III

Shen Kua

Shen Kua 沈括 was the most exceptional of the polymathic statesmen who flourished in the eleventh century. He was born in 1031, with registration at Ch'ien-t'ang 錢塘 [now Hangchow, Chekiang province], China, and died at Ching-k'ou 京口, Jun prefecture 潤州 (now Chinkiang, Kiangsu province) in 1095.

Shen was the son of Shen Chou 沈周 (ca. 978–1052) and his wife, whose maiden name was Hsu 許. Shen Chou came of a gentry family with neither large landholdings nor an unbroken tradition of civil service. He spent his life in minor provincial posts, with several years in the capital judiciary. Shen Kua apparently, like a number of other important southern intellectuals of his time, received his early education from his mother. A native of Soochow, known for its flourishing manufactures, commerce, and agriculture, she was forty-four or forty-five years old when he was born. Among other things, she taught him and his brother P'i 披 the military doctrines of her elder brother Hsu Tung 許洞 (ca. 976–ca. 1016).[1]

Shen's background made it possible for him to enter the imperial bureaucracy, the only conventional road to advancement for educated people of his time. Unlike colleagues who came from the ancient great clans, he could count on few advantages save those earned by his striving and the full use of his talents. Shortly after he was assigned to the court, he became a confidant of the emperor and played a brilliant part in resolving crises of the time. Within slightly over a decade, his career in the capital was ended by impeachment. After exemplary service in a provincial appointment and five years of meritorious military accomplishment, he was doubly disgraced and politically burnt out. The extremes of Shen's career and the shaping of his experience in science and technology become comprehensible only if the pivotal circumstances of his time are first considered.

From *Dictionary of Scientific Biography,* XII, 369-393. New York: Charles Scribner's Sons, 1975, with revisions.

1. See Hu Tao-ching, "Shen Kua chün-shih ssu-hsiang t'an yuan." Full citations for important studies of Shen are given in the Bibliography at the end of this chapter. Works pertinent only to a given point are fully documented in the notes.

Historical Setting

Shen's time was the climax of a major transition in the Chinese polity, society, and economy.

Three centuries earlier the center of gravity in all these respects still lay in the north, the old center of civilization of the Han people. Wealth and power rested in the hands of the old aristocratic land-owning families. Governmental institutions could not resolve the tension between civil servants' private interests and the emperor's inevitable desire to concentrate authority. The civil service examination system was beginning to let the central government shape a uniform education for its future officials. Since birth or local recommendation determined who was tested, the mass of commoners were not involved. The social ideals prevalent among the elite were static; the ideal past was cited to discourage innovation; and the moral example of those who ruled, rather than responsive institutions or prescriptive law, was held to be the key to the healthy state. The classicist's ideal of a two-class society—self-sufficient agriculturalists ruled and civilized by humane generalists, with land as the only true wealth—did not encourage commerce, industry, or the exploitation of natural resources. The wants of the great families, whose civil servant members were becoming city dwellers by the middle of the eighth century, nonetheless gave momentum to all of these activities. The rural majority of the population still took no part in the rudimentary money economy.

The T'ang order began a long, slow collapse about 750, until in the first half of the tenth century the empire of "All under Heaven" was reduced to a jumble of ephemeral and competing kingdoms. When the Northern Sung rebuilt the universal state (960–1126), its foundations were in many important respects different from those of the early T'ang. A new dynasty was not only, as classical monarchic theory had it, a fresh dispensation of the cosmos; it was also the occasion for institutionalizing a new distribution of power in society. Changes in taxation made the old families accountable for their estates as they had not been earlier, and encouraged smaller landholdings. The cumulative result was a wider diffusion of wealth.

The center of vitality moved southeast to the lower Yangtze valley, which had long before emerged as the major rice-yielding region. By this time its fertility, combined with fewer social restrictions, had bred a new subculture that was more productive in industry than elsewhere. It encouraged the growth of commerce and stable markets, the beginnings of a uniform money economy, and the great broadening of education that printing had just made possible. The new southern elite was, on the whole, small gentry, and lacked the military traditions of the ancient northern clans and of power holders in the period of disunion. Their families were often too involved in trade for them to despise it. Although conservative, as all Chinese elites have been, they were prepared to think of change as a useful tool. The novelties of attitude and value were often slighter or subtler than such a brief account can convey, but within the established limits of Chinese social ideals their consequences were great.

