THE DISCOVERY OF A *QUADRANS NOVUS* AT THE HOUSE OF AGNES, ST DUNSTAN'S STREET, CANTERBURY

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During what was an otherwise routine 'watching brief', a remarkable object was found amongst domestic refuse in a medieval pit in St Dunstan's Street, Canterbury. It was immediately clear that the find was special, and it has since been identified as a quadrans novus, *a rare medieval scientific instrument which has uses ranging from basic surveying, telling the time, to using the sun to calculate calendrical events. This short report describes the circumstances of its discovery preliminary to a note describing the instrument.*[1]

Through July and August 2005 a watching brief was maintained at No. 71 St Dunstan's Street, 175m outside Canterbury's Westgate (NGR 61444 15817: **Fig. 1**). The 'House of Agnes', as it is more commonly known

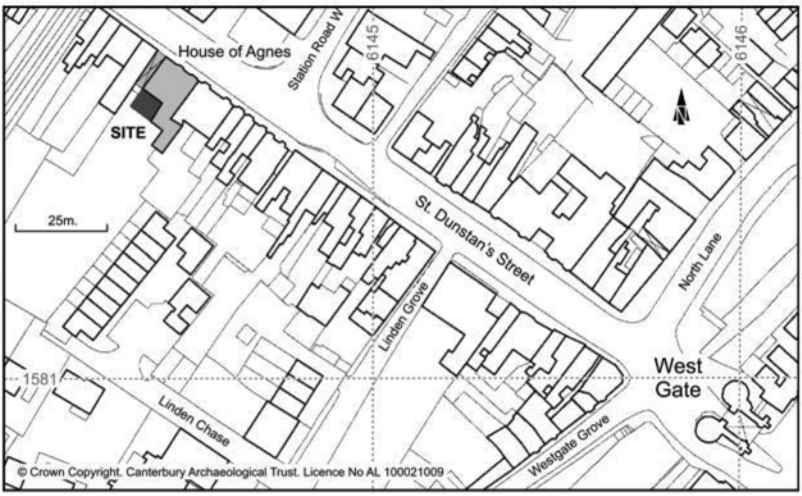

Fig. 1 Site location.

PLATE I

Early twentieth-century view of the House of Agnes. The earliest portion of the building is represented by the left and centre bays with the right bay and adjoining wagon entrance being a later addition

following an association with Charles Dickens, is regarded as a good example of a largely unaltered early seventeenth-century timber-framed town-house (**Plate I**). Originally constructed symmetrically around a centrally-positioned main entrance, its twin-gabled jettied façade is arranged over three floors with projecting bay windows at ground- and first-floor levels. An additional three-storied double jettied gable, matching the existing façade, and an adjoining wagon entrance giving access to the rear, was added at a slightly later date.

Most of the archaeological work was undertaken prior to the creation of a new extension at the rear of the existing property. The proposed new structure was to cover an area of approximately 48.5m^2, occupying the footprint of an existing twentieth-century extension. Of the total development area only 26m^2 was available for archaeological inspection, the remainder of the existing structure being remodelled and incorporated into the new building (**Fig. 2**). This largely entailed the demolition of most of the existing superstructure and the removal of a concrete surface that covered most of the available area. Across the entire area it was evident that previous terracing had taken place, probably in the medieval period, so that formation level for the proposed new building

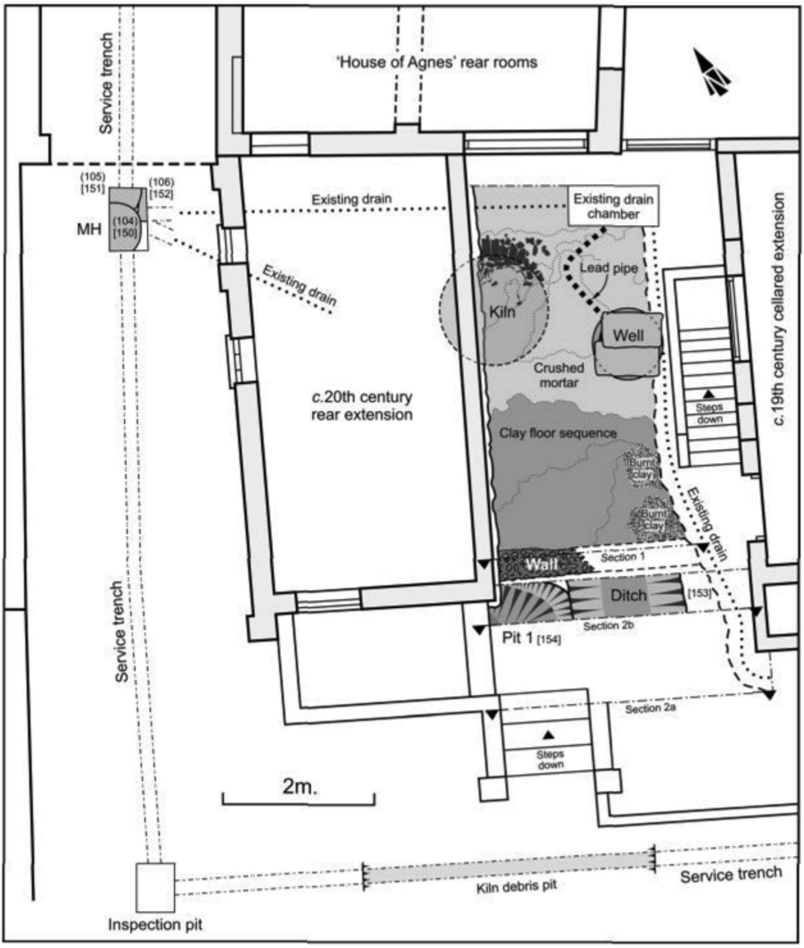

Fig. 2 Site plan.

