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The orientation of early medieval churches in England

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Early medieval (seventh to early twelfth century) churches in central and southern England display an average alignment which is close to true east ($\bar{x} = 88°$T, $n = 183$). This near liturgically-correct orientation can only have been achieved by astronomical means. Sixty-two per cent of the measured buildings lie within the range 80°–100°T; such relatively minor discrepancies may be due largely to foundation setting-out errors. A considerable proportion of those churches which deviate significantly from true east were probably established on sites which were constrained by older structures in towns, and perhaps by the natural topography in rural areas.

Introduction

Christian churches in western Europe, with notable exceptions, chiefly in Italy, are broadly in alignment with east.[1] It has been asserted that the many buildings which are not oriented *sensu stricto* are aligned with sunrise on the feast day of the saint to whom they were originally dedicated,[2] one of the solstice days,[3] the day the foundations were prepared[4] or on 1 May.[5] Rodwell, however, believed that these structures were accommodated within the existing townscape or landscape.[6] We have conducted the first large-scale field study of the orientation of early medieval English churches in order to examine these proposals.

The age of the fabric investigated

The selection of churches for study was made by reference to *Anglo-Saxon Architecture*.[7] The dating of buildings described in these volumes frequently presented their authors with difficulties.[8] Furthermore, numerous structures have foundations which are older than the visible fabric;[9] and Anglo-Saxon architectural styles were not forsaken throughout the country immediately after the Norman Conquest. An Anglo-Saxon age may be demonstrated using non-architectural evidence in only a very few instances.[10] Consequently, the time of construction of these churches is frequently uncertain; a considerable number of so-called late Anglo-Saxon buildings (including some listed by the Taylors) probably belong to the Norman period.[11] Much research has been carried out since the publication of *Anglo-Saxon Architecture*, but it has not been superseded; several revised building dates have yet to appear in print.[12] Since the precise age of the fabric is not critical to our work, we have examined churches (or parts thereof)

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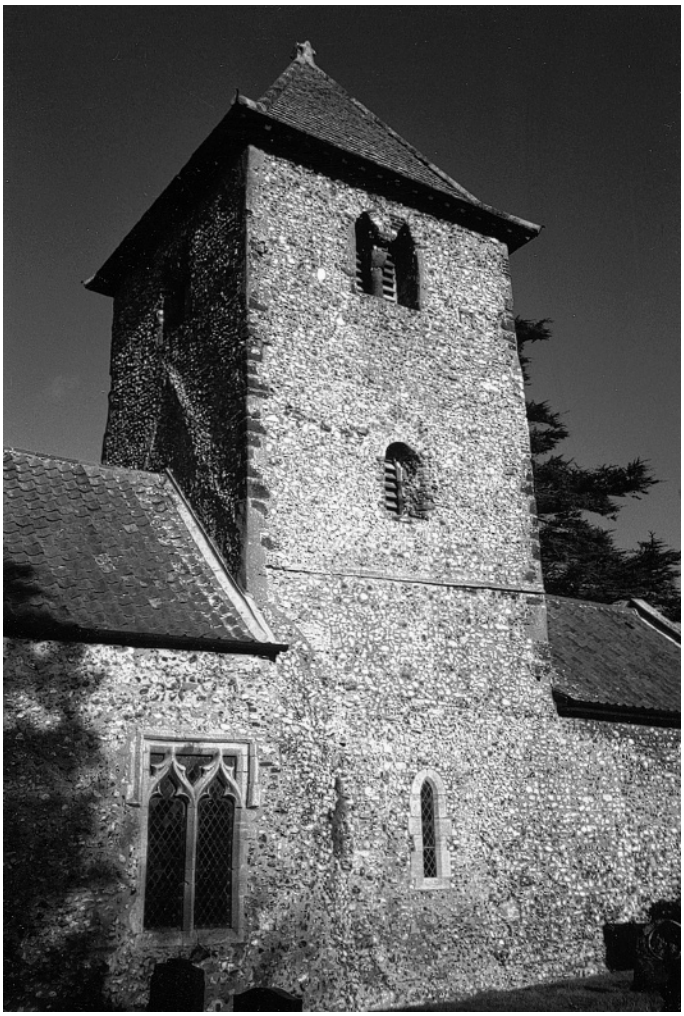

Figure 1. St Mary's and All Saints, Newton-by-Castleacre, Norfolk (52·7056°N, 0·7085°E; TF 830155) (70°T). The Taylors described this building in *Anglo-Saxon Architecture* (see Note 7) as dating from period C3. They regarded the two uppermost windows in the south wall of the square axial tower as typical of Anglo-Saxon architecture. The belfry window consists of two triangular-headed lights with a simple stone mid-wall shaft; below this, there is a (considerably modified) double-splayed, round-headed window.