In Shen Kua's time the old families of the north and west still provided many of the very highest officials and thus wielded great influence, positive or obstructive, in discussions about the future of China. But they had become merely influential members of a new political constellation that brought a variety of convictions and interests to that perennial debate. An especially obvious new element was that many southern small gentry families like Shen's established traditions of civil service, either as a main means of support or to protect and further their other concerns. Once a family's social standing was achieved, one or more members could enter the bureaucracy freely because of experience as subordinates in local administration or because they were amply prepared by education for the examinations. Their sons could enter still more freely because offspring of officials were given special access to both direct appointment and examination.

Not sharing the old vision of a social order fixed by precedent, men of the new elite were willing to sponsor institutional renovation in order to cope directly with contemporary problems. Dependent on their own talents and often needing their salaries, they were dedicated to building a rational, systematic, and in most respects more centrally oriented administration. They were willing to make law an instrument of policy, and insisted that local officials be rated not only on the moral example they set but also quantitatively—on how effectively they made land arable and collected taxes. In the name of efficiency, they devoted themselves to removing customary curbs on imperial authority and (with only partial success in the Sung) to dismantling the structures of privilege that underlay regional autonomy. Only later would it become clear that they were completing the metamorphosis of the emperor from paramount aristocrat to autocrat. At the same time they were successfully demanding more policymaking authority as the emperor's surrogates, although at the cost to themselves of greater conformity than officials of the old type had willingly accepted.

This irreversible transition did not lead to a modern state, but only to a new and ultimately stagnant pattern. The most accelerated phase of change was the activity of what is called the New Policies group *(hsin fa* 新法, actually a shifting coalition) between 1069 and 1085. In 1068 the young emperor Shen-tsung, who had just taken the throne, brought its leader, Wang An-shih 王安石 (1021–1086), to the capital. Within two years Wang had become paramount Grand Councillor. He resigned for nine months in 1074, when pressure from his antagonists persuaded the emperor to be less permissive, and returned to private life in 1076. The New Policies continued to be applied and extended, but with less and less attention to their founding principles, until Shen-tsung's death in 1085. Under the regency of the Empress Dowager, enemies of the reform attempted for eight years to extirpate Wang's influence and take revenge upon his adherents. When Emperor Che-tsung came of age in 1093, the New Policies were revived, but were so bent toward factional ends and administered so disastrously that the word "reform" is hardly applicable.

Wang An-shih's opponents were many: the old aristocrats, career bureaucrats of the sort who would oppose any change as disruptive, officials whose individual or group interests ran in other directions—and men of high ideals who found his proposals ill-advised and his personal style too intolerant.

No institution had evolved through Chinese history to work out and resolve conflicts of political viewpoint. This lack was filled by cliques, intrigues, and appeals to imperial intervention. Division and corruption among active supporters of the New Policies had been a problem from the start. Wang's program was so ambitious that he had to take competent support where he found it. The new access to power that he offered attracted enterprising men. Many had little sympathy for his convictions, and dedicated themselves to manipulation and graft. Once Wang was gone, the leadership of his group tended to become a battleground for aspirations of this kind.[2] The internal

2. In the successive reform movements of the Northern Sung there were considerable differences in the alignment of men with different beliefs and backgrounds. See the discussion in James T. C. Liu, "An Early Sung Reformer: Fan Chung-yen," in John K. Fairbank (ed.), *Chinese Thought and Institutions* (University of Chicago Press, 1957), 105–131, esp. 107–109. Robert M. Hartwell has examined regional variations of change in "Demographic, Political, and Social Transformations of China, 750–1550," *Harvard Journal of Asiatic Studies,* 1982, *42.* 2: 365–442. I am grateful to him for counsel.

and external enemies of the New Policies left the program a shambles by the time the Chin Tartars drove the Sung south in 1127.

A primary aim of the reforms was financial security of the state, which prompted initiatives in water control and land reclamation, encouragement of extractive industries and agriculture, intervention in commerce, and rationalization of taxes. Another goal, particularly at the emperor's insistence, was military strength. There had been a long confrontation along the northern border between the Chinese and the powerful Khitan empire, pastoral masters of mounted combat (renamed Liao in 1066). Seventy years of fitful peace were punctuated by humiliating Chinese failures to recapture territory south of the Great Wall. The peace was maintained by large annual bribes. For three decades the Tangut people of the northwest had posed an almost equally unpalatable demand for appeasement. The wealth that the New Policies could generate from man's exploitation of Nature,[3] the emperor hoped, could buy victory, or détente through strength, on both fronts. Either goal demanded expertise in cartography, strategic theory and tactical doctrine (both of which contained cosmological elements), design and manufacture of war matériel, fortification, troop organization and training, and development of a stable economy in border regions.

