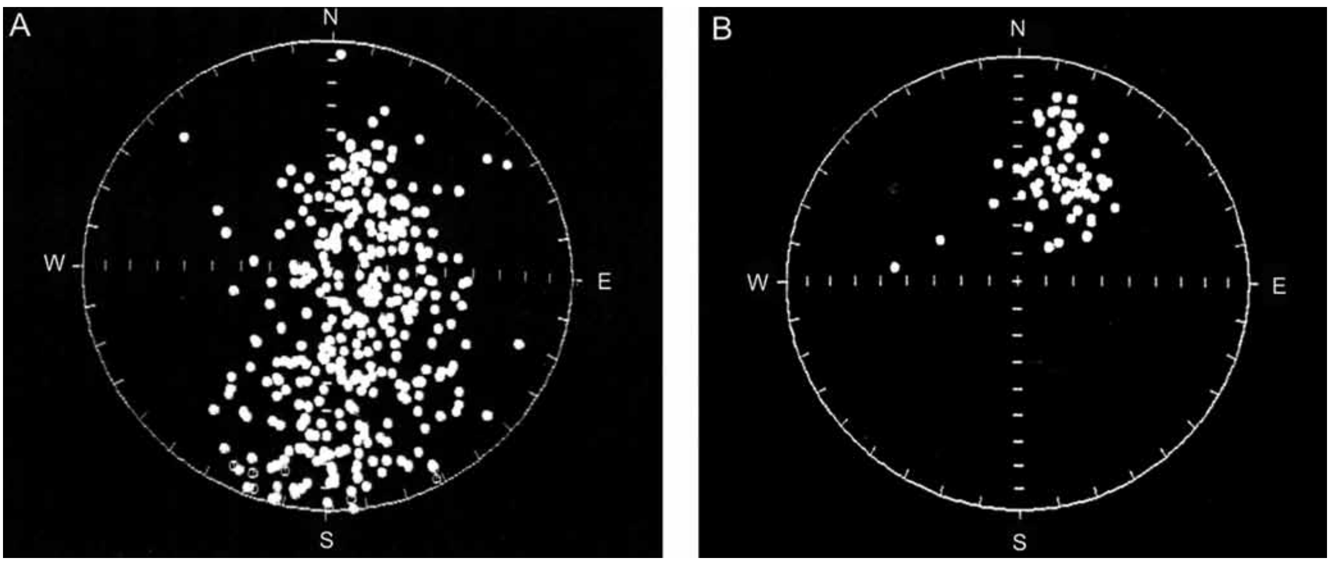

Fig. 2. Equal area stereographic plots of the natural remanent magnetization directions of the Kayenta Formation (A) and of the Tenney Canyon Tongue (B)

