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Age of Lower Jurassic Springdale Sandstone of Southwestern Utah from its Magnetic Polarity Sequence

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Abstract. The Springdale Sandstone records a large number of reversals of the geomagnetic field. Forty-three percent of the 60 m section investigated showed 25 polarity intervals. These frequent reversals follow the nearly constant normal polarity of the underlying Whitmore Point strata. Comparison of the reversal sequence of the Springdale Sandstone with a core from the Paris Basin suggests that the Springdale Sandstone spans an interval extending possibly from as early as late Hettangian to early-mid Sinemurian time. The paleomagnetic pole calculated from Springdale paleomagnetic directions is statistically identical to that of the underlying Whitmore Point Member of the Moenave Formation, and considerably different from that of the overlying Kayenta Formation. This similarity suggests that the Springdale Sandstone should be retained as a member of the Moenave Formation, not considered part of the Kayenta Formation.

INTRODUCTION AND AGE

The Springdale Sandstone is commonly a massive, cliff-forming sandstone. But at Kanab, Utah (Fig. 1), it is a series of five thickly-bedded sandstone intervals, intercalated with siltstones and mudstones that are very like those of the Whitmore Point Member. A disconformity separates it from the Whitmore Point Member of the Moenave Formation (Fig. 2). Springdale strata were sampled in a series of roadcuts and exposures left by the routing of Highway 89 in southern Utah (Fig. 1, sites 2A–C). At this locality, the formation is nearly 60 m thick, close to the thickest reported extent of 67 m.

The Springdale Sandstone had been considered a member of the Moenave Formation (Harshbarger *et al*., 1957; Wilson, 1967; Peterson, Pipiringos, 1979). Alternatively, the formation has been proposed to be part of the overlying Kayenta Formation (Lewis *et al*., 1961; Wilson, 1974; Clemmensen *et al*., 1989; Marzolf, 1994; Lucas, Tanner, 2006). A number of investigators have speculated that a hiatus exists between the Springdale Sandstone and the underlying Moenave Formation (see Lucas, Tanner, 2014). Indeed, a prominent scour surface exists between the uppermost Whitmore Point beds of the Moenave Formation and the overlying Springdale Sandstone (Fig. 2). Paleopoles above and below this surface will be compared to estimate whether a large amount of time is missing.

Definitive data have not been published for the age of the Springdale Sandstone. However, as will be shown, the contained magnetic polarity pattern suggests that it spans a portion of the Sinemurian and potentially some of the Hettangian.

SAMPLING

Three superposed sections were sampled north of Kanab, UT (37.0 N, 247.5 E) along U.S. Hwy 89 (Fig. 1). The quality of the exposures dictated the number of samples obtained. Approximately 33 m of strata were sampled in the three segments. The 33 m represent about 55% of the entire Springdale