TABLE 1 *The sub-period divisions employed by the Taylors in* Anglo-Saxon Architecture

A1	AD 600–650	B1	AD 800–850	C1	AD 950–1000
A2	AD 650–700	B2	AD 850–900	C2	AD 1000–1050
A3	AD 700–800	B3	AD 900–950	C3	AD 1050–1100
				S-N	AD 1066–1116

S-N = Saxo-Norman.

displaying architectural styles which are widely regarded as Anglo-Saxon (or Saxo-Norman) (Figure 1), but have taken the precaution of referring to them as 'early medieval'. The sub-periods employed by the Taylors in *Anglo-Saxon Architecture* (Table 1) are provided here for guidance only.[13]

The field measurement of orientation

Orientation was usually determined by holding a liquid-filled magnetic compass[14] against the wall of a church.[15] Readings were taken at intervals along the length of the early medieval fabric, and the mean was adopted if the range did not exceed $\sim 4°$. The overall alignment of particularly uneven surfaces was established by sighting with a hand-held liquid prismatic compass.[16] This instrument was also employed where the magnetic compass would have been influenced by local sources of attraction[17] and natural ferruginous materials,[18] and where the fabric was not directly accessible. The majority of the measurements were made internally; external readings were generally obtained only when we were unable to enter a church.

The builders of early medieval churches commonly displayed a remarkable disregard for the right angle.[19] Where such seemingly careless workmanship occurs, the short-axis (that is, north–south) walls usually appear to be at variance with the rest of the structure.[20] Consequently, we preferred to examine long-axis (that is, west–east) walls if these were available; the orientation of other parts of the building was determined only as a check against gross measurement errors. We tried to avoid short stretches of fabric such as tower walls, which the builders may have found difficult to align, and tower and chancel arches, which may have been repositioned. The problem of skewed churches, those in which distinct parts are not collinear, seldom arose since few of the buildings we examined had both an early medieval nave and chancel. Where skewness did occur, the difference in alignment was usually small and we adopted the mean value (but see below).

The orientation of 181 churches in central and southern England was measured between May 1994 and August 1995 and on 11 August 1997. The western baptistery and turriform nave of St Peter's, Barton-Upon-Humber, Humberside,[21] date from different periods, display significant skewness and are treated separately. The foundations of St Augustine's church, Canterbury, Kent,[22] also belong to two distinct episodes. Thus, we examined 183 discrete structures.

The reliability of the data

The magnetic compass is graduated in 2° divisions and is readable to 1°; it has a maximum accuracy of 1·8° (manufacturer's figure). The prismatic compass has 1° divisions and is readable to 0·5°; the hand-held instrument is accurate to $<1°$.[23] Other errors inherent in compasses[24] are thought to be relatively small. Since we were obliged to record an average value for an irregular wall, the definition of orientation in these instances is inexact. The quality of our data is variable, and we are unable to match the precision claimed by others.[25] The Earth's magnetic field experiences variations or 'storms'.[26] Their effect on our results is probably less important than the deviation of the compass needle caused by unseen sources of attraction close to the measurement position;[27] they are unlikely to have had a profound influence on the statistics.

Results

The location and true orientation[28] of each measured church is illustrated in Figure 2, the range of alignments is summarized in Figure 3 and statistics are given in Table 2.[29]

The orientation of the churches ranges from 42° to 128°T. The Rayleigh test provides statistical evidence of a non-uniform distribution, although the circular standard deviation ($\pm 12°$) indicates considerable dispersion about the mean (88°T). Only three