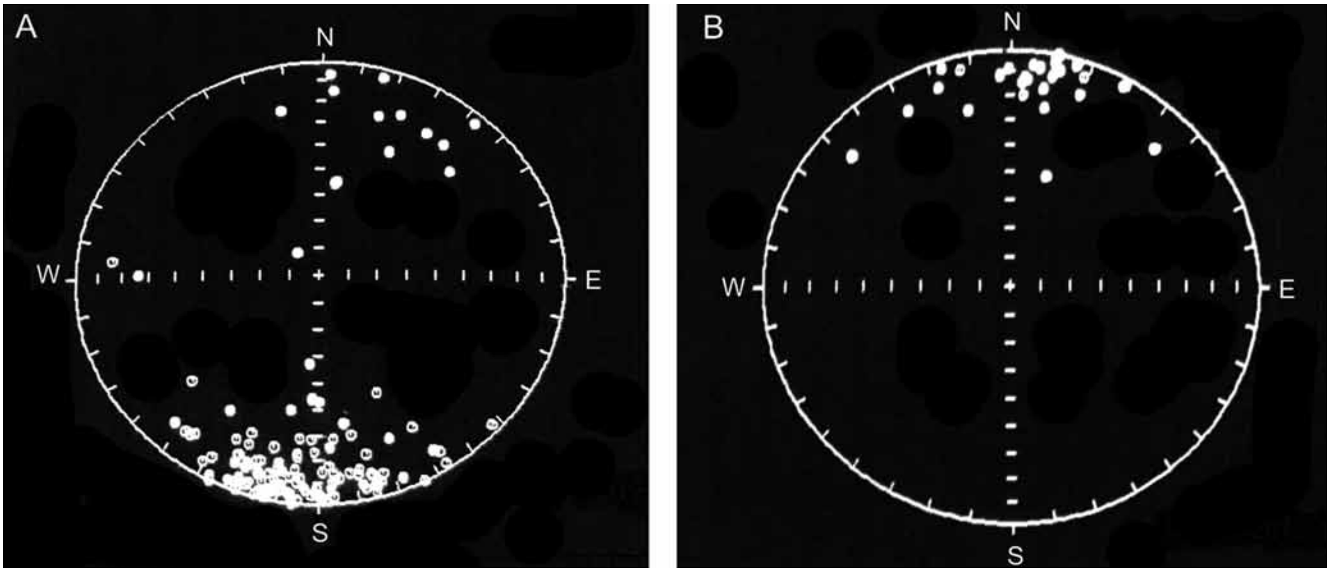

Fig. 3. Equal area stereographic plots of the demagnetized directions of the Kayenta Formation (A) and the Tenney Canyon Tongue (B)

Open circles are upper hemisphere directions; solid circles are lower hemisphere directions