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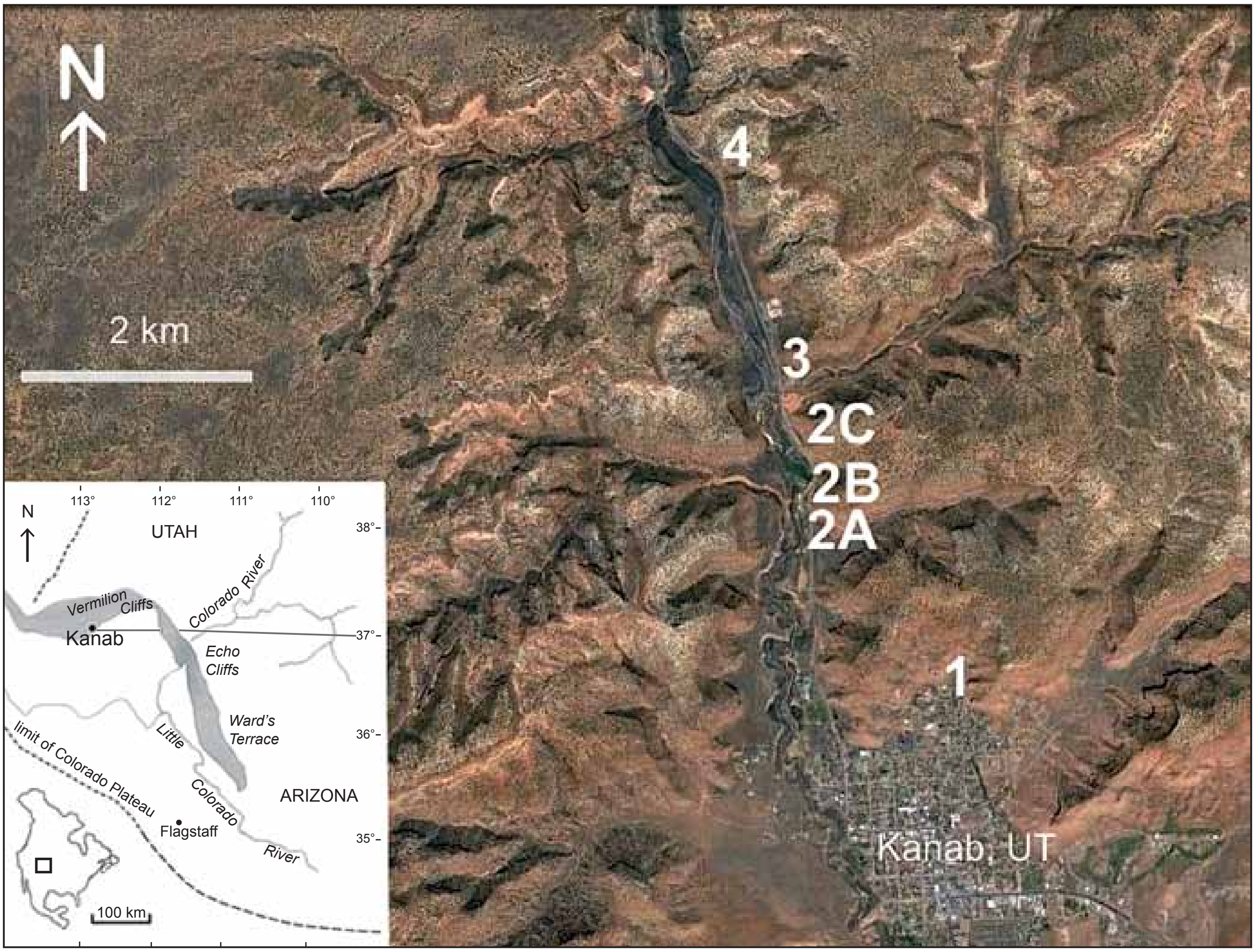

Fig. 1. Location map, showing the sampling sites near Kanab, UT

Locations 2A, 2B, 2C are the Springdale Sandstone sampling sites. The site in the lowest part of the formation is 2A and the highest, 2C. Other localities are: 1 – Whitmore Point Member; 3 – Kayenta Formation; 4 – Tenney Canyon Tongue (of the Kayenta Formation). Grey shading on inset map is outcrop area of Moenave Formation

Sandstone at this locality. Stratal dip here is 3° to the north (3° towards 10°NE). Sampling for both magnetostratigraphy and paleopole studies was done in approximately 0.3-meter intervals in each of the three exposures. The lower portion of the Springdale Sandstone was sampled in a large hill slope east of Highway 89, just above the lowest thick, massive cliff-forming sandstone, 9 m above the contact with the Whitmore Point Member of the Moenave Formation. Sampling of this lower section spanned 8.2 m. Skipping about 5 m, we then sampled 6.2 m from outcrop and some road-cut exposures of mudstone/siltstone intercalations within the thick sandstones. Finally, from roadcuts along Highway 89, we sampled the upper 13 m of the Springdale Sandstone, reaching the top of the Springdale at its contact with the Kayenta Formation.

All samples were obtained by coring with a hand-held gasoline-powered coring engine, outfitted with a 2.5 cm diameter diamond core bit. Cores were oriented with a Brunton compass attached to a core sleeve. The stratigraphic positions were measured in detail and sample numbers reflect their position in the stratigraphic sequence relative to the base of the Springdale Sandstone. Two hundred fifty-nine samples were obtained from the Springdale Sandstone.