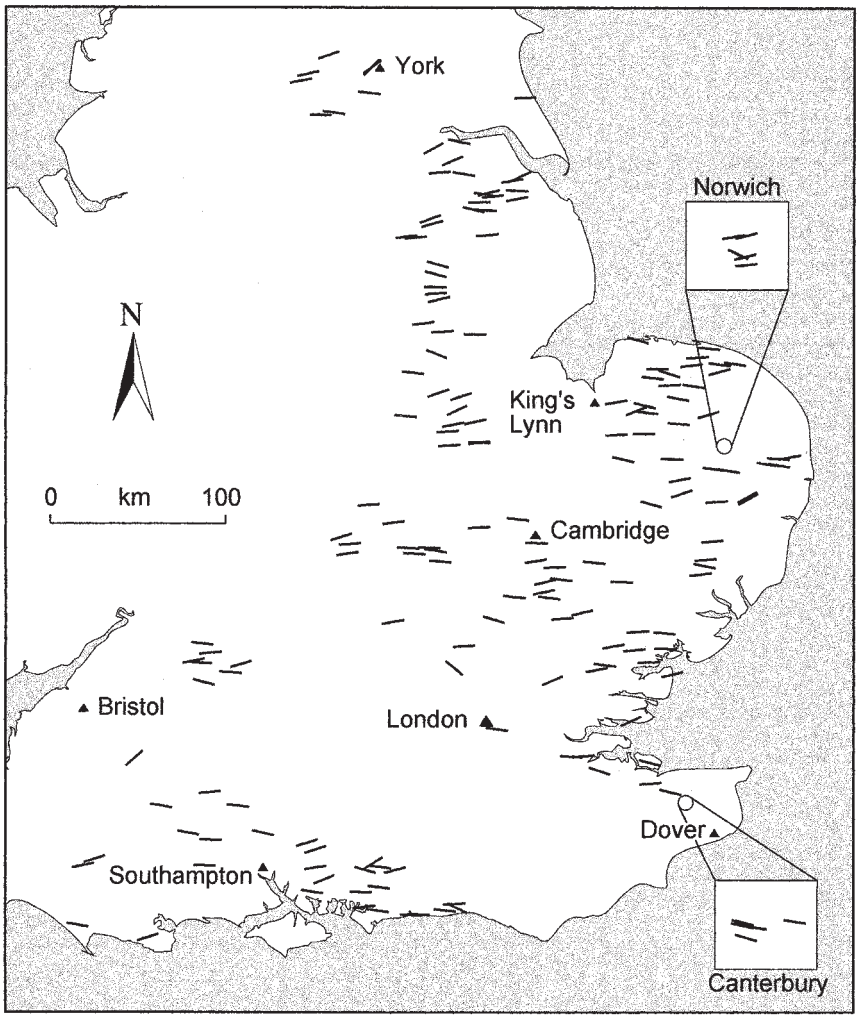

Figure 2. The position and orientation (°T) of individual early medieval churches measured in this study.

churches are aligned with true east, but 25 (14 per cent) lie between 88° and 92°T and 114 (62 per cent) occupy the range 80°–100°T. Ninety-nine buildings (54 per cent) are oriented north of east, 81 (44 per cent) to the south of east. When the results are divided according to the period of construction, each group is seen to be centred on true east or to deviate only very slightly from that direction.

Discussion

The non-uniform distribution of the data provides a statistical underpinning of the contention that Christian churches were set out according to a strongly-held purpose. The mean value is a powerful indication that a liturgically-correct alignment was regarded as desirable, and that attempts to achieve this met with considerable success. However, the range of values suggests that this ambition was sometimes overridden by other considerations or was overlooked.

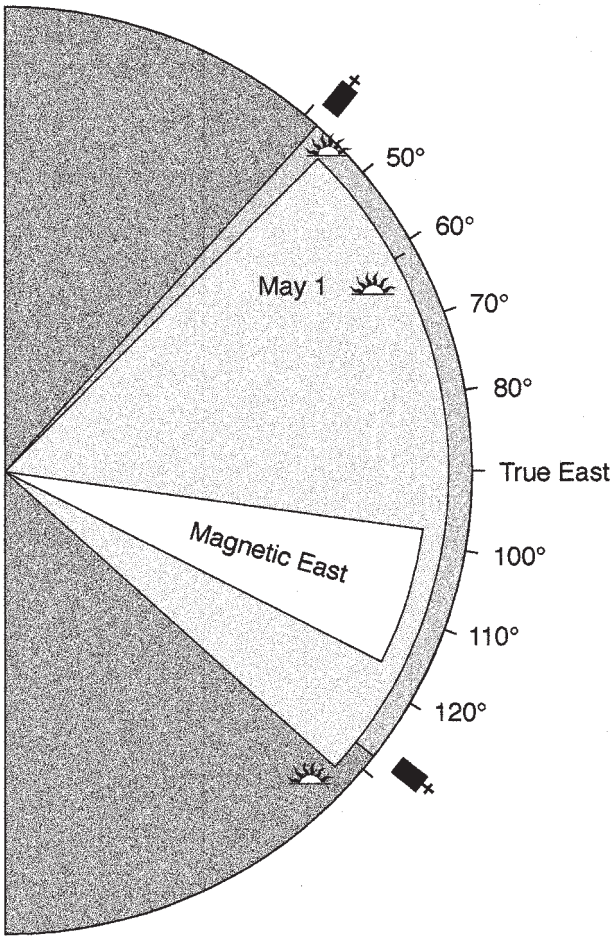

Figure 3. The range of orientations of early medieval churches determined in this study, the length of the solar arc and the position of sunrise on 1 May. Variations in the location of magnetic east during the period 600–1000 are also indicated.

First, we explain how the position of true east was established in early medieval times; second, the data are examined for evidence that one or other sunrise theory, discussed in the introduction, might be applicable; third, the irregular distribution of observations on either side of east are investigated; and finally we consider those churches which fall outside the range 80°–100°T.

The determination of true east by astronomical means

It is evident from Bede's (672/673–735) writings that early medieval folk in England possessed a significant knowledge of astronomy.[31] Thus, they would have known that true south is indicated by the position of the sun at its daily culmination, when a stick pushed into the ground gives rise to the shortest shadow.[32] Less conveniently, true east is marked by sunrise at the vernal (~20 March) and autumnal (~22 September) equinox.[33] The north celestial pole moves by 1° every 72 years; the pole star would therefore have formed an unsatisfactory reference point.[34]

TABLE 2 *Statistical summary of early medieval church orientations measured in this study*

Construction date*	All	A	C	C1	C3	?S-N
n†	183	18	55	10	76	19
Mean angle	88°	88°	90°	93°	86°	87°
Confidence interval of mean	±2°	±7°	±3°	±10°	±2°	±5°
Length of mean vector‡	0·98	0·96	0·98	0·97	0·98	0·98
Rayleigh test of uniformity§	0·00	<0·01	0·00	0·00	0·00	<0·01
Circular variance	0·02	0·04	0·02	0·03	0·02	0·02
Circular standard deviation	±12°	±16°	±12°	±13°	±11°	±11°
Standard error of mean	±0·9°	±3·8°	±1·6°	±5·0°	±1·3°	±2·4°

