47 Lewis, in a number of papers published between 1877 and 1914, expressed the notion that astronomical orientations might be incorporated in many megalithic monuments. See particularly Lewis 1892. He also pointed out (*ibid.*, 142) that horizon features might play a significant role, a possibility that would receive a great deal of attention more than half a century later in the work of Alexander Thom.

48 In fact, this idea was expressed as early as 1808 by James Headrick, in an editor's footnote on pp. 213–15 of George Barry, *History of the Orkney Isles*, 2nd edn, London, 1808. The idea may in fact be attributable to Joseph Banks: see Averil M. Lysaght, 'Joseph Banks at Skara Brae and Stennis, Orkney, 1772', *Notes and Records of the Royal Society of London*, 28 (1974), 221–34, p. 232, where Headrick's footnote is reproduced in full. Note that the version of Barry's *History* published by Mercat Press, Edinburgh in 1975 is a facsimile of the first edition of 1805, and does not contain the footnote.

49 There are many discussions of the historical development of these ideas. See, for example, Heggie 1981a, 83–4; Burl 1976, 14–17, on stone circles; Burl 1993, 12–14, with particular reference to Callanish; and Chippindale 1994, ch. 5, for the wider context of the early development of these ideas, and particularly the development of ideas associating megalithic monuments with Druidical practices.

50 J. Norman Lockyer, *The Dawn of Astronomy*, Cassell, London, 1894.

51 Lockyer 1909, v.

52 See especially Boyle Somerville, 'Prehistoric monuments in the Outer Hebrides and their astronomical significance', *JRAI*, 42 (1912), 23–52; Somerville 1923; 1927; A. P. Trotter, 'Stonehenge as an astronomical instrument', *Antiquity* 1 (1927), 42–53.

53 Burl 1993, 16.

54 See, for example, Burl 1993, 14–16, 84–6. For a statistical critique see Heggie 1981a, 179–81.

55 Indeed, one can find precursors of ley lines in the work of Lockyer (e.g. Lockyer 1909, 412–13).

56 Burl 1988a, 176, makes the point that most discoveries about stone circles have been made by non-archaeologists. In 1940, despite decades of research by surveyors, engineers, astronomers and so on, archaeologist Grahame Clark could still say of stone circles: 'what they signify no man can say' and 'in all essentials the great stone circles retain their mystery'. J. G. D. Clark, *Prehistoric England*, Batsford, London, 1940, 103 and 116.

57 Childe 1940, 109.

58 Stuart Piggott, *British Prehistory*, OUP, Oxford, 1949, 119.

59 Hawkes 1962, 168.

60 Thom 1955.

61 Cf. Archibald S. Thom, *Walking in all the Squares*, Argyll Publishing, Glendaruel, 1995, 175, 201, 217, 314. Somerville—a naval captain in 1912, later to become a Rear-Admiral—was a keen amateur astronomer and surveyor.

62 Childe 1955.

63 Childe 1940, 145.

64 *Ibid.*, 138.

65 Childe 1955, 293.

66 Hoyle 1966. Hoyle's ideas were subsequently developed and refined, and eventually published in two books: Hoyle 1972, 19–54; and Hoyle 1977.

67 These included Alexander Thom, 'The geometry of Megalithic Man', *Mathematical Gazette* 45 (1961), 83–93; 'The egg-shaped standing stone rings of Britain', *Archives Internationales d'Histoire des Sciences* 14 (1961), 291–300; 'The megalithic unit of length', *JRSS* A125 (1962), 243–51; 'The larger units of length of Megalithic Man', *JRSS* A127 (1964), 527–33; Thom 1966 and Thom 1969 [*Vistas in Astronomy*]; Alexander Thom, 'The lunar observatories of Megalithic Man', *Nature* 212 (1966), 1527–8; 'Megaliths and mathematics', *Antiquity* 40 (1966), 121–8; 'The metrology and geometry of cup and ring marks', *Systematics* 6 (1968), 173–89; 'The geometry of cup-and-ring marks', *Transactions of the Ancient Monuments Society* 16 (new series) (1969), 77–87. A number of popular articles also appeared in *New Scientist* magazine: Alexander Thom, 'Megalithic geometry in standing stones', *New Scientist* 21 (1964), 690–1; 'Observatories in ancient Britain', *New Scientist* 23 (1964), 17–19; 'Timekeeping with standing stones', *New Scientist* 32 (1966), 719–21; 'Prehistoric observatories', *New Scientist* 38 (1968), 32–5; and a further paper appeared in the *Journal of the British Astronomical Association*: Alexander Thom, 'Observing the moon in megalithic times', *JBAA* 80 (1970), 93–9.

68 Thom 1967.

69 Although he had travelled extensively throughout Scotland, England, and Wales, and later made many visits to Brittany, he never made any systematic investigation of monuments in Ireland, only ever making one trip there (Thom 1988, 9).

70 Richard J. C. Atkinson, Review of Thom 1967, *Antiquity* 42 (1968), 77–8.

71 See Glyn Daniel, editorial, *Antiquity* 55 (1981), 88; also Thom 1988, 9.

72 Thom 1971.

73 David G. Kendall, Review of Thom 1971, *Antiquity* 45 (1971), 310–13, p. 310.

74 Heggie 1972, 48. Heggie modified his view significantly in the subsequent decade (cf. Heggie 1981a).

75 In particular, these included several publications on the Carnac monuments, where Thom had returned several times since Glyn Daniel's original invitation: Thom and Thom 1971; Alexander Thom and Archibald S. Thom, 'The Carnac alignments', *JHA* 3 (1972), 11–26; Alexander Thom, 'The uses of the alignments at Le Ménec, Carnac', *JHA* 3 (1972), 151–64; Thom and Thom 1973; Alexander Thom and Archibald S. Thom, 'The Kerlescan cromlechs', *JHA* 4 (1973), 168–73; 'The Kermario alignments', *JHA* 5 (1974), 30–47; Thom 1974; Thom, Thom and Thom 1974; 1975; Thom and Thom 1975; Thom, Thom and Gorrie 1976; Alexander Thom, Archibald S. Thom, and T. R. Foord, 'Avebury (1): a new assessment of the geometry and metrology of the ring', *JHA* 7 (1976), 183–92; Alexander Thom and Alexander S. Thom, 'Avebury (2): the West Kennet Avenue', *JHA* 7 (1976), 193–7; Thom and Thom 1977.

76 Thom 1971, 9–11.

77 Hawkes 1967, 174.

78 Atkinson 1975, 51.

79 Fleming 1975.

80 For accounts of this, see O'Kelly 1978, 111–12; O'Kelly 1982, 123–5.

81 The results were published in a paper in *Nature* (Patrick 1974).

82 Barber 1973.

83 MacKie 1974.

84 MacKie 1977, 21.

85 Renfrew 1976, 261–3. The first edition was published in 1973.

86 Atkinson 1975, 51.

87 This is the title of ch. 8 of Thom 1967.

88 Heggie 1972.

89 Michael A. Hoskin, 'The fourth session, on "Megalithic Astronomy, Fact or Speculation?"', part of a longer editorial article on IAU Commission 41 at Grenoble, *JHA* 7 (1976), 219–23, pp. 219–20.

90 A collection of papers under the heading 'The place of astronomy in the ancient world' appeared in *PTRS*, A276 (1974), 1–276. A number of them are cited in this book.

91 Elizabeth Chesley Baity, 'Archaeoastronomy and ethnoastronomy so far', *Curr. Anth.* 14 (1973), 389–449.

92 See, for example, Anthony F. Aveni (ed.), *Archaeoastronomy in Pre-Columbian America*, UTP, Austin, 1975; (ed.), *Native American Astronomy*, UTP, Austin, 1977.

93 The term was actually coined by MacKie in 1969 at a talk given at the University of Glasgow (see Euan W. MacKie, *An Archaeological View of Neolithic Astronomy*, Hunterian Museum, Glasgow, 1970) though it appears to be used to mean the dating of archaeological structures by astronomical methods. It achieved more widespread use following the publication of Baity's 1973 article (see note 91), which included it in the title. The alternative term 'astro-archaeology', coined by Hawkins in 1965 (Hawkins and White 1970, 155 [p. 121 in the original 1965 edn]) found favour amongst some American commentators who used it to denote the more restricted study of astronomical alignments typical of megalithic astronomy (see for example Aveni 1981, 4; also Aveni 1994, 26), but was unpopular in Europe, mostly perhaps because it had proceeded to acquire connotations with the archaeological fringe. More recently, it has been pointed out that the term 'archaeoastronomy', defined as the study of ancient astronomy based on the fullest possible range of both written and unwritten evidence, is itself misleading precisely because the range of evidence is much wider than just the archaeological; thus the term 'cultural astronomy' has been suggested to embrace both archaeoastronomy and its twin discipline of ethnoastronomy (see chapter ten, note 103).