lay at +11.51m OD, 1.69m below the level of the current rear garden. Due to the existence of this earlier terrace, new groundworks were limited and consisted mainly of foundation trenches for replacement retaining walls associated with the proposed development to the south of the site. These provided an opportunity to recreate a continuous section through surviving archaeological deposits via a series of off-set sections (**Fig. 3**, Section 1; **Fig. 4**, Sections 2a and 2b). Observations during the excavation of new service trenches, manhole and inspection pit, beyond the terraced area extended the boundary of the archaeological work (Fig. 2).

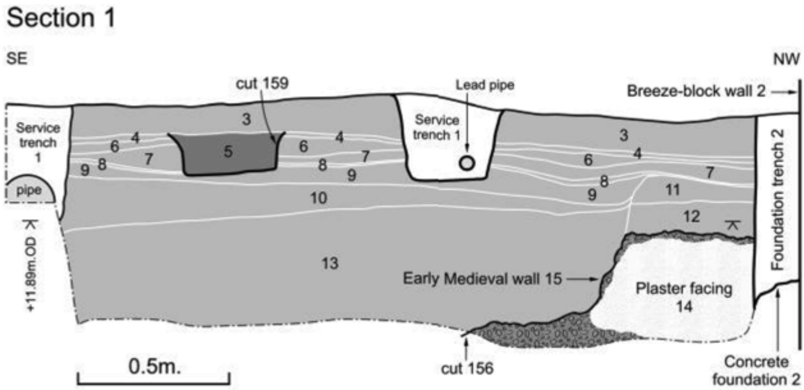

Fig. 3 Section 1.

Roman

Five features of Roman date were recorded; two in the retaining wall foundation trench (Fig. 4, Section 2: Contexts 153 and 154) and three in the manhole (Fig. 2). The upper levels of all the Roman features had been removed by terracing to the rear of the development area or scoured

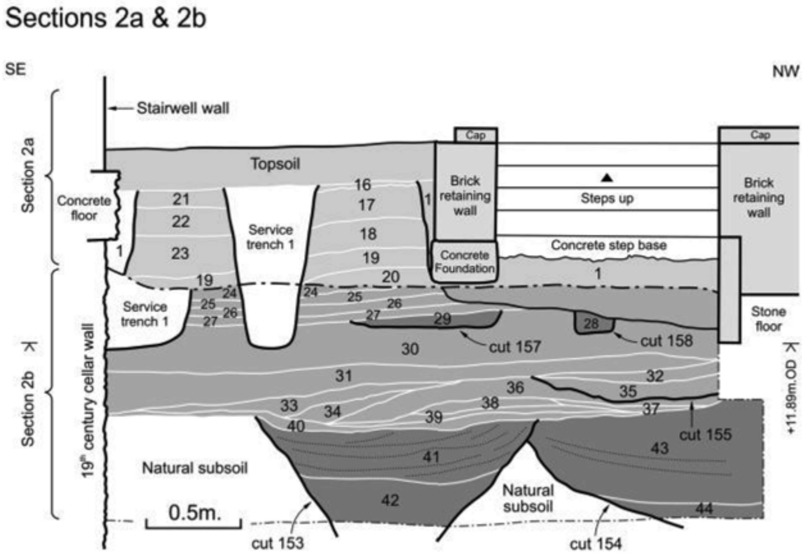

Fig. 4 Sections 2a and 2b

during the formation of a sloping passageway associated with the standing wagon entrance.

Three intercutting pits were recorded in the base of the manhole [150, 151 and 152] each filled with similar mid dark grey laminated silty clay soils containing occasional amounts of animal bone, oyster shells and abundant carbon and daub flecking [Contexts 102, 103 and 104]. All cut into the upper surface of the underlying natural Brickearth with their edges stained the pale greenish grey often the result of contact with cess. Only the latest of these three features [Pit 150] produced datable finds, consisting of several sherds of Roman pottery dating to *c.* AD 70-140.

A fourth pit [154] was recorded in the extension foundation trench (Figs 2 and 4). This was subcircular and in excess of 0.6m deep; Roman pottery dating from the first to the mid third century was recovered from its upper fill [43].