Shen Kua contributed to nearly every field of New Policies activity, both civil and military. His social background and political commitments cannot be considered responsible for his scientific talent or curiosity; the antecedents and loyalties of other major contemporary scientific figures were very different from his. But a review of his career and of his work will show how regularly his involvement with particular technical themes and problems grew out of his activities in government.

Life[4]

From about 1040 Shen traveled with his father to successive official posts from Szechwan in the west to the international seaport of Amoy. He was

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3. There was no Chinese word that exactly corresponded to "Nature," a protean and culture-bound term, until the end of the nineteenth century. I use the English word simply as a convenient label for the sum of all objects of empirical study outside of social relations. In this sense it is equivalent to *t'ien-ti* 天地, often abbreviated as *t'ien.*

4. I do not give references for the well-documented facts of Shen's life found in Chang Chia-chü's and other standard biographies.

exposed not only to the geographical diversity of China but also to the broad range of technical and managerial problems in public works, finance, agriculture, and maintenance of waterways, that were among the universal responsibilities of local administrators. Because his physical constitution was weak, he became interested in medicine at an early age.

Late in 1051, when Shen was twenty, his father died. As soon as the customary inactivity of the mourning period ended in 1054, Shen received the first of a series of minor local posts. His father's service exempted him from the prefectural examination. His planning ability became almost immediately apparent when he designed and superintended a drainage and embankment system that reclaimed some hundred thousand acres of swampland for agriculture. This was the first of a series of projects that established his reputation for skill in water control. This ability seems to have run in his family. Shen recorded a visit to his brother P'i, subprefect in Ning-kuo寧國 (now Fu-hu, Anhwei province), in 1061. After a cartographic survey and a historical study of previous earthworks in the region, Shen P'i applied the labor of fourteen thousand people to another massive land reclamation scheme that won the recognition of the emperor.[5]

In 1063 Shen Kua passed the national examinations in the highest category. Posted to Yangchow, he impressed Chang Ch'u 張蒭 (1015–1080), the Fiscal Intendant (a post then equivalent to governor), who recommended him for a court appointment leading to a career in the professional financial administration.[6]

Shen apparently used the time not occupied by his early metropolitan appointments, which were conventional and undemanding, to study astronomy. In reply to the informal questions of a superior he set down clear explanations, still extant, of the sphericity of the sun and moon as proved by lunar phases, of eclipse limits, and of the retrogradation of the lunar nodes. They demonstrate an exceptional ability to visualize motions in space, which were at best implicit in the numerical procedures of traditional astronomy and seldom were discussed in technical writing. In 1072 Shen was given an

5. The standard sources credit this accomplishment to Shen Kua, but Teng Kuang-ming has corrected this error.

6. The succession of fiscal posts that could lead to a seat on the Council of State in the eleventh century has been documented by Hartwell in "Financial Expertise, Examinations, and the Formulation of Economic Policy in Northern Sung China," *Journal of Asian Studies,* 1971, *30:* 281–314.

additional appointment as Supervisor of the Directorate of Astronomy. With the collaboration of his remarkable commoner protégé Wei P'u 衛朴 and the aid of other scholarly amateurs, using books gathered from all over the country, he undertook a major calendar reform. He planned an ambitious series of daily observations to extend over five years, using renovated and redesigned instruments.

The incompetent career officials who staffed the bureau stymied him. He forced the dismissal of six whom he caught falsifying records of phenomena. Those who remained doomed his program of observations and kept his new system of ephemeris computation from being among the two or three most securely founded before modern times. Shen's personal involvement in later stages of the reform undoubtedly was limited by his gradual movement into the vortex of factional politics.