* The approximate limits of these intervals are given in Table 1.
† There are too few churches of period B and sub-period C2 age to provide meaningful statistics. The orientation of Holy Trinity, Milton Regis, Kent,[30] is taken into account only in the 'All' column as the age of the fabric is uncertain.
‡ This statistic indicates the extent to which the observations are clustered around the mean; the larger the value (maximum = 1), the greater the clustering.
§ The Rayleigh test calculates the probability that the data are distributed in a uniform manner (0 = non-uniform; 1 = uniform); the values are quoted at the 95 per cent confidence level.

Kendall's attempt to orient graves with sunrise achieved an accuracy of ±5°.[35] We cannot expect early medieval church-builders to have been as successful since (1) their determination of a cardinal point by celestial means may have been in error to this extent[36] and (2) the derivation of east from the position of south required the construction of a right angle, a procedure they often approached in a cavalier manner.[37] Fisher believed that discrepancies of up to ∼20° could be explained by lackadaisical surveying methods.[38] It would be convenient to adopt this figure since 161 (88 per cent) of the surveyed churches fall within the range 70–110°T, but we regard it as too generous. We suggest instead a tolerance of ±10°, thus accounting for 114 (62 per cent) buildings. Such relatively small errors might be due to an inaccurate knowledge of the time of day and a variety of indeterminate causes.

Orientation by the use of the magnetic compass

The first western European records of the magnetic compass are probably those by Neckham (∼1187) who referred to its use by mariners.[39] However, it was almost certainly first employed for terrestrial navigation[40] and, significantly, Neckham does not write about the device as if it were a recent invention.[41] The earliest form of the instrument may have predated Neckham's texts by several centuries.[42]

Magnetic north lay a considerable distance to the east of true north throughout the early medieval period[43] (Figure 3). The magnitude of the magnetic declination[44] was probably not known in western Europe until the first half of the fifteenth century.[45] Figure 3 indicates that the churches in our study are centred on true, rather than magnetic, east.[46] Furthermore, since the magnetic declination increased from 8°E to 28°E between 800 and 1000, and then slowly decreased to 20°E by 1100,[47] the use of the compass to determine magnetic east (via magnetic north) would have yielded strongly positively-skewed orientation data.

Rodwell and Rodwell suggested that the ?tenth century timber church at Rivenhall, Essex,[48] which is oriented 85°T, was set out on a magnetic bearing.[49] The magnetic declination varied from 18°E to 28°E during the tenth century.[50] Thus, we would expect

the church to be aligned at least 18° to the south of true east if the site had been laid out using a magnetic compass but in ignorance of the magnetic declination.[51]

Alignment with the position of sunrise on a particular day

Since only one of the churches examined by us (St Mary Bishophill Junior, York; 42°T)[52] lies outside the solar arc (Figure 3), it is conceivable that one or more sunrise models, discussed in the Introduction, may apply to some of our results.

There are a number of imponderables.

(1) In only a very few cases can the early medieval dedication of a church in our survey be verified.[53] Furthermore, certain saints have several feast days, although one is usually more highly regarded than the others.
(2) Calculation of the sunrise position is only reliable for level sites with an unimpeded view of the eastern horizon. Intervening land masses, woods and buildings will delay the (apparent) sunrise, perhaps by as much as 20°.[54] Conversely, the sun will appear earlier than is indicated in tables, and thus farther to the north, on hill-top sites with a low, distant horizon.[55]
(3) Relatively minor differences in the position of sunrise are given by the various 'proper moment of observation' strategies: 'first flash' (when the upper limb of the sun just appears above the horizon), exposure of half the sun or 'whole orb'.

Despite these considerable uncertainties, a general test of the sunrise proposals may still be undertaken. The festival dates of saints known to have been favoured by early medieval dedications are distributed throughout the year; more significantly, several occur when sunrise is close to the limits of the solar arc.[56] Thus, we would have recorded a much more widely dispersed set of data if the measured churches had been aligned with sunrise on the patronal festival day. Similarly, we may reject the suggestion that sunrise positions at the summer (~21 June) and winter solstice (~21 December) and on 1 May are preserved in the orientation of the buildings in our survey. We therefore contend that the widespread and time-honoured support for the various sunrise models is misplaced (although an occasional building may have been so aligned).

The uneven distribution of orientations about true east

The unequal arrangement of the orientation data, with a greater number of churches being aligned to the north of east, is difficult to explain.[57] Determining the position of east by noting the equinoctial sunrise might have led to a southerly bias in the figures since the sun's appearance is delayed by obstructions. Misjudgement of the culmination of the sun would have yielded a range of church orientations, but these might be expected to display a mean value close to 90°T. The uneven distribution of values cannot be explained by changes in the character of the orbit of the Earth around the sun.[58]

Churches which fall outside the range 80°–100°T

A considerable number of the 69 churches (38 per cent) which deviate by >10° from true east, including those at the extremes of the range, can be accounted for.