Unfortunately, laboratory problems prevented the demagnetization of a large number of Springdale samples, but

Fig. 2. Disconformity scour surface at the contact between the Whitmore Point and the Springdale Sandstone (arrowed)

those that were studied tell a compelling story. The remainder will be studied in the future.

MAGNETIC CHARACTERISTICS

The magnetic mineralogy of the Springdale samples was identical to that of the Whitmore Point samples, in that both have a dominant magnetization carrier with <580°C unblocking temperatures, as well as another carrier that has unblocking temperatures of >600°C. This means that maghemite or magnetite (<580°C) is present in these red sedimentary rocks. Since magnetite/maghemite cannot be generated in a weathering environment, they must have been deposited with the sediment that makes up the Springdale Sandstone. Hence, the primary remanence, carried by magnetite/maghemite, is a remanence that had to have been acquired near the time of deposition. Above ~600°C, another remanence, commonly of the opposite polarity, is held by hematite. The timing of the formation of the hematitic remanence will be discussed further below.

DATA

The natural remanent magnetization (NRM) was measured for all samples collected (Fig. 3). Fifty two samples were collected from the lower Springdale Sandstone in the siltstone and mudstone lithologies between sandstones. Lower Springdale samples displayed normal or reversed polarity in roughly antipodal directions, however, a greater percentage were of normal polarity.

From the middle portion of the Springdale Sandstone, 68 samples were collected. Reversed polarity dominated, along with some recent geomagnetic field directions. The intervals that may have been normal polarity were all of very short interval lengths.

Eighty-two samples were taken from the upper third of the Springdale Sandstone, facilitated by its essentially complete exposure in roadcuts. Initially measured directions again displayed both normal and reversed polarity, with a larger number of samples with reversed polarity directions.

The difference in magnetization preservation between the exposures from the hillslope and the road cut were readily apparent in the greater number of samples exhibiting

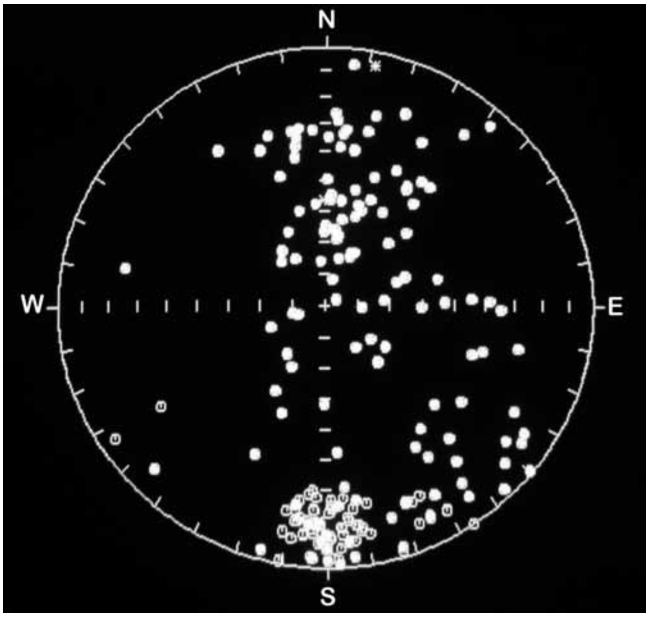

Fig. 3. Directions of Natural Remanent Magnetization (NRM) Asterisks denote the present and axial dipole field directions

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

NRM directions near the axial dipole and present day geomagnetic field directions. It was also apparent in the responses to thermal demagnetization and in the final definition of the magnetic vectors in these samples.

An initial thirty two samples from all three groups were thermally demagnetized in 18 steps, beginning at 200°C and continuing through 655°C. Alternating field demagnetization was not used because of its lack of success in the underlying Whitmore Point samples and in redbed strata in general. Directions from all thermal demagnetization experiments were subjected to principal component analysis (Kirschvink, 1980).