94 The *Archaeoastronomy* supplement to the *Journal for the History of Astronomy* was first published in 1979. *Archaeoastronomy*, the bulletin, later the journal, of the Center for Archaeoastronomy in College Park, Maryland, was first published in 1977.

95 Christopher Chippindale, 'Stonehenge astronomy: anatomy of a modern myth', *Archaeology* 39(1) (1986), 48–52.

96 Edwin C. Krupp, 'Introduction', in Edwin C. Krupp (ed.), *In Search of Ancient Astronomies*, Doubleday, New York, 1977, xiii–xvii, p. xiii.

97 Glyn E. Daniel, 'Megalithic monuments', *Scientific American* 243 (1980), 64–76, p. 71. In an *Antiquity* editorial the following year he added '. . . our sad view of those who make our megaliths into observatories [is that] they are deluded men' (*Antiquity*, 55 (1981), 87).

98 Burl 1970, 1976, and many subsequent publications considered elsewhere in this book.

99 MacKie 1977.

100 Stuart Piggott, Review of MacKie 1977, *Antiquity*, 52 (1978), 62–3.

101 For example, Fred Hoyle's interpretations of Stonehenge were criticised strongly by Gordon Moir, an applied mathematician, in 1979: see Moir 1979. The surveyor Jon Patrick published a critique of Thom's interpretation of a Scottish site in 1979: see Patrick 1979. A further critique of some of Thom's surveys appeared in Moir *et al.* 1980.

102 The conference led to the publication of a mixed volume of papers under the title *Astronomy and Society in Britain During the Period 4000–1500 BC* (Ruggles and Whittle 1981).

103 Heggie 1981a.

104 A major reason for this was that in the Americas there is a demonstrable degree of cultural continuity between the pre-Colonial past and the indigenous present. The 'Old World' and 'New World' proceedings of the conference were published as two separate volumes: Heggie 1982a and Aveni 1982, respectively.

105 *The Times*, 8 July 1994, p. 8. Ironically, in a 1997 advertisement for English Heritage membership (*Heritage Today* magazine, no. 37, March 1997, 13), Stonehenge is presented prominently as 'the world's oldest calendar', even though the small print qualifies this by adding 'considered by many to be . . .' A balanced view is in fact presented in a 1997 English Heritage publication, Souden 1997, 118–27.

106 Hugh Thurston, *Early Astronomy*, Springer-Verlag, Berlin, 1994.

107 Chippindale 1994, 276.

108 *Ibid.*, 230.

109 *Ibid.*, 263.

110 North 1996.

111 Hayman 1997.

112 This is implied rather than stated explicitly. The fuller quote is: 'in the late seventies, my first contact with [alternative archaeology] was through ley hunting which, alongside astronomy, was at that time at the height of its popularity. Although I quickly rejected anything I considered to be a non-intellectual notion of the past . . .' (*ibid.*, xiii).

113 Bradley 1984, 77.

CHAPTER 1

1 Galileo Galilei, *Dialogue on the Two Great World Systems*, transl. Thomas Salusbury, rev. Giorgio de Santillana, University of Chicago Press, Chicago, 1953, p. 398.

2 Thom 1954, 403.

3 Atkinson 1979, 96 [p. 89 in the original 1956 edn].

4 O'Kelly 1989, 50–2, 97–100.

5 Seán P. Ó Ríordáin and Glyn E. Daniel, *New Grange and the Bend of the Boyne*, Ancient Peoples and Places 40, Thames and Hudson, London, 1964, 21.

6 For the definitive description of the site and a detailed report of the excavation, see O'Kelly 1982.

7 Burnt material from within the tomb, apparently undisturbed since the tomb was being built, yielded uncorrected dates of 2475 ± 45 uncal BC (GrN-5462-C) and 2465 ± 40 uncal BC (GrN-5463) (O'Kelly 1982, 230–1). On radiocarbon dates and their calibration see ahead to Statistics Box 3.

8 Claire O'Kelly, 'Corpus of Newgrange art', Part V of O'Kelly 1982, 146–85.

9 O'Kelly estimated that if the circle had been complete and the stones fairly regularly spaced, then it would have consisted of some 35 to 38 stones. However, his excavations could find no trace of the stoneholes of the 'missing' stones. See O'Kelly 1982, 66, 79.

10 P. David Sweetman, 'A late Neolithic/Early Bronze Age pit circle at Newgrange, Co. Meath', *PRIA* 85C (1985), 195–221, pp. 208–9.

11 'New Grange . . . so far as I can make out, is oriented to the Winter Solstice' (Lockyer 1909, 430). Lockyer did not, *pace* Brennan 1983, 32, 'draw attention to this fact on a scientific level'.

12 O'Kelly 1982, 123–4. For a more detailed description with diagrams see Brennan 1983, 72–81.

13 O'Kelly 1982, 93–6 and fig. 52.

14 A quantitative response to the question may be couched in terms of a probability (see Statistics Box 1) that the phenomenon could have occurred fortuitously. However, it is notoriously difficult to derive a reliable estimate of this probability. Any attempt to do so inevitably rests upon a number of detailed, and often questionable, assumptions. Several general issues relating to this question will be tackled later in this chapter and in the book. For differing points of view on Newgrange see Patrick 1974; Heggie 1981a, 213, who estimates the probability that the solstitial phenomenon was not deliberate as a mere 'one in ten or fifteen' and hence 'not really significant enough to excite much interest'; and Ray 1989. Elsewhere, Ray is reported as estimating the probability that the solstitial phenomenon was not deliberate as about 1 in 300, which is strongly supportive of deliberate orientation ('Newgrange: the oldest observatory in the world, say scientists', *Irish Times*, 21 June 1988).

15 O'Kelly 1978, 113.

16 *Ibid.*, 94.

17 Patrick 1974.

18 Ray 1989.

19 *Ibid.*, 343.

20 O'Kelly's excavations uncovered unburnt bones, apparently from two individuals, together with fragments of burnt bone from at least three, and possibly a good many, more (T. P. Fraher, 'The human skeletal remains', part of Appendix B to O'Kelly 1982, 197–205, pp. 200 and 205).

21 O'Kelly 1982, 98 refers to this as the 'closing stone'. It was wedged in front of the entrance and behind the decorated entrance stone, which remains in situ.

22 O'Kelly 1982, 96.

23 Lynch 1973, 152.

24 O'Kelly 1982, 123. See also Burgess 1980, 52.

25 See O'Kelly 1982, 96–8. O'Kelly himself was confident he had restored the passage walls to their likely original height. The roof-box corbels had slipped behind the orthostats.

26 'It is difficult not to see this as a deliberate and successful attempt to incorporate the midwinter sunrise as a significant element in the planning and use of the monument.' Colin Renfrew, foreword to O'Kelly 1982, 7–8, p. 8.

27 Burl 1983, 26. Aubrey Burl has elaborated on this general theme in a number of publications, e.g. Burl 1981a; 1987a.

28 RCAHMS 1971, no. 57.

29 *Ibid.*

30 Thom 1954.

31 Thom 1971, 36.

32 Thom 1971, 13–14.

33 The exact figure depends upon the time of day at which the sun reaches its limiting declination, the event that actually defines the solstice.

34 In the remainder of this chapter, and in the following chapter, we shall continue to quote some declinations to a precision of one arc minute in order to derive a better understanding of past ideas and debates, and of the lessons that can be learned from them. Thereafter, throughout the remainder of the book, declinations will be quoted to at most the nearest 0°·1 (six arc minutes), since recent work on variable refraction (see Astronomy Box 3) suggests that higher precision is unjustified.

35 Thom 1954 (see also 1967, fig. 12.2) quoted a declination of −23°53′ for the centre of the sun setting so that its upper limb just clips the end of Cara Island and +23°54′ for the setting path with the sun's upper limb twinkling down the slope of Corra Bheinn. An independent investigation, assuming existing models for refraction uncertainties and working to high precision, obtained a postulated date of use of 1580 ± 100 BC for the Cara Island foresight and 1640 ± 70 BC for Corra Bheinn (Bailey *et al.* 1975).

36 This sort of 'astronomical dating' is usually unacceptable in an isolated case, because the chances are too great of being able to fit a spurious high-precision astronomical explanation to a horizon feature by choosing a suitable date for its supposed use. See chapter two for similar problems with stellar and high-precision lunar interpretations. For lower-precision astronomical explanations, where changes in the motions of the sun over the centuries have negligible effect, the possibility of astronomical dating does not arise.