Most of the early medieval churches which were constructed in major Roman settlements had to be accommodated within townscapes which, even in the seventh century and later, were still crowded with Roman masonry buildings.[59] Such urban

congestion appears to have influenced the alignment of the two churches at the limits of the range. Although St Mary Bishophill Junior in York[60] (42°T) is late in Anglo-Saxon terms (C3),[61] its orientation reflects the local Roman street grid.[62] The alignment of St Stephen's, St Albans, Hertfordshire[63] (128°T), may also preserve a Roman lineament since it occurs within a Roman cemetery and may have formed the nucleus of a small post-Roman settlement.[64] All Hallows-by-the-Tower, London[65] (111°T), lies parallel to and partly rests upon the Roman London Wall.[66] St Peter-on-the-Wall, Bradwell-on-Sea, Essex[67] (76°T), was built in the gateway of the third century 'Saxon Shore Fort' and follows a Roman alignment.[68]

The streets of the Roman towns of Lincoln and Colchester, Essex, were arranged due north–south and east–west. However, St Mary-le-Wigford[69] (108°T) and St Peter-at-Gowts[70] (106°T) in Lincoln were both originally suburban and their layout was not controlled by the Roman grid;[71] yet they hardly represent accomplished attempts to define true east! Holy Trinity, Colchester[72] (95°T), lies within a part of the town in which the Anglo-Saxon street grid is the same as the Roman one.[73] The orientation of the church may indicate that it was built squarely within the Roman/Anglo-Saxon street plan, but its alignment also falls within the experimental error associated with the astronomical determination of east.

St John Timberhill, Norwich, Norfolk[74] (115°T), may have been constructed on a site which was restricted in size and shape within the congested Anglo-Saxon street plan;[75] two of the other four churches measured by us in that city deviate from true east by only 5° and 9°.

Construction of early medieval churches was frequently suspended during the winter months.[76] Whilst some foundations may have been set out correctly during the non-building period, the markers may subsequently have been disturbed before construction began in the spring.

Conclusions

It is clear from our selection of churches that the early medieval ideal *was* to obtain a liturgically-correct alignment.[77] Relatively few buildings show major deviations from true east; some of these were arranged to fit in with the pre-existing townscape (for example, Roman or early Anglo-Saxon lineaments such as roads and walls) or with landscape elements.[78] Whilst a very few may have been oriented in accordance with one of the so-called sunrise theories, none of these is widely applicable, nor is it likely that any will ever be associated with certainty with individual buildings. We have eliminated the use of the magnetic compass for orientation purposes, but do not claim that the instrument was unavailable in England during early medieval times[79] since we must allow that church-builders preferred well-established astronomical methods of alignment for reasons of conservatism, tradition or symbolism.

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Notes

[1] It is thought that the second coming of Christ will be from the east: see, for example, Matthew 24.27 NT; and S. C. Hawkes, Orientation at Finglesham: sunrise dating of death and burial in an Anglo-Saxon cemetery in east Kent, *Archæologia Cantiana* **92** (1976) 33–51, see 39.

[2] Taylor ∼1678, cited in W. Johnson, *Byways in British Archaeology* (Cambridge 1912) 225; W. Wordsworth, *The Poetical Works of William Wordsworth* (London 1827) Volume 4, 263–264; J. M. Neale and B. Webb, *The Symbolism of Churches and Church Ornaments. A Translation of the First Book of the* Rationale Divinorum Officiorum *written by William Durandus* (London 1893) 16n; H. Benson, Church orientations and patronal festivals, *The Antiquaries Journal* **36** (1956) 205–213.

[3] Durandus ∼1286–1294, in Neale and Webb, *op. cit.*, 17.

[4] W. Airy, On festival orientation, *Bedfordshire Architectural and Archaeological Association Reports and Papers* **3** (1856), 19–27; C. J. P. Cave, The orientation of churches, *The Antiquaries Journal* **30** (1950) 47–51, see 49–50.

[5] T. W. Shore, Orientation of churches in Hampshire, *Walford's Antiquarian* **10** (1886) 105–108, see 108; idem, Characteristic survivals of the Celts in Hampshire, *The Journal of the Anthropological Institute of Great Britain and Ireland* **20** (1891) 3–20, see 17.

[6] W. J. Rodwell, Churches in the landscape: aspects of topography and planning, in M. L. Faull (Ed.), *Studies in Late Anglo-Saxon Settlement* (Oxford 1984) 1–23, see 15.

[7] H. M. Taylor and J. Taylor, *Anglo-Saxon Architecture* (Cambridge 1965) Volumes I and II; H. M. Taylor, *Anglo-Saxon Architecture* (Cambridge 1978) Volume III.