RESULTS

Temperatures at which the Springdale remanence is held and lost are similar to the Whitmore Point strata (Steiner, 2014 – this volume). The dominant unblocking temperatures are between 400° to 580°C, and between 580° to 630–640°C. This implies magnetization carriers of Ti-magnetite-maghemite (Curie temperature of ~580°C) for the unblocking temperatures below 580°C. Hematite (Neel temperature in this sequence 640–650°C) probably carries the remanence above 600°C. Nearly all of the samples exhibit two magnetization carriers. That these are the same in both the Whitmore Point and Springdale strata suggests the same lithologic source for both lithosomes. Moreover, the same reddish purple coloration is present in both, a coloration commonly associated with a magnetite remanence carrier in red-bed sedimentary rocks.

Below 580°C, polarity was clearly evident within each sample. The sample in the upper left of Figure 4 shows the response from one well-defined normal polarity sample 580°C. The other three illustrations in Figure 4 display the demagnetization of typical reversed polarity samples.

The exhibition of two remanences of opposite polarities, held at different unblocking temperatures in the same sample, indicates that the field was reversing frequently enough that the second remanence (>600°C) could be acquired by chemical weathering (forming hematite in the sediment) in the polarity opposite to that of deposition. The magnetite-maghemite carrier indicates that the primary magnetization of the Springdale Sandstone is a depositional/post-depositional remanent magnetization, because red sedimentary rock conditions would not permit magnetite to form.

The higher temperature remanence is sometimes poorly defined. This may mean that the field was reversing rapidly enough that the hematite carrying the second remanence did not have time to fully form in the polarity in which the hematite growth began before the polarity changed again.

According to the most recent timescale (Gradstein *et al.*, 2012), the reversal frequency of the lower two-thirds of the Sinemurian had 12 polarity intervals in 5 m.y; this is on average, one reversal every ~417,000 yrs. However, the Paris Basin section discussed in the magnetostratigraphy section indicates many more reversals than the Gradstein timescale. Thus, the higher temperature remanence in these samples may have been imparted much more quickly than within ~400,000 yrs of deposition. While this is not surprising, it is one solid numerical constraint on secondary remanence in red sedimentary rocks. The time may have been less, because the Springdale magnetic signature suggests that there probably are more polarity changes than recorded by the Gradstein *et al*. (2012) timescale. In fact the Paris Basin (Yang *et al*., 1996) section suggests 30 polarity changes in the uppermost Hettangian through Lower Sinemurian. At that reversal rate, reversals were occurring every 125,000 yrs on average. This suggests hematite formation and remanence acquisition within 125,000 years after sediment deposition.

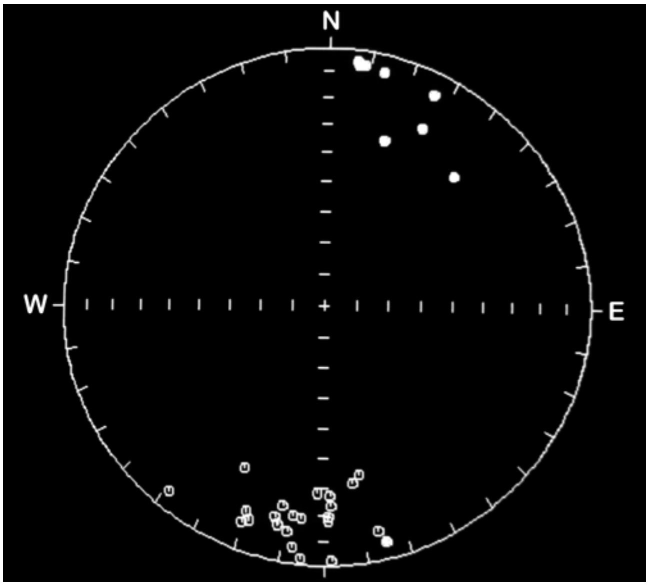

Fig. 4. Demagnetized directions in equal area stereographic projection

Open circles – upper hemisphere (reversed polarity); solid circles – lower hemisphere (normal polarity)

MAGNETOSTRATIGRAPHY

The demagnetized directions from the three sampled sections are displayed in Figure 4. However, the number of polarity changes during Springdale time is not well represented by the demagnetized data because of the many samples that have not yet been demagnetized. But even before demagnetization experiments, polarity was readily apparent in the NRM directions.