37 See MacKie 1974, 177; Heggie 1981a, 192; Ruggles 1984a, fig. 10.5.

38 MacKie 1974, 177.

39 Heggie 1981a, 190. This in turn reveals the danger that the close coincidence in the declinations of the two foresights might have come about because of the *a posteriori* selection of the Corra Bheinn declination from amongst a rather wider range of possibilities. In deriving their postulated date of 1640 ± 70 BC for the Corra Bheinn foresight, Bailey *et al.* 1975 assume that the upper limb of the midsummer sun should clip the summit of the hill. An alternative assumption, that the limb of the sun should just appear further down the slope (to an observer by stone *b*) would yield a date closer to 1250 BC.

40 MacKie 1974, 177.
41 *Ibid.*; see also J. G. Scott, 'The *Clyde* Cairns of Scotland', in Powell *et al.* 1969, 175–222, p. 198.
42 Wood 1978, 90.
43 J. L. Campbell and Derick Thomson, *Edward Lhuyd in the Scottish Highlands, 1699–1700*, OUP, Oxford, 1963, pl. v(a). See also Burl 1979a, 66; 1980, 192.
44 Heggie 1981a, 192; see also Clive Ruggles, 'Prehistoric astronomy: how far did it go?', *New Scientist* 90 (1981), 750–3, p. 752.
45 Burl 1983, 7–11.
46 Patrick 1981, 215–17. Cf. chapter nine, note 8.
47 RCAHMS 1988, no. 63.
48 Cowie 1980.
49 Simpson 1967.
50 RCAHMS 1988, no. 63.
51 Thom 1967, 156.
52 *Ibid.*, 155. See also Thom 1971, 13–14 and 37.
53 Thom 1971, 39.
54 Thom 1988, 6.
55 Thom 1971, 39–40.
56 Thom 1969, 7.
57 MacKie 1974, 180–1; see also MacKie 1988, 210.
58 MacKie 1974, 178–85; see also MacKie 1977, 84–92.
59 It would not, however, have been conclusive. It is possible, for example, that a platform might have been built merely to aid the passage of cattle along the side of the gorge (R. B. K. Stevenson, 'Kintraw again', *Antiquity*, 56 (1982), 50–1).
60 MacKie 1974, 181–3; see also MacKie 1977, 88.
61 W. C. Krumbein, 'Preferred orientation of pebbles in sedimentary deposits', *Journal of Geology* 47 (1939), 673–706.
62 J. S. Bibby, 'Petrofabric analysis', *PTRS* A276 (1974), 191–4. This forms an appendix to MacKie 1974.
63 MacKie 1974, 184. See also MacKie 1977, 89–91.
64 MacKie 1977, 92.
65 See especially Thomas McCreery, 'The Kintraw stone platform', *Kronos* 5(3) (1980), 71–9.
66 e.g. MacKie 1981, 116.
67 MacKie *et al.* 1985, 160.
68 Patrick 1981, 213.
69 MacKie 1981, 140–1.
70 Ruggles 1984b, 240.
71 McCreery *et al.* 1982.
72 Heggie 1981a, 190.
73 Patrick 1981, 213.
74 McCreery *et al.* 1982, 189.
75 Thom 1971, 37.
76 *Ibid.* In relation to the method itself the reader's attention is drawn once more to the problems of variable refraction (see Astronomy Box 3). Even Thom (*ibid.*) recognises that the procedure would be 'bedevilled by refraction changes from evening to evening'. Because of atmospheric effects on the sun's apparent position it is misleading to suggest, even if the visibility of the col itself behind the intervening ridge were not in dispute, that the platform could have been used as a 'permanent observing point from which the day of the midwinter solstice was regularly checked' (MacKie 1974, 184).
77 Patrick 1981, 211; McCreery *et al.* 1982, 187–8.
78 For example, a different interpretation is suggested by Burl (1976, 199; 1983, 42–4).
79 RCAHMS 1988, no. 364; NMRS, no. NR99NE10.
80 P. Fane Gladwin, 'Discoveries at Brainport Bay, Minard, Argyll: an interim report', *The Kist* 16 (1978), 1–15.
81 *Ibid.*; see also RCAHMS 1988, no. 364.
82 See MacKie 1981, 131.
83 *Ibid.*, 134.
84 MacKie 1988, 213.
85 MacKie 1981, 131–4; see also MacKie *et al.* 1985.
86 A date of 1060 ± 80 uncal BC (GU 1705) was obtained for charcoal associated with flints found on top of a buried sandy soil behind the back platform (MacKie *et al.* 1985, 159).
87 MacKie 1981, 134.
88 MacKie *et al.* 1985, 159.
89 See MacKie 1988, 214 and table 8.1.
90 Hoyle (1966, 270–1) made a similar point with regard to solar and lunar alignments at Stonehenge (see below).
91 Reversing the argument, MacKie (1988, 229–30) has even used the Brainport Bay evidence in support of the general principle of precise solstitial foresights, arguing that at this particular site, assuming that they discovered rather than chose the alignment, they would have had to make do with the notch that was already present and not quite at the solstitial position.
92 Fane Gladwin 1985.
93 *Ibid.*, 17.
94 Its status as a fallen standing stone is disputed by the RCAHMS (1988, no. 364; NMRS, no. NR99NE10). A 'Car Park Stone' referred to by RCAHMS, and also considered by them to be a natural boulder, is not mentioned either by Gladwin (*ibid.*) or MacKie (1981; 1988; MacKie *et al.* 1985) in the context of calendrical alignments.
95 MacKie *et al.* 1985. See also MacKie 1988, 217.
96 MacKie *et al.* 1985, fig. 4.
97 MacKie 1988, 220.
98 Euan W. MacKie, P. Fane Gladwin and Archie E. Roy, 'Brainport Bay: a prehistoric calendrical site in Argyll', *AAJ* 8 (1985), 53–69, fig. 6.
99 MacKie 1988, 218–20.
100 The declination of the notch itself is +0°9′ (MacKie *et al.* 1985; see also MacKie 1988, 218), a value greater by the semidiameter of the sun, which is about 16′.
101 MacKie 1988, 223.
102 *Ibid.*, 230.
103 MacKie 1977, 10–12; see also MacKie 1981, 113.
104 We shall turn to more general issues of theory and procedure in chapters nine and ten.
105 A classic work on the megalithic tombs of Brittany is Jean l'Helgouac'h, *Les Sépultures Mégalithiques en Armorique*, Université de Rennes, Rennes, 1965. Another on the megalithic monuments of north-western France is Glyn Daniel, *The Prehistoric Chamber Tombs of France: a Geographical, Morphological and Chronological Survey*, Thames and Hudson, London, 1960. For a more recent interpretation see Patton 1993. General descriptions and guide books include Pierre-Roland Giot, *Les Alignements de Carnac*, Ouest France, Rennes, 1983 and Burl 1985.
106 Burl 1993, 134–46. The book as a whole presents an integrated account and catalogue of the stone rows of Britain, Ireland and Brittany.
107 *Ibid.*, 135. See also Thom and Thom 1971, 149; Alexander Thom, 'Moving and erecting the menhirs', *PPS* 50 (1984), 382–4.
108 Thom and Thom 1971; Thom, Thom and Gorrie 1976. See also Thom and Thom 1978a, 98–108.
109 Hadingham 1981, 36. The process of laying out the traverses was not easy, since much of the area is now covered in dense woodland and gorse (Motz 1988, 19).
110 Atkinson 1975, 43.
111 Thom and Thom (1971) made no attempt to estimate the probability that eight suitable backsight candidates could have arisen by chance, given the total number of monuments in the area, and this was criticised by Jon D. Patrick and C. J. Butler, 'On the interpretation of the Carnac menhirs and alignments by A. and A. S. Thom', *IARF*, 1(2) (1974), 29–39, p. 30. Atkinson (1975, 44–5) did make the attempt and concluded that Thom's results could not be attributed to chance, but Peter R. Freeman, 'Carnac probabilities corrected', *JHA* 6 (1975), 219, identified errors in Atkinson's argument and concluded to the contrary. However, such arguments are of limited value since large numbers of monuments to the south of the great menhir have been destroyed since Neolithic times by the rising sea (Hadingham 1981, 36).
112 *Ibid.*, 37–9.
113 Robert L. Merritt and Archibald S. Thom, 'Le Grand Menhir Brisé', *Arch. J.*, 137 (1980), 27–39, argue that the great menhir did indeed stand, and consider various reasons for its subsequent collapse. However, R. Hornsey, 'The Grand Menhir Brisé: megalithic success or failure?', *Oxford J. Arch.* 6(2) (1987), 185–217 concludes that the stone never stood, but dropped and shattered during its erection.
114 See also notes 14 and 111.
115 For a detailed discussion of the structural history of Stonehenge, see Cleal *et al.* 1995. For other accounts of the history of Stonehenge, with interpretation, see Burl 1987a; Bradley 1991a; Castleden 1993; and various papers in Cunliffe and Renfrew 1997.
116 Atkinson 1979, 68–101. The first edition was published by Hamish Hamilton in 1956.
117 Cleal *et al.* 1995, 465–70. In brief, Atkinson's Stonehenge I is replaced by the new Stonehenge 1 and 2; the arrival of the bluestones, which brings this period to a close, is now dated between 2600 and 2500 BC rather than around 2100 BC. His Stonehenge II and III are replaced by Stonehenge 3, where a more complex sub-phasing, with considerable uncertainties remaining, has now been identified both within the interior of the monument and from the entrance outwards to the north-east. The idea that the avenue was only completed down to the River Avon at a late phase, known as Stonehenge IV (RCHM(E) 1979, 11), has now been refuted (Cleal *et al.* 1995, 533–4).
118 For a well illustrated general introduction see Souden 1997.
119 Amongst the many accounts and discussions of Stonehenge astronomy, see especially Heggie 1981a, which gives a critical discussion from the point of view of an astronomer; and Burl 1987a, which covers the topic in a wider archaeological context. The first edition of Chippindale's *Stonehenge Complete* (Thames and Hudson, London, 1983) discusses Stonehenge astronomy in some detail (pp. 216–35), but this is considerably cut down in ch. 14 of the 1994 edition (Chippindale 1994). See also Castleden 1993, 18–27.
120 Atkinson 1979, 30; see also Heggie 1981a, 196; Castleden 1993, 60. In any case, there is no firm evidence of any structure marking an observing position at the centre of the site. As Atkinson (1979, 96) remarked: 'The assumed line of sight along the axis is not marked positively in any way, . . . [but] by the mid-points of a number of empty spaces between pairs of upright stones'.
121 In order to distinguish between the sun's position on the solstice and (say) three days before or after, the observer would need to be able to distinguish a movement no greater than 2′ in declination (see Astronomy Box 3), i.e. about 3′ in azimuth. But for a foresight at a distance of 75 m, a transverse movement of only 5 cm would shift the apparent azimuth of the foresight by about 3′. See also Atkinson 1979, 96.
122 Castleden (1987, 130) suggests that the Heel Stone could have been used to pinpoint thirteen days before and after the solstice. But at these times the daily change in declination, about 6′ according to formula (A3.2) of Astronomy Box 3, is still equivalent to a transverse movement of only about 15 cm for a foresight 75 m distant. See also Hoyle 1972, 36–40; 1977, 59; Heggie 1981a, 196.
123 In order for a spot marked on the ground to suffice as an indication of where to stand, it must be sufficient to define the observing position to within, say, 1 m. This being the case, in order to achieve a resolution of 15′, half the sun's diameter, a foresight at least 200 m distant is needed; for a resolution of 3′ the distance must be at least 1 km. The distance required, d, increases in proportion to the allowable error in the observing position, p, and in roughly inverse proportion to the resolution required, θ, according to the formula $d = p / \tan\theta$ where d and p are in the same units.
124 The lines are tabulated in Hawkins and White 1970, 143, 169 and shown in fig. 14. Some had already been identified by authors such as Lockyer and by Newham: see Heggie 1981a, 196 for details. Newham's work had been prevented from publication by a series of accidents: see Lancaster Brown 1976, 103–8; 'Newham and Stonehenge', *AA* no. 4 (*JHA* 13) (1982), S73–4.
Fig. 1.22a shows a simpler scheme, including only those alignments upon the solstices and lunar limits, which follows Hawkins and White 1970, fig. 11 (see also Hawkins 1963).
125 Hawkins and White (1970, 172) actually give 0·00006, but they made an arithmetical error and the answer by their own formula should be 0·000006. See Heggie 1981a, 148.
126 For example, given that the line from Station Stone 93 to Station Stone 94 points to midsummer sunrise, then 92–91 does so too, not because the two pairs were independently aligned upon an astronomical target, but because they form the opposite sides of a rectangle. Furthermore, because the precision of alignment being considered is only about one degree and the horizon is fairly level, a line between a pair of points indicating midsummer sunrise in one direction will inevitably indicate midwinter sunset in the other. Thus lines 93–94, 94–93, 92–91 and 91–92 should really be counted as one 'hit' upon an astronomical target, not four.
127 Perhaps the most notorious manifestation of this is the fact that only one of a line of four entrance postholes was included (Atkinson 1966, 214).
128 Atkinson considered it likely that holes *F*, *G* and *H* were tree-root holes rather than stoneholes (Atkinson 1966, 215; see also Cleal *et al.* 1995, 288–9). To this can be added the fact that the Station Stones and Heel Stone probably belong to Stonehenge 3 (see Archaeology Box 3).
129 Hawkins's targets included the 'equinox moon' at declination ±5°, but see Heggie 1981a, note 43 to p. 95, on p. 239; see also Hoyle 1966, 275. Eight equinoctial sun and 'equinox moon' alignments were included in the total of 24, but similar probability arguments apply even if these are excluded.
130 Different methods were proposed by Hawkins 1964 (see also Hawkins and White 1970, 177–83) and Fred Hoyle, 'Stonehenge—an eclipse predictor', *Nature*, 211 (1966), 454–6 (see also Hoyle 1977, ch. 5). See Heggie 1981a, 101–4 for a discussion.