Immediately to the east of this pit and cutting its eastern edge, was a ditch [153] aligned roughly north-north-east by south-south-west (Figs 2 and 4). Measuring approximately 1.50m wide across its surviving upper edge and extending to a depth similar to the adjacent pit, its sides sloped steeply to suggest a V-shaped profile. This is in contrast to the relatively level nature of its upper fill [41] suggesting a short period of rapid silting typical of Roman boundary ditches. Although the upper fill of the ditch failed to produce any datable material despite containing reasonable amounts of domestic refuse, a small assemblage of pottery retrieved from its primary fill [42] was dated to *c.* 130-240.

Anglo-Saxon

There were no positively identified features dating to the Anglo-Saxon period, though one sherd of residual pottery dating to *c.* 950-1050 was retrieved from an early medieval soil deposit [32].

Earlier Medieval

A masonry wall and a sequence of clay floors and occupation deposits, together with a well possibly represented the earliest medieval activity on the site and appeared to be constructed on a primary terrace. This terrace had been cut into the rising ground surface to the south of St Dunstan's Street to form a level surface prior to the construction of a masonry structure along the road frontage.

The wall [15] was located in the southern extent of the monitored area and ran on a rough east-west alignment. Constructed of irregular medium flint nodules in a typical early medieval bonding of coarse mid orangey/brown gritty lime mortar, the northern face of the wall was covered with orangey/brown coarse gritty lime plaster [14], whilst its southern face was left undressed with exposed horizontal flint bands. The wall is the only structural evidence for an earlier medieval building preceding the present 'House of Agnes'.

A series of clay deposits [37-40] (Fig. 4, Section 2) south of the wall are clearly internal floor surfaces and may be associated with a utility structure to the rear of the building represented by Wall 15. These were sealed by a compacted layer of small-medium flint gravel, forming a 0.11m thick metalled surface [36], maybe suggesting a change in the function of this secondary structure. A shallow pit [155] (Fig. 4, Section 2), filled with two mixed soil deposits [32] and [35], cut this metalled surface to the west of the excavated area. Both deposits had spilled over the gravel surface to the east [33] and [34] sealing the earlier clay floor [40]. No directly datable material was recovered from either context, but fragments of coarse sand-tempered Tyler Hill peg-tile amongst animal bone and oyster shell fragments imply an earlier medieval date.

All of these deposits associated with the earlier possible utility structure were capped by two soil horizons [30 and 31] (Fig. 4), which equate with fragments of two soil horizons [11] and [12] in Section 3 (Fig. 3). Pottery retrieved from these contexts dated to the late twelfth through to the mid thirteenth century.

A masonry-lined well measuring roughly 0.95m in diameter and located approximately 3m north of Wall 15 (Fig. 2), and therefore falling within the postulated footprint of the early building, may have been contemporary. Extending vertically to a depth of 3.60m before widening to a diameter of 1.80m, its base was at a depth of 5.80m below modern ground surface (6.09m OD). Its masonry lining was constructed from irregular medium flint nodules interspersed with large water-worn pieces of Thanet Beds, bonded with a comparable coarse mid orangey/brown gritty lime mortar as Wall 15. The similarity between its mortar and construction materials and those of Wall 15 suggest a contemporary date. Apparently clean water was still present in the bottom.

Later medieval

Alterations to the early medieval building took place towards the end of the thirteenth century.

A large pit [156] (Fig. 3, Section 1), recorded in the extension foundation trench, cut the upper courses of Wall [15]. Its fill [13] (Fig. 3, Section 1) consisted of mixed dark grey silty clay containing typical medieval domestic refuse of animal bone, oyster shell and peg-tile with a moderate collection of pottery sherds dating between *c.*1150 and 1400. The *quadrans novus* or astrolabic quadrant was found amongst this material.

Pit 156 was capped with a deposit of firm greyish brown soil that contained an abundant amount of waste building material such as crushed mortar, fractured flint and broken peg-tile [10]. This deposit appears to have formed a consolidation level for a series of clay floors [4 and 6-9] (Fig. 3). Though very little datable material was retrieved from this sequence, the same series of floors was identified in Section 2 [Contexts 24-27] (Fig. 4), there directly overlying two lesser features, which cut into the top of deposit 30 [Contexts 157 and 158] (Fig. 4). Several pottery sherds of *c.* 1275-1375 were recovered from this sequence that had also been cut into by a vertical-sided near flat-bottomed feature [159] (Fig. 3, Section 1).

Floors 4, 6-9 and 24-27 were covered by a mixed soil horizon of greyish brown silty clay containing abundant fragments of building debris and domestic refuse [3] (Fig. 3); [20] (Fig. 4) possibly representing an abandonment of this later phase of the building. This was sealed by three horizons of mixed soils [17 = 22], [18 = 23] and [19] containing varying amounts of domestic refuse and fragmented building material, all covered by a gravel surface [16 and 21] (Fig. 4).

Apart from the well, which undoubtedly remained in use throughout the medieval period, it was difficult to positively date any of the features or associated deposits observed following the removal of the modern concrete surface across the available area of the development. However, the upper surface of a clay floor sequence was exposed abutting the northern side of masonry Wall 15, extending northwards beneath a later sequence of crushed mortar debris associated with a post-medieval kiln base (see below).