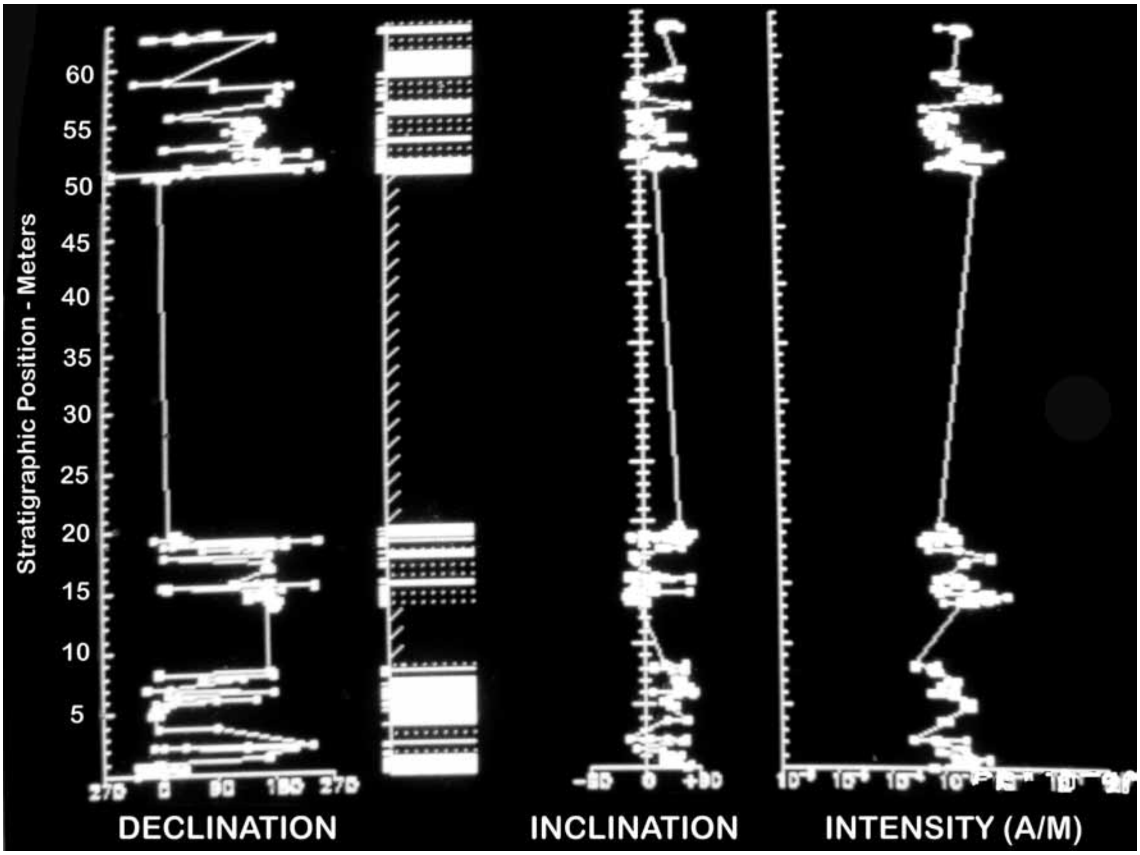

Fig. 5. Magnetostratigraphic polarity sequence, showing the NRM directions in stratigraphic sequence. Normal polarity is white; reversed is designated by horizontal dots

Figure 5 shows the magnetostratigraphic sequence of all samples in their NRM data. The sampled portions of the Springdale Sandstone record a minimum of 25 polarity intervals. This record of 25 intervals of normal and reversed polarity is from only 43% of the Springdale beds. A continuous core in the Paris Basin yielded a magnetostratigraphic sequence spanning the Hettangian and Sinemurian (Fig. 6) (Yang *et al*., 1996). These data show very frequent changes of polarity during the latest Hettangian through Early to Middle Sinemurian. The magnetostratigraphic data from the Springdale Sandstone corroborate this rapidly reversing pattern for the (potentially) uppermost Hettangian through Lower Sinemurian, suggesting many more polarity intervals probably exist in the unsampled portions of the Springdale Sandstone.