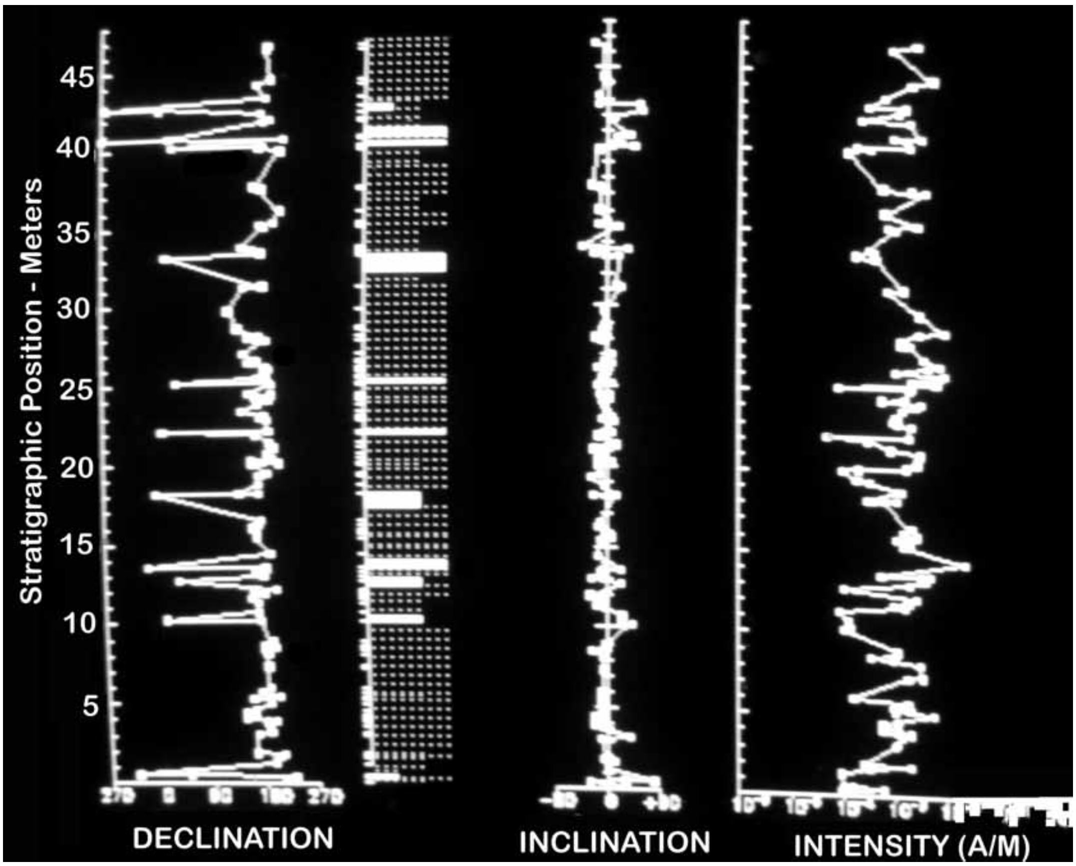

Fig. 4. Magnetostratigraphic plot of the Kayenta Formation

White is normal polarity; stippled is reversed polarity. The 1/3 and 2/3 column width fillings indicate degrees of uncertainty

Canyon Tongue clusters between the present day field at the site and a normal polarity Jurassic direction (approximately a declination of ~N15E and ~+20° inclination, Fig. 2B). Most of the Tenney Canyon samples exhibit normal polarity, but several display poorly defined reversed polarity, commonly after exhibiting a few low temperature steps of normal polarity directions. Four intervals exhibit clearly reversed polarity magnetization, and two others may also but the remanence is mixed normal and reverse directions that do not separate during demagnetization. A typical transit of such intermediate samples would be normal directions to 300°C and intermediate at higher demagnetization temperatures. All demagnetized directions of the Tenney Canyon Tongue samples are shown in Figure 3B.

MAGNETOSTRATIGRAPHY

Even after thermal demagnetization, the magnetization of much of the Kayenta Formation retains some amount of secondary magnetization. The strata display largely reversed polarity directions (Fig. 4). Eleven sampled intervals interrupt the dominant reversed polarity of the 46 meters of Kayenta strata by displaying normal polarity. These are exhibited below 580ºC and appear to represent very short normal polarity intervals. These short intervals are fairly evenly distributed throughout the section. Therefore, despite the dominance of reversed polarity, the geomagnetic field polarity was not solely reversed during deposition of this Kayenta sequence.

The reversed polarity signature with, short intervals of normal polarity (Fig. 4) bears a resemblance to the magnetic polarity sequence of the Early Pliensbachian, “e Pli-R” of the recent geomagnetic polarity timescale (Fig. 5 and fig. 26.10 of Gradstein *et al*., 2012). This sequence was derived from the Carixian (Lower Pleinsbachian) of the Paris Basin core (Moreau *et al*., 2002). The sequence “e Pli-R” is one and one half million years of dominantly reversed polarity, with six relatively very short normal polarity intervals interspersed within it (Fig. 5). Most of the normal polarity intervals within “e Pli-R” appear to be in the range of 10,000 to 100,000 years (Gradstein *et al*., 2012, and Fig. 4). Comparison of this Kayenta sequence to the Gradstein *et al*. (2012) timescale may suggest that these Kayenta strata span 1.5 m.y.