Post-medieval

The partial remains of a kiln, and a large pit containing an extensive collection of pottery wasters coupled with deposits of crushed pottery observed in service trenches, all suggest manufacturing activity on the site in the post-medieval period (Fig. 2).

The kiln itself consisted of a circular outer wall of radiating red bricks surrounding a sunken-floored kiln base of red brick fragments, all bonded with orangey/brown clay (Fig. 2). The full extent of the kiln base was not visible since much of its southern part was obscured by a sequence of crushed mortar surfaces, whilst to the west it continued beneath the existing foundations for the twentieth-century extension. However, by projecting the inner arc of the exposed curving outer wall, an internal diameter of approximately 1.5m could be estimated. Evidence for a possible east-west aligned channel or flue was identified immediately to the north-east, filled with a mixture of burnt clay and carbon. Unfortunately the kiln remains and its associated crushed mortar surfaces all fell below the formation level for the new building, so it was not possible to examine the kiln or its associated mortar horizons any further by excavation.

A sizable pit was recorded in a service trench beyond the southern site boundary (Fig. 2). The pit measured 4m wide and despite the narrow trench removing only a 0.65m depth of its upper fill, a considerable quantity of pottery kiln waste was retrieved, dating between *c.* 1625 and 1700. If this material was associated with the kiln it would suggest that it went out of use towards the close of the seventeenth century. The pit was capped by a series of compact chalk and gravel deposits beneath a layer of garden topsoil forming the present ground surface.

Observation of the service trench between the new manhole and an inspection pit recorded laminated lenses formed from heavily crushed pottery fragments sandwiched between firmly-compacted layers of coarse sandy flint gravel and compressed mixed dark silty sandy clay (Fig. 2). These deposits were probably all that remained of metalled surfaces associated with the formation of a trackway to the rear of the wagon entrance in the mid seventeenth century.

In the yard area, immediately beneath the concrete, two Yorkstone slabs covered the well head which had been raised by five courses of unfrogged red brick. Beneath the brickwork the original medieval masonry lining of the well was found to be virtually intact apart from near its base where a repair in brick was required following the installation of a lead pipe down the side of the well shaft. The lower end of this pipe, which was pierced by six 1.5cm diameter holes presumably to act as a basic water filter, was plugged by an inserted timber that stood upright in the silt at the bottom of the well. Midway down the well, the pipe was held in place by a lead plate mounted on a timber plank arrangement that was braced across the shaft by its ends being inserted into the masonry lining. Examination of the interior showed that it had been in use until relatively recent times.

At the well head the pipe ran to a hand-pump mounted on the exterior wall of a nineteenth-century rear extension to the House of Agnes, forming the eastern side of the investigated area. It is assumed that the well head extension, the Yorkstone capping and lead pipe arrangement may have been contemporary with this nineteenth-century cellared extension.

THE *QUADRANS NOVUS* by Elly Dekker

The brass instrument discovered in 2005 in Canterbury and now part of the collection of the British Museum was known in the Middle Ages as a *quadrans novus* (**Plates II and III**). So far seven such instruments from medieval times have been recorded.[2] What do we know about these instruments?

Profatius's quadrant

The *quadrans novus* was first described by Jacob ben Machir ibn Tibbon

(Marseille? 1236 - Montpellier 1305), an astronomer from Montpellier, better known by his Latin name Profatius Judeus. He was brought up in a family which came from Granada and possessed a long tradition in translating Arabic texts into Hebrew.[3] In addition to these translations a few of Profatius's own astronomical works have survived: Prologue to Abraham Bar Hiyya's *Calculation of the Courses of the Stars*, extracts from the *Almagest, Roba' Yisrael* and *Almanac*. The new quadrant is described in the *Roba' Yisrael*, meaning literally *The quadrant of Israel,* which was written in Hebrew in *c.* 1288. The interest in this new instrument can be measured by a number of Latin translations of Profatius's treatise that followed soon after 1288.[4]

One of the predecessors of the new quadrant is the instrument known as the *quadrans vetus*, the basic features of which are the shadow square and lines for finding unequal hours.[5] This instrument has a complicated history. An early description of its basic principles in a ninth-century Islamic manuscript attests its Arabic origin.[6] When precisely this instrument was introduced in the Latin West and through which channels is not known. Early Latin treatises discussing its construction and use were written in the middle of the thirteenth century by Johannes Sacrobosco and Campanus of Novara.[7] These treatises seem to have been replaced around 1260 by the most popular treatise on the instrument written by Johannes Anglicus in Montpellier.[8] Working in the same city, it is very likely that Profatius has known this latter treatise.[9]

Profatius's translations show that he was also familiar with the principles of the *common astrolabe*, the other predecessor of the *quadrans novus.* The astrolabe proper consists basically of two parts: a fixed latitude plate on which the lines of constant altitude are marked for a local observer at a given geographical latitude φ, and a movable plate, the so-called rete, on which the moving celestial sphere is represented through its main celestial circles and a selection of stars. By rotating the rete around the celestial North Pole the daily motion of the Sun and the stars across the lines of constant altitude are imitated. The astrolabe was introduced in the Latin West at the turn of the tenth century. The first texts describing the astrolabe were rather rough and often unintelligible but later generations of authors produced better texts.[10]