Using the underlying largely constant normal polarity of the Whitmore Point as reference, the frequent polarity changes through the Springdale stratigraphic section suggest that Springdale Sandstone deposition at Kanab corresponds approximately to the uppermost Hettangian through Lower Sinemurian, and that the gap in time between the two units (Fig. 2) is small, possibly a few thousand years at best.

POLE POSITION

A paleopole for the Springdale Sandstone was calculated from the 32 demagnetized samples. However, four of the 32 samples had appreciable unremoved secondary magnetization. Hence their demagnetized directions gave poor definition of their original magnetizations. The pole was recalculated without these four sample directions. Both pole calculations are listed in Table 1.

Paleopoles above and below the disconformity/unconformity surface between the Whitmore Point Member and the Springdale Sandstone (Fig. 2) are quite similar, and are statistically the same paleopole. The similarity of the two poles for the strata above and below that surface suggests that very little time is missing between the Springdale Sandstone and the Whitmore Point Member. Therefore, that disconformity surface cannot represent much time. This comparison demonstrates that appreciable relief on a disconformity surface (Fig. 2) does not necessarily mean that significant time is missing or that significant plate motion occurred in the interim.

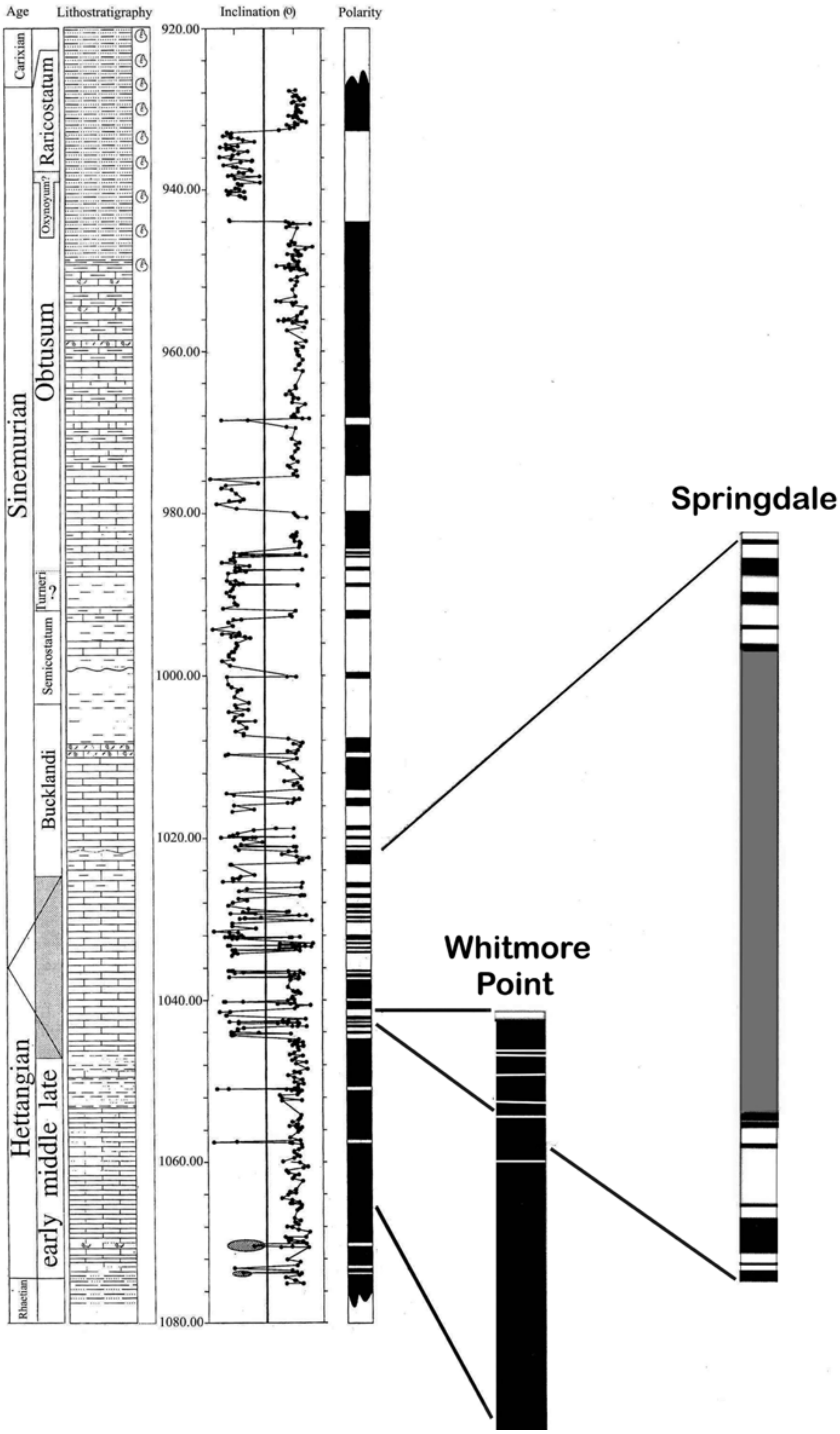

Fig. 6. Comparison between the paleomagnetic polarity from the Hettangian and Sinemurian of the Paris Basin (after Young *et al.*, 1996) and the Whitmore Point and Springdale magnetostratigraphy

Lithology and stratigraphy after Young *et al.* (1996) and earlier papers cited therein. Black is normal polarity; white is reversed polarity. Gray in polarity column indicates unsampled strata; gray in age column indicates unknown age

Table 1

Paleopoles calculated for Springdale and Whitmore Point samples

Formation	Pole				
	E Long	N Lat	α_{95}	N	k
Springdale All	48.4	60.2	5.3	32	24.007
Springdale Sel	51.6	60.6	4.3	28	41.737
Whitmore All	60.4	55.7	3.1	81	16.362
Whitmore Sel	47.9	58.3	3.6	44	21.967

N – number samples; α_{95} – the 95% confidence limit; k – a precision parameter; Sel – least overprinted samples