Shen was early known to Wang An-shih, who composed his father's epitaph while a young provincial official. Shen eventually was publicly identified by enemies of the New Policies as among the eighteen members of Wang's intimate clique. In late 1072, in support of Wang's program, Shen used an original technique to survey the silting of the Pien Canal near the capital, dredged it, and demonstrated the value of the silt as fertilizer. Until mid-1075 he spent much time traveling as a troubleshooter of sorts, inspecting and reporting on water control projects, military preparations, and local administrations—and, it has been conjectured, providing encouragement to Wang's provincial supporters. Shen was put in charge of arsenal activities and, in 1075, was sponsored by Wang (then head of government) to revise defensive military tactics, a task the throne had proposed for Wang himself.

In 1074 the Khitan were pressing negotiations to move their borders further south. Incompetent and timorous Chinese negotiators were conceding unfounded Liao claims about the language and substance of previous agreements. Shen built a solid Chinese case by going to the archives, as no one before him had bothered to do. His embassy in mid-1075 to the camp of the Khitan monarch on Mt. Yung-an 永安 (near modern P'ing-ch'üan, Hopei) was triumphant. He described himself, encircled by a thousand hostile onlookers, calling on his staff, who had memorized the old documents of the

Khitan themselves, to cite without pause or flurry the exact reference to refute one historical bluff after another.[7]

Shen returned to China (with biological specimens and maps of the territories he had passed through) to become a Han-lin Academician, to take charge of a large-scale water control survey in the Yangtze region, and then to become head of the Finance Commission. While in this very powerful position he untangled a variety of contradictory policies, producing in the process some of the most penetrating writings before modern times on how to affect and regulate supply and demand, how to forecast prices in order to intervene effectively in the market, and how hoarding, counterfeiting, and melting affect the supply of currency as the price of the metal in it fluctuates about its controlled monetary value. In the autumn of 1077, just as he had launched his revision of critical fiscal measures, the corrupt and vindictive censor Ts'ai Ch'ueh 蔡確 (1036–1093) impeached him. The charge was that Shen had opposed a New Policies taxation measure in an underhanded, inconsistent, and improper way. Historians credited it for centuries, but modern Chinese research has refuted it in every detail.[8] His protector Wang An-shih had just left government. By threatening an established budget item in order to ease the burdens of the poor, it seems, Shen became an easy victim of factional maneuvering.

The emperor was not only the ritual synapse between the political and natural orders. He was a human being whose likes and dislikes courtiers indulged within broad limits that could be further widened by force of his charisma and will. The closer to him an official penetrated, the more achievement and even survival became subject to imperial whim and the intrigue of colleagues. Wang An-shih maneuvered Shen Kua into the proximity of the throne because of Shen's brilliance, judgment, and effectiveness at complicated tasks. He was not adept at protecting himself. He attracted the most damaging animosity not from opponents of the New Policies but from designing members of the coalition to which he belonged. Once the emperor qualified his support of the New Policies in 1074, the risk of debacle remained imminent. Many officials who had risen with Wang fought furiously for the power that would keep them afloat even though the program sank. They did

7. Chang Ya-ch'in 张雅琴, "Shen Kua yü Sung Liao hua chieh chiao-she 沈括与宋辽划界交涉" (Shen Kua and the border negotiations between Sung and Liao), *Shih i* 史绎, 1975, 12: 10–25.

8. Chang Chia-chü, 121-127.

not wish to be deterred by a colleague who judged issues on their own merits. They probably also felt, as others did, that a man in his early forties and low in rank did not merit the emperor's increasing confidence.

Ts'ai Ch'ueh was rising into the vacuum that Wang's retirement had left. The emperor depended increasingly on Ts'ai's monetary counsel and could not easily disregard what he insisted upon. For three years it was impossible to overcome his objections and those of another censor, and to rehabilitate Shen. In 1080 he was sent to Yen-chou 延州 (now Yenan, Shensi province), on the inevitable route for military operations by or against the Tanguts, as Commissioner for Prefectural Civil and Military Affairs. The Tanguts were then divided and weakened, minor Chinese conquests around 1070 had set the stage for a war, and the treasury had ample funds. Shen played an important part in organizing and fortifying for the victorious offensive of the autumn of 1081. In extending Sung control he showed a practical as well as a theoretical mastery of the art of warfare. He was cited for merit and given several honorary appointments. It was probably at the same time that he was ennobled as State Foundation Viscount. In his sixteen months at Yen-chou, Shen received 273 personal letters from the emperor. His standing at the court was in principle reestablished. Whether he had become shrewd enough to survive there was never tested.