Arab astronomers invented all sorts of variants of astrolabe design. It is not unlikely that Profatius derived the folding technique applied in his *quadrant novus*, which turns the common astrolabe into a quadrant, from a manuscript describing the Islamic *almucantar quadrant.* The use of the latter instrument is restricted to the latitude for which the altitude and azimuth curves are drawn. According to King, the descriptions of these quadrants go back to the twelfth century.[11] Surviving examples of *almucantar quadrants*, albeit of a late date, show on the back the semi-circles for calculating the *corda recta* and *corda versa* (trigonometric

PLATE II

The front of the *quadrans novus* (© Erik de Goederen)

quantities closely related to the sine and cosine as used today) included in the design of the Profatius's quadrant. It is plausible that the same source from which he borrowed the principle of the folding technique provided him with the necessary information on these two semi-circles.[12]

The new instrument designed by Profatius was quickly taken up by contemporary astronomers who considered it as a proper successor to the older quadrant known at the time which to distinguish it from Profatius's new quadrant became known as the *quadrans vetus*.

PLATE III

The back of the *quadrans novus* (© Erik de Goederen)

The Canterbury quadrant

The Canterbury instrument is made of a copper-based alloy. Of all extant medieval copies of the *quadrans novus* that found in Canterbury is the smallest (see Description, below).[13] The front side (Plate II) includes a multitude of features, all of which are described in treatises of the *quadrans novus*.[14] These include the shadow square, the lines for finding unequal hours, two semi-circles for calculating the *corda recta* and *corda versa*,

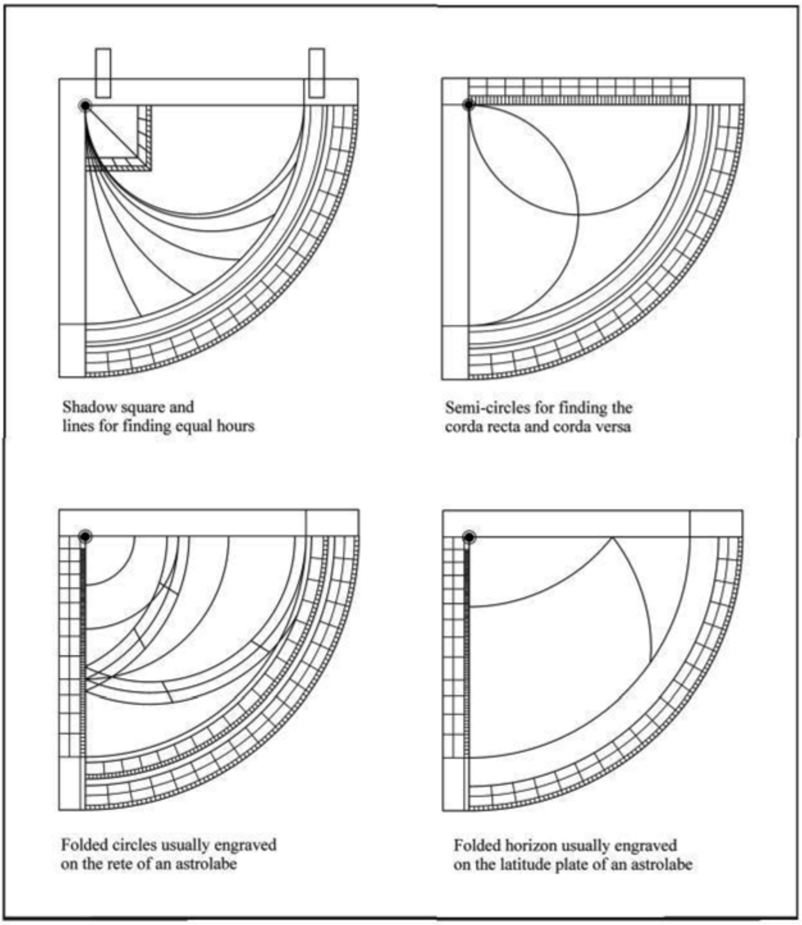

Fig. 5 Summary of the features on the front side of the *quadrans novus*.

the folded circles of the rete of a common astrolabe with a selection of stars and a series of folded horizons, usually engraved on latitude plates belonging to the common astrolabe (see **Fig. 5**).

In addition to the usual folded circles, the tropics and the equator, the Canterbury *quadrans novus* has another circle centred on the North Pole of the quadrant which appears to be located at a distance of about 38° from the North Pole, that is, it passes through the zenith of London. And rather than having a range of folded horizons, the Canterbury quadrant has only one horizon which intersects with the scale for the distance from the North Pole at an angular distance of 53°. This value is close to the geographical latitude of London. The maker probably meant 52°, considering that the parallel through the zenith drawn on the instrument passes through 38°. It emphasizes that the instrument has restricted use, at one geographical latitude only. Another limitation is indicated by the absence of stars which limits the use of the quadrant to finding time during the day by means of the altitude of the Sun.