In addition, the polarity patterns of the Whitmore Point and Springdale correspond to those from the continuous section of the Paris Basin (Yang *et al*., 1996) with seemingly only a small portion of the reversal sequence missing. The similarity of the Whitmore Point-Springdale reversal sequence to that of the Paris Basin suggests that the Early Sinemurian polarity sequence depicted by the Gradstein *et al*. (2012, fig. 26.10) timescale does not represent a true rendition of the geomagnetic polarity sequence for the Early Sinemurian.

It has been argued that the Springdale Sandstone should be considered a member of the Kayenta Formation, rather than a member of the Moenave Formation (Lucas, Tanner, 2006). The similarity of paleopole positions also argues that the Springdale Sandstone is more closely associated with the Whitmore Point Member of the Moenave Formation than with the Kayenta Formation. On fresh outcrop, the color of the Springdale and Whitmore Point Members are exceedingly similar. The two have the same purple-pink color, the same dual magnetization carriers, and similar paleopole positions. These similarities strongly suggest that the Springdale Sandstone should be retained as part of the Moenave Formation, or perhaps treated as a separate formation.

CONCLUSIONS

The Springdale Sandstone recorded a large number of reversals of the geomagnetic field. The frequently reversing polarity of the Springdale Sandstone stands in stark contrast to the dominantly single polarity of the underlying Whitmore Point Member. Comparison to the most recent timescale (Gradstein *et al*., 2012) and to the continuous core from the Paris Basin (Yang *et al*., 1996) shows that the polarity patterns in the Whitmore Point and Springdale strata correspond to the polarity pattern found in the Paris Basin for Hettangian and early half of Sinemurian time, and not to the Gradstein *et al*. (2012) timescale. The magnetic directions and paleopole position for the Springdale are very similar to those of the Whitmore Point. Despite conclusions to the contrary (Lucas, Tanner, 2006) the Springdale Sandstone shows greater affinity with the Whitmore Point Member in lithology and in paleopole position than it does with the Kayenta Formation.

Finally, despite considerable relief on the erosion surface that separates the Whitmore Point Member from the Springdale Sandstone (Fig. 2) the similarity of pole positions of the two stratigraphic units indicates that that surface represents little elapsed time.

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