[8] See, for example, Taylor, *op. cit.* 735–65. Accounts of the forms which are considered by many to be indicative of Anglo-Saxon church architecture may be found in T. Rickman, *An Attempt to Discriminate the Styles of Architecture in England, from the Conquest to the Reformation: with a sketch of the Grecian and Roman orders* (Oxford 1862) 55–96; G. B. Brown, *The Arts in Early England. Ecclesiastical Architecture in England from the Conversion of the Saxons to the Norman Conquest* (London 1903), especially 99–271; idem, *The Arts in Early England. Anglo-Saxon Architecture* (London 1925); A. W. Clapham, *English Romanesque Architecture before the Conquest* (Oxford 1930) 107–126; and Taylor and Taylor, *op. cit.*, 4–15.

[9] Rodwell, *op. cit.*, 1; Dr W. J. Rodwell, personal communication, October 1996. T. Bell, Churches on Roman buildings: Christian associations and Roman masonry in Anglo-Saxon England, *Medieval Archaeology* **42** (1998) 1–18.

[10] See, for example, Taylor, *op. cit.*, 737–41.

[11] Dr R. D. H. Gem, personal communication, June 1997.

[12] Dr R. D. H. Gem, personal communication, July 1997.

[13] In assigning ages to church fabric, Taylor and Taylor, *op. cit.* xxv, 17 adapted the period scheme of Brown (1903, 35, 288, 1925, 3–4, 5–6). They adjusted Brown's (1903, 290, 1925, 439) sub-period divisions to give the intervals shown in Table 1. Period C and the Saxo-Norman interval are not mutually exclusive; for a discussion of this and other inadequacies of the 'ABC' chronology, see R. D. H. Gem, ABC: How should we periodize Anglo-Saxon architecture?, in L. A. S. Butler and R. K. Morris (Eds), The Anglo-Saxon church: papers

on history, architecture, and archaeology in honour of Dr H. M. Taylor, *The Council for British Archaeology Research Report* **60** (1986) 146–155.

[14] The Type 15 model manufactured by Silva.

[15] Initially, the orientation of 28 churches was measured on 1:2500 scale Ordnance Survey plans and the results checked in the field; discrepancies were frequent, irregular, rarely minor, often significant and, on one occasion, massive (22°).

[16] The M-73 model manufactured by Francis Barker and Son Limited.

[17] Steel and iron objects and electrical wires are the commonest causes of compass deviation: see, for example, Cave, *op. cit.*, 48; and H. Erlandsson, The orientation of the cathedral of Lund and its relation to the place of the old pagan cult, *Meddelande Från Lunds Astronomiska Observatorium 123, Historical Notes and Papers* **21** (1948) 9.

[18] For example, All Saints, Brixworth, Northamptonshire (52·3331°N, 0·9038°W; SP 747712) is constructed predominantly of iron-rich ashlar.

[19] E. A. Fisher, *The Greater Anglo-Saxon Churches* (London 1962) 49, 49n, 114, 214, 347, 348, 358, 371; Taylor and Taylor, *op. cit.*, 81; W. J. Rodwell, *The Archaeology of the English Church: The Study of Historic Churches and Churchyards* (London 1981) 92; but see W. J. Rodwell, Anglo-Saxon church building: aspects of design and construction, in L. A. S. Butler and R. K. Morris, *op. cit.*, 156–175, see 157.

[20] See, for example, Fisher, *op. cit.*, figures 38 and 39; W. J. Rodwell and K. A. Rodwell, Excavations at Rivenhall church, Essex: an interim report, *The Antiquaries Journal* **53** (1973) 219–231, see figure 4; and W. J. Rodwell, The archaeological investigation of Hadstock Church, Essex, an interim report, *The Antiquaries Journal* **56** (1976) 55–71, see 60, 62.

[21] 53·6831°N, 0·4344°W; TA 034219.

[22] 51·2768°N, 1·0879°E; TR 154577.

[23] F. Debenham, *Map Making* (London 1954) 60; R. Farrar, *Survey by Prismatic Compass* (London 1980) 6–7.

[24] For example, those due to a difference between the magnetic and geometric axes of the needle, to friction in the bearings and to parallax when reading the Silva compass.

[25] Cave, *op. cit.*, 47; N. Abrahamsen, Evidence for church orientation by magnetic compass in twelfth-century Denmark, *Archaeometry* **34** (1992) 293–303, see 295, 296.

[26] These result from the arrival of charged particles produced by sunspot activity. A magnetically stormy day in the United Kingdom is one in which the declination varies by >0·5°. Magnetic declination is the difference in angle between true north (which does not alter position substantially) and magnetic north, at a given place and time. On a typical quiet day in England variation in the magnetic declination is $\leq 10'$ in winter and $\sim 15'$ in summer. The frequency of such days and the variation in magnetic declination become greater with increasing latitude. Hartland, Devon (50·992°N, 4·484°W; SS 256245), for example, experienced 11 stormy days during the measurement periods, whereas Eskdalemuir, Dumfries and Galloway (55·312°N, 3·205°W; NT 235026), had 35 (Miss E. Clarke, personal communication, September 1996; Dr T. Clark, personal communication, July 1998). As a precaution, therefore, we compared the Eskdalemuir record against the days on which we undertook field work. The vast majority of our readings were made on quiet days; four Essex churches were examined on the stormiest day (7 April 1995) when the magnetic declination varied by 1·428° at Eskdalemuir and by 0·997° at Hartland.