Manuscript descriptions of the back of a *quadrans novus* are usually more varied than those of the front. Most texts mention the circles of the zodiac and the calendar placed alongside each other (for finding the place of the sun in the zodiac at a given day of the year), the lunar mansions and a lunar volvelle. None of these features are marked on the back of the Canterbury quadrant. Instead there are two concentric rings with calendar-related data: in the innermost ring the ordinal number of a 19-year lunar cycle is given and in the outer ring the corresponding date of the Easter Moon in the style used in the Roman calendar.[15] In the centre of these rings is an eagle with its wings spread. The bird is fixed to the quadrant by a rivet in the middle around which it once could turn. As found it is completely fixed to the quadrant through oxidation. The Eagle was presumably used to help reading off the date of the Easter Moon.

The dates in the ring are well engraved with the exception of the one corresponding to the ordinal number 3, where the first letter of the month is either a much distorted A or it is replaced by another letter, an upside-down B. The letter B cannot stand for the first letter of any month but it could mean instead *Bisextus,* to indicate that the year corresponding to the ordinal number 3 is a leap year.[16] In the fourteenth century there are only two leap years that correspond to an ordinal number 3 (corresponding to a golden number 2 on the present instrument): 1312 and 1388. Considering that the Canterbury *quadrans novus* lacks a number of features that belong to the original design of the instrument, the later date seems more probable.

The properties which are combined in the Canterbury *quadrans novus* make it a practical measuring instrument, a suitable timekeeper and a pocket calculator at the same time. Geometrical problems can be solved by means of the shadow square and through the properties of the folded astrolabe many of the astronomical problems can be addressed, such as to find the lengths of the day and the night, the times of rising and setting, the places of sunrise and sunset.[17]

Conclusion

By detailed examination of the instrument the following conclusions can be drawn:

1. *The* quadrans novus *was made in England for use in that country.*

The reasons for this are three fold: the metallic composition is typical for England, not the continent.[18] The presence of only one horizon for the geographical latitude of 52° shows that the instrument was intended for use in England only and a comparison with the other still extant examples show a clear affinity between the present quadrant and that preserved in Oxford Merton College.[19]

2. *The* quadrans novus *was made in the fourteenth century (possibly 1388).*

The style of the lettering is consistent with that used in the fourteenth century. Since the style did not change much in that century, it is not possible to be more precise unless the interpretation of the distorted letter A as the letter B for *Bisextus* is correct, in which case the instrument can indeed be dated to 1388.

3. *The* quadrans novus *was made for use only with the Sun.*

The main reason is, of course, that stars, lunar mansions and a lunar volvelle, seen on other medieval copies of the instrument, are lacking. The emphasis on the Sun is also endorsed by the Eagle. The association of the Eagle with the Sun goes back to antiquity.[20] Through the *Etymologies* of Isidore of Seville it was known in the Middle Ages:

> The eagle (*aquila*) is named from the acuity of its vision (*acumen oculorum*), for it is said that they have such sight that when they soar above the sea on unmoving wings, and invisible to human sight, from such height they can see small fish swimming, and descending like a bolt, seize their prey and carry it to shore with their wings. It is said that the eagle does not even avert its gaze from the sun; it offers its hatchlings, suspended from its talons, to the rays of the sun, and the ones it sees holding their gaze unmoving it saves as worthy of the eagle family, but those who turn their gaze away, it throws out as inferior.[21]

The ability of the eagle was referred to in the early fourteenth century in the first canto of the *Paradiso* (line 48) of Dante's *Divina Comedia*. There the eagle's ability to look directly at the Sun symbolises the ability to look directly at God. The eagle's sun-gazing ability had lost nothing of its charm at the end of the fourteenth century when Geoffrey Chaucer used it to describe the Royal Eagle in his '*Parlement of Fowles*': '*with his sharp lok perseth the Sonne*'.[22] The Eagle on the back of the quadrant might well symbolize that for using the *quadrans novus* one has to be as sharp as an Eagle.

4. *The instrument was owned by an educated clerical scholar.*

The common astrolabe is easier to use than the *quadrans novus* but the latter's construction is much simpler and therefore cheaper, especially as its use is restricted to the Sun. Since a user of the *quadrans novus* had to have a good understanding of the rudiments of astronomy and of trigonometry, the owner can be counted among the small circle of scientifically educated scholars in fourteenth-century England. At the same time, one notes that the engravings of the circles on the front of the instrument, such as the horizon, are not as precise as is seen on other instruments such as astrolabes made in the same period by professional instrument makers.[23] In contrast, the eagle is a very nice piece of art, delightfully shaped with its spread wings. It suggests that the instrument was made by a professional metal worker, inexperienced in making instruments. The small size of the instrument suited a traveller, who may have kept it in a leather case now lost. Two such leather cases have been preserved elsewhere.[24] This recalls the image of a travelling scholar (staying in Canterbury and losing his instrument there?) who was acquainted with instruments as well as with books, judging from his use of the Roman style for the calendar dates. This Roman style was common in medieval calendars, such as discussed in treatises on the *computus* and included in hour books as it was in calendars. However, it is rarely seen in instruments, and suggests again that the making of the Canterbury *quadrans novus* was not carried out in circles of professional instrument makers.