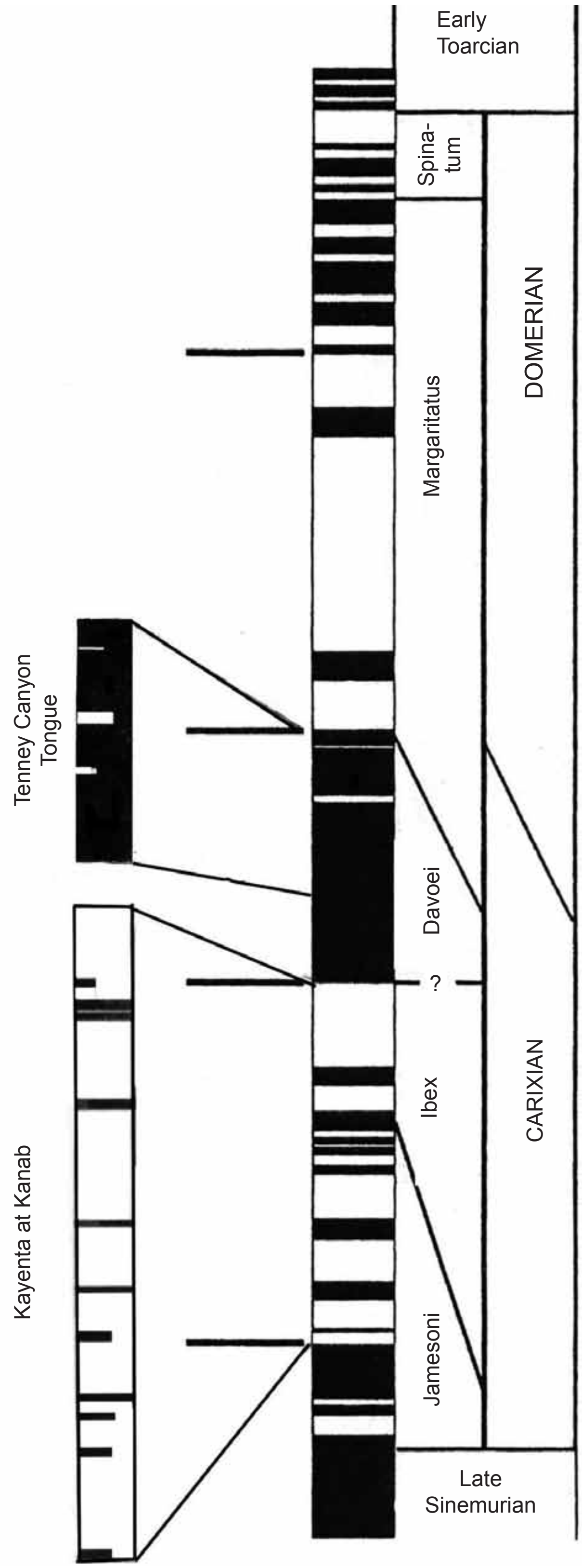

Fig. 5. Comparison of the Kayenta and Tenney Canyon magnetostratigraphies to that of the Paris Basin (Moreau *et al*., 2002)