[27] Professor D. H. Tarling, personal communication, July 1996.

[28] S. J. Gale and P. G. Hoare, *Quaternary Sediments: Petrographic Methods for the Study of Unlithified Rocks* (London 1991) 136–137 describe the procedure for adjusting magnetic readings to true ones.

[29] A list containing the grid reference, possible date of construction, magnetic and true orientation of all the measured churches is available from the authors.

[30] 51·3547°N, 0·7398°E; TQ 908654.

[31] J. L. E. Dreyer, *A History of Astronomy from Thales to Kepler* (New York 1953) 223; W. M. Stevens, Bede's scientific achievement (Jarrow Lecture 1985), in *Bede and his World. Volume II The Jarrow lectures, 1979–1993* (Aldershot 1994) 647–688, see 659–660; E. Edson, *Mapping Time and Space: how Medieval Mapmakers Viewed their World* (London 1997) 64–66.

[32] R. C. Bless, *Discovering the Cosmos* (Sausalito 1996) 16 notes that at local noon, the sun lies directly to the south for observers situated to the north of latitude 23·5°N. The presence of sundials in many early medieval churches is an indication that time was held to be

important, see A. R. Green, Anglo-Saxon sundials, *The Antiquaries Journal* **8** (1928) 489–516.

[33] See, for example, Durandus ∼1286–1294, citing S. Isidore, in Neale and Webb, *op. cit.*, 16, 179.

[34] The star Alpha Ursæ Minoris (Polaris) is now <1° from the north celestial pole, but the distance had increased to ∼7–8° between 400 and 1000 as a result of the precession of the equinoxes. The double star Σ1694, which is visible to the naked eye as a single 4.8 magnitude star, lay within ∼1–1·5° of the pole during part of this time (Dr I. R. Parry, personal communication, February 1996).

[35] G. Kendall, A study of grave orientation in several Roman and post-Roman cemeteries from southern Britain, *The Archaeological Journal* **139** (1982) 101–123, see 116.

[36] Abrahamsen, *op. cit.*, 299 notes that mistiming of the sun's culmination by 15 minutes would result in an angular discrepancy in the location of true south of ∼4°.

[37] See note 19.

[38] Fisher, *op. cit.*, 49.

[39] G. A. L. Sarton, *Introduction to the History of Science Volume II From Rabbi Ben Ezra to Roger Bacon* (Baltimore 1931), see 24, 299, 509, 510, 630; A. C. Mitchell, Chapters in the history of terrestrial magnetism. I—On the directive property of a magnet in the Earth's field and the origin of the nautical compass, *Terrestrial Magnetism and Atmospheric Electricity* **37** (1932) 105–146, see 120, 123, 125, 130; W. E. May, The birth of the compass, *The Journal of the Institute of Navigation* **2** (1949) 259–263, see 261; idem, Alexander Neckham and the pivoted compass needle, *The Journal of the Institute of Navigation* **8** (1955) 283–284, see 283; H. L. Hitchins and W. E. May, *From Lodestone to Gyro-compass* (London 1952) 20; D. W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times* (Greenwich 1978) 22, 23; N. J. T. M. Needham, *Science and Civilisation in China.* Volume 4: *Physics and Physical Technology Part 1: Physics* (Cambridge 1962) 246; R. T. Merrill and M. W. McElhinny, *The Earth's Magnetic Field: Its History, Origin and Planetary Perspective* (London 1983) 3.

[40] May, *op. cit.*, 259.

[41] Sarton, *op. cit.*, 299, 510, 630; H. Winter, Who invented the compass?, *The Mariner's Mirror* **23** (1937) 95–102, see 95.

[42] May, *op. cit.*, 259.

[43] A. J. Clark, D. H. Tarling and M. Noël, Developments in archaeomagnetic dating in Britain, *Journal of Archaeological Science* **15** (1988) 645–667; C. M. Batt, The British archaeomagnetic calibration curve: an objective treatment, *Archaeometry* **39** (1997) 153–168.

[44] See note 26 for a definition of this term.

[45] Hartmann 1544, cited in A. C. Mitchell, Chapters in the history of terrestrial magnetism. Chapter II—The discovery of the magnetic declination, *Terrestrial Magnetism and Atmospheric Electricity* **42** (1937) 241–280, see 247; L. Digges, *A Geometrical Practise, named Pantometria, divided into three bookes, Longimetra, Planimetra and Stereometria, containing rules manifolde for mensuration of all lines, superficies and solides: with sundry straunge conclusions both by instrument and without, and also by perspective glasses, to set forth the true description or exact plat of an whole region* (London 1571) 70; S. Chapman and J. Bartels, *Geomagnetism. Volume II Analysis of the Data, and Physical Theories* (Oxford 1940) 907–909; Waters, *op. cit.*, 24–25; S. R. C. Malin and E. C. Bullard, The direction of the Earth's magnetic field at London, 1570–1975, *Philosophical Transactions of The Royal Society of London* **A 299** (1981) 357–423, see 370, 383.