131 Heggie 1981a, 103.
132 The methods predict 'eclipse seasons' or 'danger periods', which recur with a period of roughly 173 days and last for about three weeks, when it is possible that one or more eclipses (solar or lunar) may occur. All that is actually certain is that an eclipse cannot occur outside these periods. It is by no means certain that a lunar eclipse, if it occurs, will be a 'proper' umbral one; penumbral eclipses often pass unnoticed. Even if it is umbral, it will only be visible at best from that half of the earth where the moon is up in the sky at the time. A solar eclipse, if that occurs, will most likely be partial, and once again most partial solar eclipses pass unnoticed. It is highly unlikely that a total solar eclipse (which may well be what many people have in mind when they hear of these ideas) will be visible from a given spot such as Stonehenge. 'A priest could hardly gain credit by successes that might be ten years apart' (Hawkes 1967, 176). For the technical background see Thom 1971, 17–19. See also Heggie 1981a, 103.
133 Sadler 1966; see also Heggie 1981a, 104.
134 Two relatively recent examples are the idea that they were used to help determine the exact length of the lunar synodic (phase-cycle) month (C. T. Daub, 'The Aubrey Holes revisited', *QJRAS*, 34 (1993), 563–5) and the idea that they were used as a device for calculating areas of land (T. H. Kirk, 'The significance of the 56 holes of the Aubrey Circle at Stonehenge', *QJRAS*, 34 (1993), 567–8).
135 Cf. Chippindale 1994, 223–5.
136 Burl 1969, 7–8; 1981b, 22–3 and table 1, which is reproduced in Burl 1987a, table 8.
137 The fact that it is possible to invent other schemes to predict eclipse seasons using different numbers of pits in the circle (Sadler 1966, 1120; R. Colton and R. L. Martin, 'Eclipse cycles and eclipses at Stonehenge', *Nature*, 213 (1967), 476–8, p. 478; and even see Hawkins and White 1970, 185; for an overview see Heggie 1981a, 205) shows how easy it is to fit this sort of theory to a given number of pits and reinforces the general conclusion that eclipse prediction was not the actual purpose of the Aubrey Holes.
138 E.g. Richard F. Brinckerhoff, 'Astronomically-oriented markings on Stonehenge', *Nature*, 263 (1976), 465–9; A. D. Beach, 'Stonehenge I and lunar dynamics', *Nature*, 265 (1977), 17–21. For a rejoinder see Richard Atkinson, 'Interpreting Stonehenge', *Nature*, 265 (1977), 11.
139 Thom, Thom and Thom 1974, 86–8; 1975. See also Thom and Thom 1978a, 151–62.
140 Of the four proposed foresights one, a mound at Hanging Langford, is part of a complex dating to the Late Iron Age or Romano-British period; one, an earthwork at Gibbet Knoll, is probably the remains of a Civil War gun-battery; one, a mound at Figsbury Rings, overlies modern ridge and furrow cultivation; and the fourth, Peter's Mound, has been shown by excavation to be a First World War military rubbish dump (Atkinson 1981, 209; see also Atkinson 1982, 114). The Thoms also identified the top of Chain Hill as the site of a further lunar foresight, but found no surviving candidate for the foresight itself. The Thoms identified these putative foresights by examining the eight possible lunar sightlines radiating out from Stonehenge (Thom and Thom 1978a, 151), as was the case with the putative backsights for Le Grand Menhir Brisé. See also Castleden 1993, 25.
141 Burl 1987a; Castleden 1993.
142 Pitts 1981. Interestingly, R. S. Newall had suggested in 1929 ('Stonehenge', *Antiquity*, 3 (1929), 75–88, p. 84) that the Heel Stone might have had a companion, on the grounds of symmetry about the axis. See also Archaeology Box 3.
143 Atkinson 1966, 215.
144 Cleal *et al.* 1995, 102–7, 152–3. This does not, of course, prove Hawkins's or Hoyle's arguments.
145 Newham 1993, 35–8 [1972, 23–5]. See Burl 1979a, 65; 1987a, 144.
146 In 1973 they were assumed to date to the Late Neolithic (Lance Vatcher and Faith Vatcher, 'Excavation of three post-holes in Stonehenge car park', *WANHM*, 68 (1973), 57–63), but the presence of pine, and subsequent radiocarbon dating (A. J. Walker, R. S. Keyzor and R. L. Otlet, 'Harwell radiocarbon measurements V', *Radiocarbon*, 29 (1987), 78–99, pp. 78–9) indicated dates back in the eighth millennium BC. See Cleal *et al.* 1995, 526–7; also Castleden 1993, 28–9.
147 Castleden 1993, 30, 52.
148 Box entitled 'Dead snails and Stonehenge astronomy', in Christopher Chippindale, 'Life around Stonehenge', *New Scientist*, 101 (1984), 12–17, p. 13.
149 Castleden 1993, 92.
150 See, for example, the passage written by Thom and quoted in Chris Jennings, 'Megalithic landscapes', in Ruggles 1988a, 155, 172.