Shen and a colleague followed up the victory by proposing fortifications to close another important region to the Tanguts. The emperor referred the matter to an ambitious and arrogant official who, ignoring the proposal, changed the plan to provide defenses for what Shen argued was an indefensible and strategically useless location. Shen was commanded to leave the vicinity of the new citadel so as not to share in the credit for the anticipated victory. When the Tangut attack came, the emissary's force was decimated while Shen, with imperial permission, was successfully defending a key town on the enemy invasion route to Yen-chou. He denied the Tanguts an opening for advance.

Be that as it may, Ts'ai Ch'ueh was now a Grand Councillor. As titular military commander Shen was held responsible for the defeat and considerable loss of life. At the age of fifty-one he found his career was over. The anti-New Policies regime later, to no advantage, abandoned the towns he protected, just as another negotiator lost the lands he had saved from the Khitan through diplomacy.

Shen spent six years in fixed probationary residence, forbidden to engage in official matters. He used at least two of these years to complete a great imperially commissioned atlas of all territory then under Chinese control. He had been working on this atlas intermittently since, as Finance Commissioner a decade earlier, he had had access to court documents. His reward included the privilege of living where he chose.

Ten years earlier Shen had bought, sight unseen, a garden estate on the outskirts of Ching-k'ou. In 1086, visiting it for the first time, he recognized it as a landscape of poignant beauty that he had seen repeatedly in dreams, and named it Dream Brook *(Meng ch'i* 夢溪, also read *Meng hsi)*. He moved there in 1088. With a pardon and sinecures to support him, he spent his last years in leisure, isolation, and illness.[9]

Writings

Shen's writings, of which only a few are extant even in part, included commentaries on Confucian classics, two atlases, reports on his diplomatic missions, a collection of literary works, and monographs on rituals, music, mathematical harmonics, administration, mathematical astronomy, astronomical instruments, defensive tactics and fortification, painting, tea, medicine, and poetry. Of three books compiled during his last years at Dream Brook, one, Good Medicinal Formulas *(Liang fang* 良方), was devoted to medical therapy, doctrine, and philology. The other two belong to particularly Chinese genres.

Records of Longings Forgotten at Dream Brook *(Meng ch'i wang huai lu* 夢溪忘懷錄), a collection of notes on the life of the gentleman farmer in the mountains, contains useful information on implements and agricultural technique and, unlike more conventional agricultural treatises up to that time, on the culture of medicinal plants.

Brush Talks From Dream Brook *(Meng ch'i pi t'an* 夢溪筆談) survives and has been well edited in modern times. It is by any reckoning one of the most remarkable documents of early science and technology, not to mention philosophy, art and literary criticism, diplomacy, occultism, linguistics, archaeology, and not a few other topics. It is a collection of about six hundred recollections and observations, ranging from one or two sentences to about a

9. For a translation that conveys the flavor of Shen's autobiography see Holzman, "Shen Kua," 275–276.

page of modern print. "Because I had only my writing brush and ink slab to chat with, I call it Brush Talks." The jottings are loosely grouped under topics (seventeen in all current versions), of which seven are most pertinent to Nature and man's use of it: "Regularities Underlying the Phenomena" (mostly astronomy, astrology, cosmology, divination), "Technical Skills" (mathematics and its applications, technology, medicine), "Philology" (including etymology and meanings of technical terms), "Strange Occurrences" (incorporating various natural observations), "Artifacts and Implements" (techniques reflected in ancient objects), "Miscellaneous Notes" (greatly overlapping other sections), and "Deliberations on Materia Medica" (most of it devoted to untangling historic and regional confusions in identities of medical substances).

Under all these rubrics, notices of the highest originality stand cheek by jowl with trivial didacticisms, court anecdotes, and ephemeral curiosities. Other sections are given to topics conventional in collections of jottings—memorable people, wisdom in emergencies, and so on. Shen's theoretical discussions of scientific topics employed the abstract concepts of his time—yin-yang, the Five Phases *(wu-hsing* 五行), *ch'i* 氣, and so on.