[46] But see the survey of twelfth century Danish churches by N. Abrahamsen, Romanske kirkers orientering og den magnetiske misvisning i 1100-tallet i Danmark (Orientation of Romanesque churches and magnetic declination in the 12th century in Denmark) *Geoskrifter* **23** (1985); and idem, 1992.

[47] Clark *et al.*, *op. cit.*, see figure 6.

[48] 51·827°N, 0·652°E; TL 828177.

[49] W. J. Rodwell and K. A. Rodwell, Rivenhall: investigations of a villa, church, and village, 1950–1977, *Chelmsford Archaeological Trust Report* **4**/*The Council for British Archaeology Research Report* **155** (1985) 91. This church was replaced by the present ?tenth century stone building which has an identical orientation.

[50] Clark, *et al.*, *op. cit.*

[51] Dr W. J. Rodwell (personal communication, September 1996) accepts that the orientation is within the experimental error associated with the determination of true east by astronomical means.

[52] 53·9552°N, 1·0872°W; SE 599514.
[53] A. M. Binns, *Dedications of Monastic Houses in England and Wales, 1066–1216* (Woodbridge 1989) 3 notes that the patron saint of numerous ancient village churches cannot be determined for the period before the eighteenth century; but see R. M. Serjeantson and H. I. Longden, The parish churches and religious houses of Northamptonshire: their dedications, altars, images and lights, *The Archaeological Journal* **70** (1913) 217–452; K. E. Kirk, *Church Dedications of the Oxford Diocese* (Oxford 1946); C. L. S. Linnell, Norfolk church dedications, *St Anthony's Hall Publication* **21** (York 1962); and N. Orme, *English Church Dedications with a Survey of Cornwall and Devon* (Exeter 1996) 11–24.
[54] Benson, *op. cit.*, 206.
[55] *Ibid.*, 213.
[56] Orme, *op. cit.* notes that dedications to St Peter and SS Peter and Paul (festival date 29 June), All Saints or All Hallows (1 November) and St Andrew (30 November) were popular in early medieval times. Alignment of churches according to the sunrise position on these days would have given orientations up to $\sim 43°$ north and south of east.
[57] The following authors also found that the majority of their surveyed churches are oriented to the north of east: Shore (1886, 1891, 17); F. C. Eeles, The orientation of Scottish churches, illustrated by an analysis of some examples in Aberdeenshire and Banffshire, *Proceedings of the Society of Antiquaries of Scotland* **48** (1914) 169–183, see 179; and Cave, *op. cit.*
[58] Professor R. C. Bless, personal communications, December 1998 and March 1999.
[59] Rodwell, Churches in the landscape, 3.
[60] 53·9552°N 1·0872°W; SE 599514.
[61] Taylor and Taylor, *op. cit.*, 697–699.
[62] Rodwell, Churches in the landscape, 9.
[63] 51·7402°N, 0·3477°W; TL 141060.
[64] Rodwell, Churches in the landscape, 11.
[65] 51·5077°N, 0·0795°W; TQ 333806.
[66] P. Norman and F. W. Reader, Recent discoveries in connexion with Roman London, *Archaeologia* **60** (1906) 169–250, see plate 25.
[67] 51·7340°N, 0·9395°E; TM 030081.
[68] Dr W. J. Rodwell, personal communication, September 1996.
[69] 53·2258°N, 0·5411°W; SK 974709.
[70] 53·2213°N, 0·5427°W; SK 933704.
[71] Dr W. J. Rodwell, personal communication, September 1996.
[72] 51·8879°N, 0·9001°E; TL 996251.
[73] W. J. Rodwell and K. A. Rodwell, Historic churches—a wasting asset, *The Council for British Archaeology Research Report* **19** (1977), see 32.
[74] 52·6251°N, 1·2961°E; TG 231082.
[75] P. Brown (Ed.), *Domesday Book 33 Norfolk (Part One)* (Chichester 1984) 116a–116b, 117a–117b; B. S. Ayers, *Book of Norwich* (London 1994) 30–40; Dr B. S. Ayers, personal communication, January 1995.
[76] L. F. Salzman, *Building in England down to 1540. A Documentary History* (Oxford 1952) 59–60 observed that, in the centuries immediately following the period of concern here, building often ceased in the depth of winter due to the shortness of the days and to the dampness of the weather; but he also noted that much work went on uninterrupted. W. J. Goode, *Round Tower Churches of South East England* (Burnham Market 1994) 35 attributed the winter break in building activity to the likelihood that frost would damage fresh mortar.
[77] Contrast the opinions expressed by Cambridge Camden Society, *A Few Words to Church Builders* (Cambridge 1841) 9–10; idem, *A Few Words to Church-Builders* (3rd Edn, Cambridge 1844) 13; and Rodwell, Churches in the landscape, 15.
[78] See also Rodwell, Churches in the landscape, 15.
[79] Contrast the views of R. Davies, Church orientation in Rutland, *Rutland Record* **4** (1984) 142–143, see 142; C. Wells and C. Green, Sunrise dating of death and burial, *Norfolk Archaeology* **35** (1973) 435–442, see 436; and Hawkes, *op. cit.*, 39.