151 For examples see chapter seven, note 3.
152 Peter D. Hinge, 'The distribution of visibility from stone alignments: a case study', unpublished MSc thesis, University of Leicester, 1990, 2.
153 Newham 1993, 26 [1972, 18].
154 See note 136.
155 Henshall 1972, 381–3, no. ARN 10.
156 Burl 1981a, 253, 256.
157 *Ibid.*, 254–6. Table 7.1 lists 22 tombs, fig. 7.3 shows 21 (tomb ARN 13 is omitted and ARN 8 contains three tombs) and the text on p. 256 refers to twenty (Carn Ban plus 'nineteen others').
158 Strictly, the orientation pattern of the Arran tombs as a whole leads us to have much less confidence in the Carn Ban alignment being anything other than fortuitous, but we can never say for certain that it was not intentional: particular considerations may have operated at this monument alone. Further consideration of this possibility leads us towards issues that will be addressed in chapter ten.

CHAPTER 2

1 Thom 1981, 54–7.
2 Gingerich 1981, 117.
3 Ferguson 1988, 32.
4 The four levels were first identified in Ruggles 1981, 153–4 and 189. While they present Thom's ideas in a logical progression, they do not entirely reflect the order in which those ideas developed. For instance, a 'Level 2' histogram showing the sun's limbs appears in Thom 1954 (fig. 2).
5 Thom 1955, tables 5 and 6.
6 Thom 1967, table 8.1. The table also contains a line at Burnmoor, Cumbria (Thom's L1/6) simply marked 'meridian' with no declination given.
7 Thom 1967, chs 9 and 10 respectively.
8 Thom 1969. The definitive version was published in book form in 1971 (Thom 1971).
9 Thom 1971, ch. 7.
10 Thom and Thom 1978b; 1980a; Thom 1981.
11 Thom and Thom 1980a, S88; Thom 1981, 38.
12 Ruggles 1981; 1982b; 1983.
13 Heggie 1981b, S18–19.
14 The term 'curvigram' was coined by this author as a convenience (Ruggles 1981, 156).
15 Measured declinations are quoted by Thom to the nearest 0°·1.
16 For Thom's own graphs, see Thom 1955, fig. 8 and Thom 1967, fig. 8.1. These are similar in form but distinguish between rising and setting lines and show all the constituent humps rather than just the cumulative result. They also show the proposed astronomical targets.
17 The area under each constituent hump is 1·0. The *y*-values reflect this and have no other significance. Note especially that comparison from one graph to another on the basis of the y-values will only have meaning if the *x*-axes are calibrated in the same units and the areas under the two sets of humps truly reflect the relative weightings to be assigned to the two sets of indications.
18 The *x*-axis resolution used in displaying these graphs is 0°·2, which is all that is needed in order to illustrate the points made here. In the case of Fig. 2.3c, where the standard deviation of most constituent humps is only 0°·1, this results in a very jagged appearance. For a version of Fig. 2.3c with a much finer *x*-axis resolution, see Ruggles 1984b, fig. 5, which can be directly compared with Thom's own graph (Thom 1967, fig. 8.1).
19 For the form of curve that would be expected given random orientations, see ahead to Fig. 3.4. Whether they are significantly different has, of course, to be determined by suitable statistical analysis. See, for example, Thom 1955, 286–8; Freeman and Elmore 1979; Patrick and Freeman 1988. However, our primary concern here is with data selection questions that affect the validity of such statistical tests in the first place.
20 Cooke *et al.* 1977, 130. The dangers are evident in using supposed stellar alignments to try to provide a construction date, a good example being the various attempts to fit stellar explanations to the avenue and radial rows of stones at Callanish in Lewis (see chapter eight, note 123), all of which yielded dates around 1750 BC. In fact, it is clear that they represent 'no more than the selection by modern researchers of stars which happened to be rising in the right place at the seemingly right time' (Burl 1982, 145), as is confirmed by the archaeological evidence placing the construction of the monument considerably earlier (chapter eight).
21 Thom 1955, 284–8. The analysis found that significantly more stellar 'hits' were obtained for a date of around 2100 BC than for other dates, suggesting that many of the supposed stellar alignments were indeed deliberate and mostly erected around this same date. For a commentary see Heggie 1981a, 162–8.
22 Thom himself addressed this issue in Thom 1967, ch. 13.
23 Bradley E. Schaefer, 'Atmospheric extinction effects on stellar alignments', *AA* no. 10 (*JHA* 17) (1986), S32–42. The implication is that if a structure was aligned upon the first appearance, or last disappearance, of a certain star, the shallow angle at which celestial bodies rise and set at the latitude of Britain or Ireland would generally result in an orientation significantly different from that to be expected if the point of reference was the theoretical point of appearance or disappearance on the horizon (see *ibid.*, S37–41 for quantitative arguments). Where the horizon is higher the problem is lessened.
24 This means that even if a number of alignments were set up at around the same time and oriented upon the appearance or disappearance of the same star, changes in day-to-day atmospheric conditions, and conditions from site to site, would be sufficient to scatter the orientations considerably (*ibid.*, S38).
25 See also Ruggles 1984b, 246–8.
26 Thom 1955, 284.
27 Thom 1967, table 12.1.
28 *Ibid.*, 135.
29 Thom was kind enough to supply the author in the early 1980s with a copy of his full unpublished site list, which was used in the full reassessment described in chapter three.
30 Thom 1967, table 8.1.
31 Examples are the five-stone row (in which four stones now remain) at Quinish, Mull (Thom's M1/3; ML2 in List 2) and the three-stone rows at Dervaig S (Thom's M1/6 'Dervaig C'; ML11 in List 2) and Balliscate (Thom's M1/8 'Tobermory'; ML4 in List 2).

We prefer wherever possible to use the term 'stone row' rather than to follow Thom and speak of 'stone alignments'. This is because the use of the latter term tends to lead to a prejudgement about the function of the monument. In this we follow, for example, Ó Nualláin 1988 and Burl 1993.

32 Examples are the three-stone row at Carloway (Clach an Tursa), Lewis (Thom's H1/16; LH6 in List 2) and the alignment of two slabs at Barbreck, mid-Argyll (Thom's A2/3; AR3 in List 2), a monument that will be mentioned later (p. 76).
33 Ruggles 1981, 156–8.
34 Examination of the unpublished site list does show, however, that a great many sites included there and not carried forward to the general reference list are antiquities marked on nineteenth- or early twentieth-century 1:10560 (6-inch) Ordnance Survey maps which are of doubtful archaeological status or in a hopeless state of repair, and thus were quite legitimately omitted from further consideration (Ruggles 1982a, 93).
35 Many megalithic rings are accompanied by outlying standing stones placed a small distance outside the ring. This type of indication raises the issue of how accurately the centre of the ring can be defined, especially when it is significantly non-circular. With the exception of a few rings with a central standing stone (Burl 1976, 205–8), we usually know of no marker at the centre.
36 'The most difficult part of the whole investigation is to decide when to include a line and when to exclude it. The decision must always be a matter of personal opinion and is influenced by the viewpoint and the other lines with which, at the time, it is being compared' (Thom 1967, 96).
37 Examples are Blashaval (Na Fir Bhreige), North Uist (Thom's H3/8; UI19 in List 2), Maol Mor, Mull (Thom's M1/4 'Dervaig A'; ML9 in List 2); Ardnacross, Mull (Thom's M1/9; ML12 in List 2); *BFL* ($S_5S_1S_2$) at Nether Largie ('Temple Wood'), mid-Argyll (Thom's A2/8; AR13b in List 2); Dunamuck I, Mid-Argyll (Thom's A2/21 'Dunamuck North'; AR28 in List 2); and Escart, Kintyre (Thom's A4/1; KT5 in List 2). See also Heggie 1981a, 160.
38 In his 1967 data table (Thom 1967, table 8.1), Thom did include eighteen indications (Class C, see *ibid.*, 96) for no reason other than that they produce an interesting astronomical declination. However, these were omitted from his own graph (*ibid.*, fig. 8.1) and are omitted from our Fig. 2.3. The most serious questions relate to almost half (112) of the remaining 243 lines which are classified as Class B: 'borderline cases' in which there is a subjective element. These are shown unshaded in Thom's figure, but mixed in with Class A alignments which Thom considered to be fully objective. They are also shown unshaded in Fig. 2.3, but separated from Class A lines so that their effect upon the overall result is clear. For additional commentary see Heggie 1981a, 153.
39 Ruggles 1982a, 94. Similar questions will arise at the higher Levels. On unwritten selection criteria see also Heggie 1981a, 159–62.