A large fraction of the book's contents is devoted to fate, divination, and portents. Historians seeking in him the prototype of the modern scientist have ignored Shen's belief in such things, normal among people of his time.[10]

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10. Brenier et al. perceptively contrast the modern view of Shen as a scientist and the traditional view of him as a man of letters ("Shen Gua," 350). It is necessary to qualify this contrast in two respects. First, for a thousand years, while littérateurs have seen Shen as a distinguished author, Chinese astronomers have considered him one of their own predecessors. "Man of letters" is itself a Western stereotype, and ignores Shen's service in the highest technical post in the empire. Second, the view of Shen as a scientist in the modern mold has faded out of historical writing since the 1950's. It hardly survives outside the People's Republic of China, as the innovative work of Teraji Jun in Japan and Fu Daiwie (Ta-wei) in Taiwan attests. In China it subsists in large measure because history is an ideologically sensitive profession. A rejection of positivism is correctly understood to be a challenge to the Marxist-Leninist view of science.

Historians of science will also find odd the judgments in this essay that yin-yang, *ch'i,* and so on are not "real" theoretical concepts, but mere labels for correspondence schemata. The authors define "theory" anachronistically as "an exclusive and coercive explanatory system," which makes it possible to deny that there were scientific theories anywhere before the nineteenth century. Equally oddly, the authors find yin-yang et al. unimportant because such terms appear in only an estimated

The author of Brush Talks has been compared with Leibniz. In an era of happy relations between China and the Soviet Union, Hu Tao-ching 胡道靜, the foremost authority on Shen, called him the Lomonosov of his day. But Shen was writing for gentlemen of universal curiosity and humanistic temperament. Custom, wisdom, language, and spiritual anomaly were as important themes as nature and artifice.[11]

Because Shen's interests were multifarious, the record unsystematic, and its form too confining for anything but fragmentary insight, only accumulation can fairly convey why he is important. What follows is a mere sample of his attempts to deepen the contemporary understanding of Nature, his observations that directed the attention of his educated contemporaries to important phenomena or processes, and his own technical innovations. I have grouped them to bring out contiguity of subject matter without interposing the radically different, and quite irrelevant, disciplinary divisions of modern science. On the basis of these samples I discuss—tentatively, given the state of research—the epistemological underpinnings of Shen's work, and the unity of his scientific thought with elements that today would be considered unscientific, primitive, or superstitious. That done, I evaluate Shen's life as a case study in the reconcilability of Confucianism and science, which the conventional wisdom among Sinologues for over a generation has tended to place in opposition.

Quantity and Measure

Mathematics was not the queen of sciences in traditional China. Chinese natural philosophers, unlike most in the postclassical West, did not dismiss the possibility that terrestrial phenomena could conform to mathematical regularities. But given the strength of Chinese quantitative sciences in numerical rather than geometric approaches, the very late and partial devel-

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five per cent of the jottings in Brush Talks (p. 345, n. 31). This conclusion (aside from inflating the significance of simple counting) ignores the commonplace observation that in *belles lettres* theory is more often implicit in notions of order and harmony than explicit.

11. Fu Daiwie has studied systematically the jottings on marvels and oddities. He argues that their character is directly related to the "newly emerging official-intellectual culture of the Northern Sung," which involves a rejection of "the old aristocratic high culture." "A Contextual and Taxonomic Study of the 'Divine Marvels' and 'Strange Occurrences' in the *Mengxi bitan," Chinese Science,* 11: 3–35, esp. 22.

opment of mathematical generalization, and the complete absence of notions of rigor, it is only consistent that much of the effort to discover such regularities produced numerology (that is, the use of numbers to label qualities, mainly in order to establish associations, meanings, or hierarchies). This practice was firmly founded on the "Great Commentary" to the Book of Changes.

Mathematics was, at least until the seventeenth century, embodied in specific problems about the physical world. Abstract thought about numbers was always concerned with their qualities rather than their properties, and thus remained numerology. This art, although it blended into arithmetic, was only partly distinct from other symbolic[12] means for exploring the inherent patterns of Nature and man's relation to it. Computation, on the other hand, was applied in a coherent tradition of textbooks to a great variety of mensurational, accounting, and other everyday tasks of the administrator. They were categorized by the type of practical problem to be solved: surveying, computing land tax, estimating requirements, and so on. Occasionally curiosity and skill pushed beyond these pragmatic limits, but, in Shen's time, never very far. Some of the problems that Shen presented in Brush Talks had no application, but his enthusiasm for them was undiminished.