Detailed Description

The instrument is 1.5mm thick. One side of the quadrant (OX) is 67.3mm and the other side (OY) is 67.6mm (**Fig. 6**). There are two sight vanes with holes of about 1.5mm fixed by rivets on one edge (OX) with approximate dimensions: height 11.7mm, width of the base 3.7mm, depth 3.4mm. The sight vanes are located a distance of 9.6mm from respectively O and X.

There is a suspension with a hole for a (now lacking) silken cord with bead at N, fixed by a rivet around which it could turn. This suspension is now immobilized by oxidation. There are four rivets on the other edge (OY), two of which are in the middle of a cut below the suspension at a distance of 9mm from O and the other two are at a distance of 9.4mm from Y. The rectangular cut is about 4.5mm long and 7.4mm wide.

The rivets show that repairs have been made on the side OY of the quadrant. The repair close to Y indicates that a piece of brass has been placed there to hide a cut. This shows up on the front and on the side. The piece of brass placed below the suspension is lost, revealing the shape of the cut (greyish area in Fig. 6). The most probable explanation for these repairs is that the maker first placed sight vanes on the side OY and then, after noticing his error, replaced them on the other side OX, while mending the cuts he had already made on the side OY. Other damaged

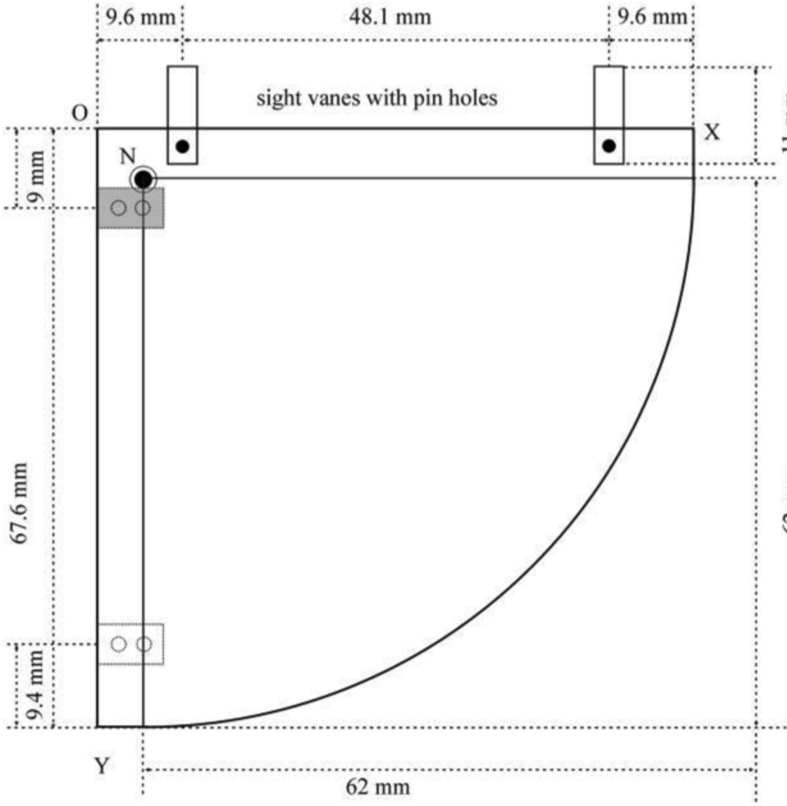

Fig. 6 Dimensions of the *quadrans novus*.

areas occur on the front (one just above the equator and another close to the ecliptic) and the back of the quadrant, all of which are caused by oxidation.

ACKNOWLEDGEMENTS

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Akerman of the British Museum for her assistance and advice following the initial finding and identification of the Canterbury quadrant.

ENDNOTES

1 The note is based on a more detailed study of the instrument by Elly Dekker published as ' "With his sharp lok perseth the sonne": a new quadrant from Canterbury', *Annals of Science* 65 (2008), 201-20.

2 These seven instruments have been described by Elly Dekker, 'An Unrecorded Medieval Astrolabe Quadrant from *c.* 1300', *Annals of Science*, 52 (1995), 1-47. At the time of writing one of these instruments (labelled PCII in this study) was not available for a detailed investigation. It was later described in the *Sales Catalogue, Christie's South Kensington*, Thursday 2 March 1995, lot 198, p. 35. This copy is now in the British Museum.

3 J. Vernet, 'Jacob ben Machir Ibn Tibbon', *Dictionary of Scientific Biography,* edited by C.C. Gillispie, XIII (1976), p. 400. Most of the Hebrew translations by Profatius are of astronomical texts such as: *On the Moving Sphere,* an Arabic translation of the Greek treatise by Autolycus (*c.*330 BC), *On the Use of the Celestial Globe,* a treatise by the Arabic astronomer Qustā ibn Lūqā who died in *c.*912, *On the Use of the Astrolabe,* a work from al-Andalus by Ibn al-Saffār (d.1035) and, also from al-Andalus, a treatise *On the Use of the Saphea* by al-Zarquāli (died 1100), an astronomer and maker of scientific instruments known in Spain as Azarquiel. For the manuscripts, see Moritz Steinschneider, *Die hebräischen Übersetzungen des Mittelalters* (Berlin, 1893; repr. Graz 1956), and José María Millás Vallicrosa, *Tractat de l'assafea d'Azarquiel* (Barcelona, 1933).