40 Ruggles 1981, 168–9.
41 Ruggles 1982a, 94–5.
42 Thom, Thom and Burl 1990, 323. The fact that the quoted declination is that of an indicated foresight is not recorded in Thom 1967, table 8.1.
43 Thom 1971, 11–12; Thom and Thom 1978a, 178. On Castlerigg itself, see Thom 1966, 22, figs 21, 38 and 39.
44 The distant island of Boreray is listed as an indicated foresight with a declination of +8°·8 (Thom 1967, table 8.1).
45 RCAHMS 1928, no. 170; Ruggles 1984a, 46 (UI12). See also Moir 1981, 233.
46 Moir 1981, 226–7; Ruggles 1984a, 48 (AR36).
47 'Another of [Captain Riddel's] imitations was a Bronze Age stone circle which he erected on a knoll a short way up the river. It is now a most realistic affair, correct in lay-out and so weathered as to take in anyone. It should be a warning to all antiquaries.' 'The Glencairn Area', in 'Field meetings', *TDGNHAS* 25 (1948), 182–6, p. 185. See also Moir 1981, 232.
48 Thom 1967, 151.
49 Burl 1988a, 179. See also Moir 1981, 235.
50 Thus for example Thom's Leacach an Tigh Chloiche (H3/11), 'a mixture of open kists and upright stones' which from the astronomical point of view he considered the most important site on North Uist (Thom 1967, 131), is in fact the remains of a large chambered tomb known to archaeologists as Unival (Moir *et al.* 1980).
51 Even the relatively few (sixteen) solstitial alignments listed in Thom's earliest paper on megalithic astronomy (Thom 1954, table 5) include many different types of indication.
52 It also seems to contradict the related idea of Thom that a precisely defined unit of measurement (the megalithic yard) was uniform from the Orkney islands to Brittany to a precision of about 0·1 mm, a point made by Fleming 1975.
53 In addition, the construction of the various monuments in Thom's sample spans over two thousand years of prehistory, and excavations have highlighted instances where monuments have been modified and reused over considerable periods of time (see p. 77), which only serves to reinforce this doubt.
54 Ruggles 1982a, 94.
55 Thom's data are given in Thom 1967, table 10.1 and the result resembles Thom's own graph, *ibid.*, fig. 10.1. We have assumed a standard deviation of 0°·1, with 0°·2 being used for those less accurate lines marked '±' by Thom. To judge by the specimen humps shown at the foot of Thom's graph, these values appear to match those employed by Thom. Three lines marked '±' in Thom 1967, table 8.1 are not marked thus in *ibid.*, table 10.1, but have nonetheless been assumed to be less accurate. For other details concerning the raw data, which explain minor differences between our graph and Thom's, see Ruggles 1981, 159.

The major and minor limiting declinations are taken, following Thom (1967, table 10.1), to be −29°·95, −19°·58, +17°·94 and +28°·17. This corresponds to a date somewhere between 2000 and 1500 BC (see Astronomy Box 6), but given the level of precision concerned, the data are not greatly affected by date.

56 In fact, Thom 1967, fig. 9.2 shows a slight preference for the upper limb at the winter solstice and almost total preference for the upper limb at the summer solstice. There is no definitive bimodal structure amongst the clusters of declinations at other calendrical epoch dates included in the same graph, but then even if there was a preference for one or other solar limb in such observations, it would be blurred out by the inherent uncertainty in each epoch declination and by the fact that two distinct epoch dates fall close together in each case. See also Heggie 1981a, 156–7.
57 In fact, a Kolmogorov–Smirnov test suggests that a normal distribution does provide an adequate fit, at least to the data in Thom 1966, table 4, which represents a subset of the data in Thom 1967, table 10.1. See Heggie 1981a, note 124 to ch. 7.
58 Thom 1967, 165; Alexander Thom, contribution to 'Hoyle on Stonehenge: some comments', *Antiquity* 41 (1967), 95–6.
59 Ruggles 1981, 159–74.
60 See Thom 1967, 121. Thom also cuts off the data further than 0°·8 from the mean and excludes these other lines—i.e. humps whose maxima fall outside the range −0°·8 to +0°·8—from his graph (Thom 1967, fig. 10.1). For the same graph but with the other data included, see Ruggles 1981, fig. 4.1a.
61 The authenticity of a further monument, Corogle Burn (L20), was considered doubtful by Ruggles (1981, 165 (site 18)), but subsequent work (Burl 1988b, 108–9) suggests that it is in fact genuine, comprising a four-poster and outlying pair.
62 Five indications involve chambered tombs or cairns, either as foresights or backsights. Ruggles (1981, 164) also relegated these to lower archaeological status, arguing that such monuments were dubious contenders as components of sightlines since they had an obvious primary function as burial places. This reasoning, however, attempts to impose a single function and meaning on such monuments, and is thus flawed (see p. 89). The symbolic placement of burial monuments within the natural landscape, and in relation to earlier monuments pre-existing within the landscape, is an important topic that will be considered later.
63 The use of 'stones' that are not necessarily antiquities as foresights also raises the question of whether they were identified by the dangerous procedure of searching outwards from a putative backsight in promising directions: see pp. 34–5.
64 In one case (L18), the 'outlier' is also very close to the stone circle, an inherently imprecise method of indication which fails to conform to Thom's own selection criteria for solar or lunar lines (Thom 1967, 94). The other outlier (L8) is more distant but still violates these criteria (Ruggles 1981, 168 (site 6)).
65 This is greater than the figure quoted in Ruggles 1981 because lines involving chambered tombs or cairns have not been assigned lower status for this reason alone (see note 62).
66 As an example, one of the indications (at site L51, Castlerigg in Cumbria) is the major axis (maximum diameter) of a flattened stone circle, according to Thom's interpretation of its geometry (see Thom, Thom and Burl 1980, 28–9). Yet the major axis of Brats Hill (Thom's 'Burnmoor E', site L53(e)), a stone ring in the same region that has a very similar geometrical form (a fact noted by Thom himself: see Thom, Thom and Burl 1980, 40–1), has no astronomical interpretation, lunar or otherwise. The two proposed lunar indications at Burnmoor E are from its centre towards the centres of other stone circles.
67 For details see Ruggles 1981, 168–72 and table 4.1.
68 See also Ruggles 1981, 169.
69 The detailed comments given in Ruggles 1981 have been thoroughly rechecked and updated as necessary.
70 Thom 1971, table 7.1.
71 *Ibid.*, ch. 6. For cross-references see Table 2.3.
72 *Ibid.*, ch. 5.
73 For a horizon feature 30 km distant, a sideways shift in the observer's position of 10 m will cause the azimuth of the foresight to change by approximately 1 arc minute. But for a horizon only 3 km distant, a sideways shift of only 1 m will have the same effect. In fact, in Thom 1971, table 7.1 azimuths and altitudes are only quoted to the nearest arc minute.
74 This terminology follows Cooke *et al.* 1977.
75 A standard deviation of 0′·75 has been used, which appears to match Thom's humps, in all but two cases where a declination is only quoted to 1′ by Thom and a standard deviation of 1′·5 is used. The mean extreme (geocentric lunar) declinations used to calculate the relevant differences are ±29° 2′·3 and ±18° 44′·6.
76 It actually varies between about 14′·7 and 16′·7.
77 See Thom 1971, 45–51.
78 Ruggles 1981, 175.
79 At Nether Largie, for example, the only direct indication of the proposed foresight to the north-west is the alignment from a rectangular setting of small stones 5 m SSW of the large standing stone *F*, which Thom labelled 'Group *Q*', over the south-west circle at Temple Wood. A number of equally (and at least some arguably more) plausible alignments, can easily be identified (see Fig. 2.9d), and the subsequent discovery by excavation of a second stone circle at Temple Wood (Scott 1989) merely increases the possibilities, given that one is prepared to speculate that the Nether Largie stones and either of the nearby Temple Wood circles were contemporary and directly related in the first place.