In addition to this accumulation of individual problems, there were two exact sciences in which mathematics served to advance knowledge of the patterns underlying the phenomena. One was mathematical harmonics *(lü lü* 律呂), which explored the relations between musical intervals and the dimensions of instruments that produced them, in ways analogous to the Pythagorean art. Its appeal was much the same in both China and Greece: it demonstrated how deeply the power of number was rooted in Nature. For this reason in China mathematical harmonics was often put into the same category as mathematical astronomy, which also had foundations in cosmology. Astronomy, by far the more technically elaborate of the two exact sciences, was normally employed on behalf of the monarch. Successfully predicting a phenomenon fitted it into the dynamic cosmic and social order that the emperor maintained on behalf of his people. Unpredictable phenomena and failed predictions were either good or bad omens. Each challenged the established order, and each had a meaning. Bad omens warned that the emperor's mediating virtue, which maintained concord between the cosmic and political orders, was deficient. Good portents generally signalled,

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12. In the anthropologist's sense: ritual, religious, divinatory.

and approved, a step in a new direction. Successfully predicting celestial events neutralized their ominousness, preserving the charisma of the ruling dynasty.

The annual calendar (or almanac) issued by the throne was thus important in the solemn ceremonies that asserted the emperor's authority, as the ancient motto put it, to "grant the seasons." The calendar encompassed all predictable events, including planetary phenomena and eclipses. The utilitarian calendrical aspects—lunar months and solar years—had long since been refined past any practical demand for accuracy, but astronomical reinforcement of the Mandate of Heaven called forth endless attempts to improve constants. As it became conventional to institute a complete new system for computing these ephemerides when a new emperor was enthroned, technical novelty was at a premium. When new ideas were unavailable, the Directorate of Astronomy tended to trivially repackage old techniques.

Repeated failures of prediction were another motive to reform the astronomical system. In such cases too, the system was in principle replaced as a unit rather than repaired. Most systems survived or fell on their ability to predict eclipses, particularly solar eclipses. These were the least suited of all celestial phenomena to the algebraic, non-geometric style of mathematics. Prior to Shen's time little effort had gone into predicting the apparent motions of the planets, which lacked the significance of solar and lunar phenomena. This was, in fact, an omission that Shen seems to have been the first to confront.

General mathematics. As wood-block printing became widespread, the government, eager to control the content of education, recognized its value. The court used it to propagate carefully chosen and edited collections of ancient textbooks. It was doing so for medicine at the time Shen entered the capital bureaucracy. In 1084 it printed a collection of ten mathematical manuals, made four centuries earlier and reconstituted as well as extant texts allowed. The authority of these projects served both to fix textual traditions, preserving selected treatises from further attrition, and to consign to oblivion the books that government committees decided not to include. Shen thus lived at a decisive period in the development of mathematical traditions. His judgments on lost techniques and disused technical terms (e.g., 300, 306)[13]

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13. Numbers in parentheses are item numbers in the Hu Tao-ching 1960 ed. of *Meng ch'i pi t'an* (or "Brush Talks"). Roman volume numbers followed by page numbers refer to translations in Joseph Needham et al., *Science and Civilisation in*

have played an important part in later attempts to interpret them. Brush Talks is also an essential source for the study of pre-Sung metrology, currency, and other subjects related to computation.

Shen used mathematics in formulating policy arguments more consistently than most of his colleagues. Examples are his critique of military tactics in terms of space required for battle formations (579) and his computation that a campaign of thirty-one days is the longest that can feasibly be provisioned by human carriers (205). But of the computational methods discussed in his "Technical Skills" chapter, those not related to astronomy are almost all abstractly oriented.

This original bent emerges most clearly in two problems. One is a new method for computing the frustum of a solid rectangular pyramid. Shen worked out the volume of the same figure if composed of stacked articles (he mentioned flat round chess pieces, bricks, and wine vats) that leave interstices (301). Since Shen intended this "volume with interstices" *(hsi chi* 隙積) method to be applicable regardless of the shape of the objects stacked, what he gave is a correct formula for the number of objects, which are thus to be considered of unit volume. His presentation has several interesting features. Needham has suggested (III, 142–143) that the concern with interstices (and, one would add, unit volumes) may have been a step in the direction of geometric exhaustion methods, although it was tentative and bore fruit only in seventeenth-century Japan. Second, instead of the worked-out problem with actual dimensions that is conventional in early textbooks, Shen simply gave a generalized formula: "double the lower length, add to the upper length, multiply by the lower width," and so on. Third, this was the earliest known case in China of a problem involving higher series. Built on earlier numerical approaches to arithmetical progressions, it provided a basis for more elaborate treatment by Yang Hui 楊輝 (1261) and Chu Shih-chieh 朱世傑 (1303).