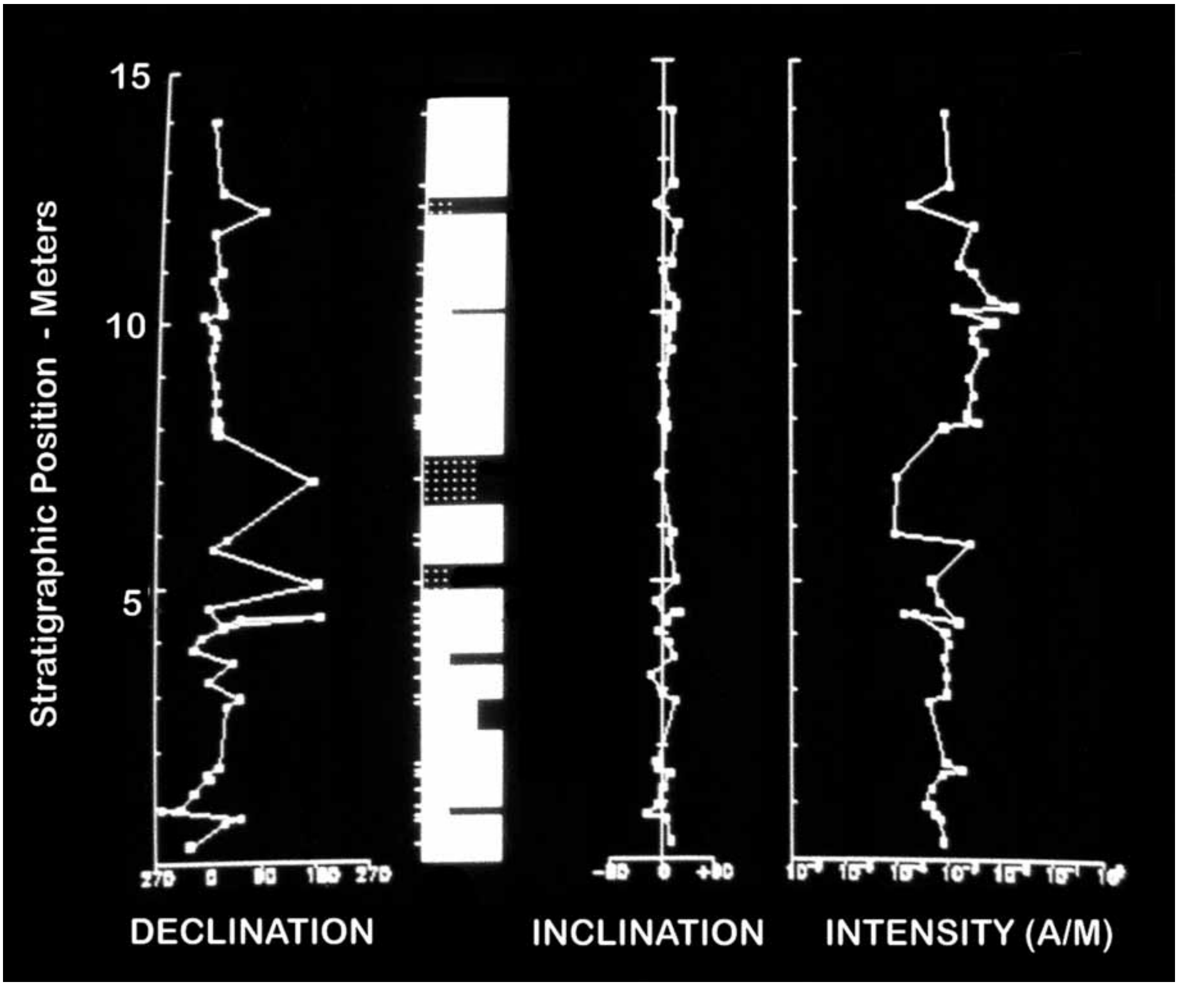

Fig. 6. Magnetostratigraphic plot of the Tenney Canyon Tongue

White is normal polarity; stippled is reversed polarity. The 1/3 and 2/3 column width fillings indicate degrees of uncertainty

The Tenney Canyon Tongue possesses a magnetostratigraphy that is dominantly normal polarity interrupted by four short, poorly defined, reversed polarity intervals. Normal polarity directions dominate the demagnetized data, and seem to overprint the samples of reversed polarity, such that fully reversed demagnetized directions are not observed. This dominance of normal polarity with very short, reversed polarity intervals (Fig. 6) suggests that the sampled lower half of the Tenney Canyon Tongue may represent the upper Pliensbachian interval "lt Pli-N" and its preceding N interval "M Pli N (Fig. 5 and fig. 26.10 of Gradstein *et al*., 2012).

PALEOPOLE POSITIONS

A large amount of the secondary magnetization in the Kayenta Formation of this study could not be removed; for this reason, a great many samples are unsuitable for paleopole calculation. The successful removal of secondary magnetization is judged by the linearity of the decay of magnetization towards the origin of orthogonal axes plots upon successive thermal demagnetization steps. Of the 125 Kayenta samples demagnetized in this study, 50 exhibited this linear decay. A paleomagnetic pole was calculated from these 50 sample directions and is listed in Table 1.

Table 1

Paleopoles calculated from this study compared to previous studies

Formation	Study	POLE				
		E Long	N Lat	α_{95}	N	k
Kayenta	this study	56.8 E	57.9 N	4.0	50	19.8
Kayenta	Bazard, Butler (1991)	66.6 E	59.0 N	2.4	23	155.0
Kayenta	Steiner, Helsley (1974)	74.4 E	61.9 N	6.8	105	81.0
Tenney Canyon Tongue	this study	54.5 E	55.3 N	4.0	30	18.3
Chinle Late Triassic Mean	Steiner, Lucas (2000)	66.6 E	57.2 N	2.1	4	2635.2