Regarding the overall figures, two of the four lines at Nether Largie/Temple Wood listed by Ruggles 1981, 178–9 as indicated are in fact unindicated; on the other hand two lines at Kintraw listed as unindicated are in fact indicated (*ibid.*, 198, note 1). Thus the total is unaltered.

80 This fact is obscured by the scarcity of site plans in Thom 1971. In 1971 Thom evidently felt, as he had a few years earlier, that 'if there is a suitable natural foresight which gives a commonly found solar or lunar declination exactly then we are entitled to suspect that there had been a secondary indicator which would have identified the foresight but that it has vanished' (Thom 1967, 94) but no longer felt that 'such a line could only be given a low classification and would not be put on a general histogram' (*ibid.*).
81 Later, Thom and Thom (1980b, S90–1) did precisely this, stating: 'if we

stand at a marked backsight and make careful measurements of the profile of part of the horizon which turns out to contain a significant position, we can assume that we are at a real observing point.' This is quite evidently a circular argument.

82 This is evident for two reasons. First, at such locations there are generally very many horizon features similar to those that have been considered elsewhere by Thom as putative foresights (cf. Burl 1976, 143 on the western horizon at Nether Largie; Gingerich 1981, 117). Second, at this level of precision astronomical targets are numerous: there are nine in each lunar band (see Astronomy Box 7), making a total of seventy-two potential targets on any 360° horizon. Assessing the probabilities formally would involve going out to randomly selected locations and undertaking a careful survey of all the horizon features with the same enthusiasm as would be applied at a real monument, something that few have been prepared to do. However, control data of a similar nature have been collected as part of the North Mull project (see chapter seven).

83 This is difficult using purely statistical methods. We could analyse all equally plausible horizon features around the entire horizon regardless of their astronomical potential; but since no more than a handful could possibly have been used simultaneously, even from the most propitiously placed monument, and since without prejudging the result we can not know which, any significant trends would inevitably be submerged in the loud 'background noise' of random data (Ruggles 1981, 180). The problem is similar to that of detecting foresights close to the solar solstices suitable for 'halving the difference', which was discussed in chapter one. An approach that attempts to overcome this problem by introducing contextual argument is discussed in chapter seven.

84 Ruggles (1981, 186; 1982a, 87–8) describes several more examples. Further evidence is provided by a comparison of the indicated foresights in both Level 2 and Level 3: see *ibid.* (169 and table 4.2).

85 The standard deviation is taken as 1′·5 throughout. For reasons why nothing greater is justified see Ruggles 1981, 183. See also Patrick 1979, S81–2.

86 See particularly McCreery 1979 and Gordon Moir, 'A review of megalithic lunar lines', *NA*, 1(1) (1980), 14–22.

87 For example, at Knockrome (L35) there are two standing stones in line with a third 1 km away at Ardfernal (JU3 in List 2). The long alignment provides a much more precise and convincing indication than the flat faces of the central stone, but appears to have no astronomical significance (Ruggles 1981, 183).

88 An example is the north-west foresight at Nether Largie (Patrick 1979, S78–83).

89 The most notable example here is Parc-y-Meirw (L56), where the proposed foresight is 145 km away in Ireland. McCreery (1979, 50–2) argues that the proposed foresight could probably never have been seen at all. The opposite direction along the row, uphill towards a megalithic tomb, was more probably of interest (Burl 1993, 99).

90 Thom 1971, ch. 8. For other explanations of Thom's extrapolation procedure see Wood 1978, 114–29; McCreery 1980, 7–11; Heggie 1981a, 98–100.

91 Thom 1971, 103–5.

92 Ruggles 1981, 193–4. At Dirlot (L2), for example, the alleged markers of the extrapolation length are stones in a modern stone fence (Atkinson 1981, 206 (site 2)).

93 *Ibid.*, 194.

94 Heggie 1972, 47; McCreery 1980, 12–14. See also Ruggles 1981, 194.

95 Heggie 1972, 47.

96 Ruggles 1982a, 87.

97 In fact, the dataset used by Thom and Thom 1980a and Thom 1981 consisted of all indications they considered to have been reliably measured—a total of forty-two. Detailed reasons are given by Archie Thom (Thom 1981, appendix 1.1) why indications included in earlier analyses were not now suitable. Of these forty-two lines, twenty-three were amongst a sample of twenty-five examined separately in an earlier paper (Thom and Thom 1978b) as being most convincing according to strict terms of reference. Following Ruggles 1982b, S21 we take as the Level 4 dataset all lines in either or both of the Thoms' analyses, forty-four in all.

The full dataset at Level 4 is not reproduced here, since it overlaps considerably with that at Level 3. For a complete list see Ruggles 1982b, table I.

98 This overcomes some of the problems identified in the Level 3 reassessment but fails to address others, and actually creates several more. For full details see Ruggles 1983; for brief notes on the astronomical complications at Level 4 see Astronomy Box 7.

99 In both the analyses of twenty-five lines and of forty-two lines (see note 97), the calculated residuals (differences between measured and expected declinations), and hence the inferred precision of the sightlines, are of the order of 1′ or 2′. In the first case see Thom and Thom 1978b, table 3. In the second see Thom and Thom 1980a, table 1 or Thom 1981, table 1.1.

100 Ruggles 1982b; 1983.

101 For more detailed descriptions and archaeological interpretations of Brodgar and Stenness see Renfrew 1979, ch. 5; Ritchie 1985. On historical accounts of Brodgar, see Ritchie 1988.

102 Thom and Thom 1973; 1975; 1977. See also Thom and Thom 1978a, ch. 10. The quote is from *ibid.*, 123.

103 Ruggles 1982b, S23–7.

104 Thom and Thom 1978a, 137.

105 Excavations of the ring ditch at Brodgar (Renfrew 1979, ch. 5) yielded no useful radiocarbon dates, but the conclusion can be made by comparison with other Class II henges and, indeed, henges in general (see Archaeology Box 2). The Ring of Brodgar itself is central to the whole astronomical interpretation. Two of the nine proposed sightlines involve Fresh Knowe, the Thoms' mound *B*, which is possibly even earlier (see Ruggles 1982b, S24), but the date of all the mounds is uncertain and they could in fact have been constructed as late as 1700 BC.

106 The date of the rock-cut ditch at Stenness has been established by excavation and radiocarbon dating. See Ruggles 1982b, S27 (line 11).

107 The data are taken from Ruggles 1982b, table I, col. 13. This shows 15 class 'A' lines, one of which is at Brodgar.

108 Atkinson 1981, 207–8, site 38.

109 For details see Ruggles 1982b. For further commentary see Ruggles 1984b, 253–5.

110 For details, and the results of an attempt at fairer selection using predefined criteria, see Ruggles 1983, S9–13.

111 See note 11.

112 See in particular Thom and Thom 1978a, ch. 2; 1978b, 174–8; and 1980a.

113 Ruggles 1983, S13–31.

114 Thom and Thom 1978b, 174.

115 See Ruggles 1983, S25 and note 157.

116 Thom and Thom 1978b, 178.

CHAPTER 3

1 Heggie 1981a, 140.

2 Bradley 1984, 77.

3 Ruggles 1984a.

4 *Ibid.*, 20–1.

5 For example, the stone circle and nearer 'outliers' at Lochbuie, Mull (ML28 in List 2) may seem like one site, but what about the circle and standing stone at Strontoiller, Lorn (LN17 in List 2), 200 m apart and hidden from each other by intervening high ground? Similarly, it may seem obvious that each of the stone rows of North Mull—up to 20 m long—should be treated as a single site, but what about the 900 m-long alignment of three standing stones at Ardfernal/Knockrome in Jura (JU3 and JU4 in List 2)? See *ibid.*, 26.

Indeed, the whole concept of a 'site' may be unhelpful and even questionable in the first place (see ahead to Archaeology Box 6).

6 This judgement was strongly influenced by Thom's results at Level 1, so that, at the very least, it promised to reveal what remained at the core of Thom's 'megalithic astronomy' once any preferences owing to unwitting selective bias in Thom's own data were removed.

7 The code of practice used in the project evolved from an initial set of selection criteria developed in 1975 and tested at the group of sites around Callanish, Lewis (Cooke *et al.* 1977). These earlier criteria were modified in order to take account both of unexpected site configurations that were encountered, and of suggestions and criticisms by others (on the difficulties of devising suitable criteria see Heggie 1981a, 141; 1981b, S19). A further guarantee that selection procedures at particular sites were not influenced by astronomical predilections was provided by the fact that the reduction of the site survey data did not commence until the entire programme of fieldwork had been completed in 1981; the results did not start to become available until 1983.