4 A Latin translation by Armengaud Blasius was made in 1290 under the supervision of Profatius himself, whereas a second edition dates from 1301. After 1301 the descriptions of the construction of the instrument have hardly changed, *see* E. Poulle, 'Le quadrant nouveau médiéval', *Journal des Savants* (1964), 148-67; 182-214, esp. 183.

5 N.L. Hahn, 'Medieval Mensuration: Quadrans Vetus and Geometrie Due Sunt Partes Principales', *Transactions of the American Philosophical Society,* 72, no. 8, (1984).

6 David A. King, *A vetustissimus Arabic treatise on the* QUADRANS VETUS', *Journal for the History of Astronomy*, 33 (2002), 237-55.

7 W.R. Knorr, 'The Latin sources of quadrans vetus, and what they imply for its authorship and date', in E. Sylla and M. McVaugh (eds), *Texts and contexts in ancient and medieval science: Studies on the occasion of John E. Murdoch's seventieth birthday* (Leiden 1997), 23-67.

8 W.R. Knorr, 'Sacrobosco's quadrans: Date and sources', *Journal for the History of Astronomy*, 28 (1997), 187-222.

9 Hahn, 1982 (*op. cit.*, see note 5), xxi-xxii.

10 There is an enormous literature on the introduction of the astrolabe in the Latin West. A convenient summary of Greek, Arabic and early Western developments is found in Richard Lorch, 'The literature of the astrolabe to 1450', in Koenraad Van Cleempoel, *Astrolabes at Greenwich. A Catalogue of the Astrolabes in the National Maritime Museum, Greenwich* (Oxford, 2005), 23-30.

11 David A. King, *Islamic Astronomical Instruments* (London, 1987), chapter I, 8-10.

12 A very clear summary of the historical development of the sine and cosine is presented by Menso Folkerts, 'Die Beiträge von Johannes von Gmunden zur Trigonometrie', in Rudolf Simek and Kathrin Chlench (eds), *Johannes von Gmunden (* c.*1384-1442) Astronom und Mathematiker* (Wien, 2006), 71-89.

13 For details, see Dekker 1995 (*op. cit.,* see note 2), 24, Table 3.

14 For a detailed description, see Dekker 2008 (*op. cit.*, see note 1), 207-12.

[15] For the perpetual calendar see O. Pedersen, 'The ecclesiastical calendar and the life of the church', in G.V. Coyne, M.A. Hoskin and O. Pedersen (eds), *Gregorian Reform of the Calendar: Proceedings of the Vatican Conference to Commemorate its 400th Anniversary, 1582-1982,* Città di Vaticano, (Vaticano,1983), 17-74; W. E. van Wijk, *Le Nombre d'Or, Etude de chronologie technique suivie du texte de la Massa Compoti d'Alexandre de Villedieu avec traduction et commentaire* (The Hague, 1936), 143-55.

[16] For a detailed description of the calendar data, see Dekker 2008 (*op. cit.*, see note 1), pp. 214-17.

[17] Poulle 1964 (*op. cit.*, see note 3), esp. 203-5 and 212. The instructions for using the shadow square resemble those in manuscripts on the geometric quadrant, the common astrolabe and the *quadrans vetus*; see S.K. Victor, 'Practical Geometry in the High Middle Ages', *Memoirs of the American Philosophical Society*, 134 (1979); Hahn 1984, 'Medieval Mensuration' (see note 5), liv-lxv.

[18] The instrument has been analysed by Peter Northover of Oxford Materials. Details are presented in his report 'Analysis and metallography of copper alloy quadrant'.

[19] For details, see Dekker 2008 (*op. cit.*, see note 1), 213, Table 1. A picture is presented in Dekker 1995 (*op. cit.*, see note 2), fig. 10.

[20] In the first century both Lucan in his *Pharsalia*, book 6, verse 799-800 and Pliny the Elder in his *Natural History*, Book 10, 3-6, wrote of the ability of the eagle to look directly at the Sun.

[21] The *Etymologies* of Isidore of Seville, edited by Stephen A. Barney, W.J. Lewis, J.A. Beach, Oliver Berghof, with the collaboration of Muriel Hall (Cambridge 2006), Book XII. vii.10-11, 264.

[22] Geoffrey Chaucer, *The Parliament of Fowls*, line 331.

[23] As an example one can quote the horary quadrants of the type made for Richard II and John Holland, see Silke Ackermann and John Cherry, 'Richard II, John Holland and three Medieval Quadrants', *Annals of Science* 56 (1999), 3-23.

[24] Dekker 1995 (*op. cit.*, see note 2).