A paleopole calculated from the samples of the Tenney Canyon Tongue is essentially the same as the Kayenta pole (Table 1). Table 1 compares the Kayenta and Tenney Canyon poles with the mean Upper Triassic pole from the Chinle Group (Steiner, Lucas, 2000). Unfortunately, the relative movements are small enough that all confidence limits overlap. Nevertheless, it appears that the J-1 cusp is formed by the poles from the Whitmore Point and the Springdale Sandstone. By Kayenta time, the apparent polar wander curve has left the J-1 cusp behind and returns along the same path that it took to the cusp. Poles of the Kayenta and Tenney Canyon are statistically indistinguishable and overlap the confidence limits of the mean Late Triassic Chinle pole.

DISCUSSION AND CONCLUSIONS

The Kayenta Formation and the Tenney Canyon Tongue of the Kayenta give statistically identical paleopoles (Table 1). The paleopole comparison is compatible with the concept of the Tenney Canyon being a tongue of the Kayenta Formation, enclosed within the Navajo Formation. The paleopole similarity suggests similar times of deposition and remanence acquisition.

The Kayenta Formation has been studied twice previously, first by Steiner and Helsley (1974) and then by Bazard and Butler (1991). Bazard and Butler (1991) studied a total of 100 m of a 400 m section of the Kayenta along Wards Terrace. They observed six polarity intervals in their study (their table 3). However, the relative stratigraphic information of their three sites was not reported, and thus it is unknown whether they sampled the same stratigraphic and polarity interval more than once. They nevertheless observed polarity intervals of 10s of meters thickness, entirely different from the Kayenta Formation near Kanab.

The polarity of the Kayenta at Kanab also is completely different from the Kayenta near Moab, Utah (Steiner, Helsley, 1974). The portion of the Kayenta sampled at Moab exhibited eight normal and reversed polarity intervals in stratigraphic succession, with average thicknesses of ~8 meters each. Moreover, the formation only 100 m of the formation was sampled. The large number of sequential quasi-lengthy polarity reversals recorded by the Kayenta Formation near Moab and Wards Terrace appear to indicate that the Highway 89 Kayenta was deposited and/or magnetized at a different time than the other two exposures of the Kayenta Formation. Obviously more study of the Kayenta is needed, for it appears to be complexly time-transgressive. All that can be said at this point is that the Kayenta along Hwy 89 is not time-equivalent to the Kayenta at Moab or Wards Terrace.

The lower portion of the Glen Canyon Group records the J-1 cusp of the North American apparent polar wander curve. The most eastward position of the cusp may have occurred between the deposition of the Whitmore Point and Springdale Sandstone. The North American paleopole position then returns to a position close to the Late Triassic Chinle pole location.

The Kayenta at Moab and at Wards Terrace indicate multiple reversals; the Kayenta at Kanab indicates very rapid reversals. The Kayenta at Kanab appears to be dissimilar to the Kayenta at Moab or the Kayenta at Wards Terrace.

The Springdale Sandstone should not be grouped into the Kayenta Formation (Lucas, Tanner, 2006) because of the different positions of the paleopoles of these superposed formations. Although not statistically significant at the 95% confidence level, the Springdale pole is not as similar to the Kayenta pole as is the Tenney Canyon pole. The fact that the Springdale pole is statistically the same as that of the Moenave Formation, and the Kayenta Formation paleopole appears to be a return to the Late Triassic pole position also argues against associating the Springdale Sandstone with the Kayenta Formation.

In conclusion, comparison of the Kayenta paleopole and magnetostratigraphy of this study to previous Kayenta studies does not indicate similar times of deposition (Table 1). The two earlier determined poles positions are statistically identical to one another. They are notably farther north and west than that of the Kayenta from this study or of the Tenney Canyon Tongue. Further the magnetostratigraphies of the earlier studies do not resemble that of the present study. These data suggest that the Kayenta Formation is much more complex than we know, or that the strata at Kanab that are called Kayenta are a different formation than Kayenta elsewhere.

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