8 For a different attempt to define selection criteria see Hawkins 1968, 48–50; for a critique see MacKie 1977, 98–100.

9 See, e.g., Ruggles 1984b, 255–6.

10 Ruggles 1984a, 21.

11 RCAHMS inventories were being prepared for mainland Argyll and the Inner Hebrides during the 1970s and 1980s, so that up-to-date information for these areas was generally available. During the lifetime of the project two of the Argyll Inventories were already published (RCAHMS 1971; 1975), and pre-publication information was available for two more (RCAHMS 1980; 1984) thanks to the co-operation and generosity of the Commission. Only information for mid-Argyll was lacking, and an extensive site list published by Campbell and Sandeman (1961) was used instead. The site list given in this book (List 2) gives cross-references to the more recent mid-Argyll inventory (RCAHMS 1988); for cross-references to Campbell and Sandeman's list see Ruggles 1984a, table 2.1.

In the Outer Hebrides, however, the only information available from the RCAHMS was collected back in the 1920s (RCAHMS 1928).

12 This archive, held at the time of the project on index cards by the Ordnance Survey office in Edinburgh, provides descriptions of Scottish monuments of all periods organised geographically. The NMRS is now held in electronic form by RCAHMS (see Archaeology Box 1).

13 There are 207 such sites, of which the fullest published list (Thom 1967, table 12.1) contains only eighty-five.

14 Burl 1976, appendix 1.

15 For a discussion of these criteria see Ruggles 1984a, 23 and 26.

16 For the full list see Ruggles 1984a, table 2.1.

17 This was due to the fact that the RCAHMS inventory of the island was being prepared while the project was under way.

18 For full details see *ibid.*, 44–58.

19 Ruggles 1984a, 20–1. As an example, consider the selection criterion: 'the orientations of all lines joining two standing stones at a site are to be included in the analysis (in both directions)'. At a site consisting only of two standing stones this is a good criterion, as these are the most obvious ways in which an orientation at the site might be significant. However now consider a circle of twenty stones: the criterion would have us include from the site some 380 orientations, virtually all without a doubt of no particular significance. See also Heggie 1981a, 151–2.

20 An exception was made where there were more than six structures of the highest existing classification at a site. In this case no indications were considered at the site.

21 For all the details see Ruggles 1984a, 59–64.

22 The most significant departure from Thom's own selection criteria at Level 1 was the decision not to consider any indications involving stone rings. The problem is that most stone rings are not perfectly circular or in a good state of repair, which means that there can be considerable uncertainty in determining the centre unless geometrical assumptions are made. Geometrical hypotheses are formally independent of astronomical ones, and until a consensus has been reached in both areas, it can be highly misleading to make geometrical assumptions in the process of testing astronomical hypotheses (Ruggles 1984a, 61; see also Clive Ruggles, comment on Ellegård 1981, *Curr. Anth.*, 22 (1981), 121–2, p. 122). Quite apart from this, there are very few instances of a stone ring together with a single outlier amongst the western Scottish data. The orientations of stone rings and outliers should, it was felt, form the basis of a separate study based in regions where such monuments are more common. See Ruggles 1984a, 61.

23 Ruggles 1984a, 63.

24 Although examples are found throughout the region, there are three notable concentrations: one, around Callanish in Lewis (sites LH10–24), consisting mainly of stone rings; another, in the flat neck of Kintyre between Machrihanish and Campbeltown (sites KT27–39), consisting almost entirely of single stone slabs; and the last, in North Uist (sites UI22–37), consisting of a greater diversity of types of monument.

25 Ruggles 1984a, 65–7. In brief, foresights more than 6 km distant were dismissed. Those on the horizon as seen from the backsight, or on a ridge with more distant horizon beyond, and subtending at least 1 arc minute, were assigned to Class 1. Class 2 contains all other foresights within 3 km, and Class 3 all others within 6 km.

26 For full details, including on-site lines of lower categories and inter-site lines, see Ruggles 1984a, table 11.1.

27 This was to ensure that the assumed observing positions for different indications had been chosen in a consistent manner, rather than to imply that observations had necessarily been made from that position in prehistoric times (*ibid.*, 59–60).

28 See note 7.

29 Ruggles 1984a, 60.

30 *Ibid.*, 60, 65.

31 *Ibid.*, 65.

32 For details see *ibid.*, sections 5.3, 6.3, 7.3, 8.3, 9.3 and 10.3.

33 *Ibid.*, figs 5.2–5.14, 6.3–6.15, 7.2–7.11, 8.2–8.12, 9.2–9.10, and 10.2–10.12.

34 For curvigrams of the overall azimuth and declination distributions see Ruggles 1984a, figs 12.10, 12.11, 12.14 (which presents the same data as Fig. 3.3) and 12.15.

35 This was felt to be important in order to avoid a subjective decision as to the original probable indication in cases where the direction of the original structure orientation was uncertain within wide bounds (Ruggles 1984a, 307; 1984b, 247).

36 See Ruggles 1984a, 19.

37 Although the classical hypothesis-testing method adopted dictated that a null hypothesis of this form should be considered (see Statistics Box 4), the orientations observed could not in fact have arisen randomly, although they could have arisen through the interaction of factors unrelated to astronomy. There remains a need to test that such processes would in fact lead to a pseudo-random distribution of declinations, for this is not self-evident (see Ruggles 1984a, 17–19). Account must also be taken of the fact that the indications in opposite directions by a single structure are not independent of each other (*ibid.*, 228).

38 Data generated in this way, for example by computer random-number generators, are 'pseudo-random' rather than truly random. See, e.g., Peter R. Freeman, 'How to simulate if you must', in Clive L. N. Ruggles and Sebastian P. Q. Rahtz (eds), *Computer and Quantitative Methods in Archaeology 1987*, BAR (International Series 393), Oxford, 1988, 139–46, p. 142. The whole paper gives useful procedural hints for this sort of simulation.

39 This is elaborated in Statistics Box 4.

40 Ruggles 1984a, 255.

41 The results are given in *ibid.*, table 12.2.

42 *Ibid.*, 303–4. For the derivation of these conclusions see *ibid.*, 254–75.

43 Ruggles 1984b, 264.

44 This was the interpretation favoured by Ruggles (1984a), but it depends critically upon the existence of a significant cut-off below −31°. An independent statistical appraisal of the data, using a cluster analysis method (Patrick and Freeman 1988) suggests that this cut-off may not in fact be significant. If the northern trend represents the cause and the southern one the effect, then an alternative explanation may be that structures were oriented preferentially to point farther along the horizon to the north than the moon (or sun) ever rose or set (Ruggles 1984a, 303). On the other hand, it is also possible that this is simply a reflection of the general preference for orientation around north–south.

45 Of the 261 indications listed in Thom 1967, table 8.1, 114 come from the areas covered by Ruggles 1984a.

46 Patrick and Freeman 1988, 257.

47 See also Ruggles 1984a, 306–8.

48 Ruggles (1984a, 307) concluded that there were no discernible trends at all amongst the inter-site alignments, although Patrick and Freeman (1988, 257–9) found evidence of a greater preference for directions between south and west amongst these data than amongst the on-site indications.

49 An exception is Nether Largie (AR13(b)), which really consists of two aligned pairs and a single slab, all parallel to one another, placed in three lines each some 30 m apart. Two class 1 indications in the sample (lines 163/164 and 165/166 in Table 3.2) represent longer alignments of three stones from Nether Largie, comprising one from each of the shorter lines.

50 For diagrams showing regional and other subsets of the data see Ruggles 1984a, figs 12.2–12.3 and 12.5–12.7.

51 *Ibid.*, 242–3.

52 Ironically, this evidence lay unremarked upon amongst the datasets in some of Thom's early publications. This is evident from Fig. 2.3a, where we display the same data as Thom 1955, fig. 8 but use shading to show the data from stone rows and aligned pairs, so that the unshaded data, from ring centres to outliers, can be more easily ignored. The accumulations at the solar solstices and lunar standstill limits observed by Thom were formed largely by the data from the stone rows and aligned pairs. In other words, they were at the basis of the early evidence that encouraged Thom to proceed to postulate ideas of higher precision observations of the sun and moon. Underlying these later and less sustainable claims was a clear trend that was obscured because the stone rows were never examined by themselves as a coherent group.

53 For a detailed discussion of the evidence on types of monument and indication falling within different preferred declination intervals see Ruggles 1984a, 266–75.

54 Twenty-seven rows, pairs and single flat slabs in Mull and mainland Argyll are oriented in the south upon a declination that the moon can reach at the southern limit of its monthly motions (Ruggles 1984b, 265; for the raw data see Ruggles 1984a, 282). In a further fourteen cases the southern indication was excluded from consideration because the horizon was closer than 1 km. Ten examples fall outside this range, but none of these is a stone row or aligned pair, and in six cases there is