The second problem of interest was said "in a story" to have been solved by one of China's greatest astronomers, the Tantric Buddhist patriarch I-hsing 一行 (682–727). It sought the number of possible situations on a *go* board, with nineteen by nineteen intersections on which any number of black or white stones may be placed. Whether I-hsing actually solved this problem we do not know; Shen's single paragraph was the first and last known discussion of permutations in early Chinese mathematics. It stated the order of

China. Where my own understanding differs considerably from Needham's, an asterisk follows the page reference. All translations are my own.

magnitude of the answer—"approximately speaking one must write the character *wan* 萬 (10,000) fifty-two times in succession." This amounts to an order of magnitude of roughly 10^{208}. Shen added to this solution exact answers for smaller arrays, three methods of solution, and a note on the limited traditional notation for very large numbers (304).[14]

Mathematical harmonics. The Pythagoreans were fascinated by the relations of concordant intervals to the plucked strings that produced them, since the lengths between stops were proportionate to simple ratios of integers. By about 200 B.C., the Chinese built up a similar science on a gamut of standard pipes. Beginning with a pipe eight inches long and 0.9 inch in diameter, they generated the lengths of subsequent pipes by multiplying the previous length alternately by 2/3 and 4/3, making twelve pipes within an approximate octave. The dozen were then related to such categories as the twelve divisions of the tropical year, in order to provide a cosmic basis for the system of modes that the pipes determined. A pentatonic scale, which could be used in any of the twelve modes, provided similar associations with the Five Phases. This basis was extended to metrology by defining the lengths and capacities of the pipes in terms of millet grains of standard dimensions. Shen lucidly and concisely explained these fundamentals of mathematical harmonics, and corrected grotesque complications that had crept into a canonic source through miscopying of numbers (143, 549).

He also studied stringed instruments. By straddling strings with paper figures, he showed that strings tuned to the same notes on different instruments resonate, as do those tuned an octave apart on the same instrument (537; cf. IV.1, 130). His two chapters on music and harmonics are also a trove of information on composition and performance.

Astronomy. Shen's major contributions in astronomy were his attempts to visualize celestial motions spatially, his arc-sagitta methods that for the first time moved algebraic techniques toward trigonometry, and his insistence on

14. Needham has translated part of this jotting (III, 139*). The extant text, even in Hu's edition, is very corrupt. Ch'ien Pao-ts'ung has edited and considerably emended it in *Sung Yuan shu-hsueh-shih lun-wen-chi,* 266–269. For a general study of the treatment of large numbers in Chinese mathematics see Joël Brenier, "Notation et optimisation du calcul des grandes nombres en Chine. Le cas de l'échiquier de go dans le Mengqi bitan de Shen Gua (1086)," in *Nombres, astres, plantes et viscères. Sept essais sur l'histoire des sciences et des techniques en Asie orientale,* ed. Isabelle Ang & Pierre-Étienne Will (Memoires de l'Institut des Hautes Études Chinoises, 35; Paris: Collège de France, 1994), 89-111.

daily observational records as a basis for his calendar reform. The first had no direct application in computation of the ephemerides, although it may well have inspired (and at the same time have been inspired by) the second, which evolved from traditional mensuration. It has been suggested that the clarity of Shen's cosmological explanations led to his appointment to the Directorate of Astronomy, which provided opportunity for his contributions in the second and third areas. But circumstances that arose from the bureaucratic character of mathematical astronomy made these contributions futile in his lifetime.

Shen's discussions of solar, lunar, and eclipse phenomena (130–131; excerpts, III, 415–416) have been mentioned (p. 6). By far the most remarkable of his cosmological hypotheses attempted to account for variations in the apparent planetary motions, including retrogradation. This concern is not to be taken for granted, since traditional astronomers, in addition to their disinterest in planetary problems, preferred purely numerical approaches to prediction, unlike the spatial geometric models of Greek antiquity. Constructing explanatory models was not part of their work. Noting that the greatest planetary anomaly occurred near the stationary points, Shen proposed a model in which the planet traced out a figure like a willow leaf attached at one side to the periphery of a circle. The change in direction of the planet's motion with respect to the stars was explained by its travel along the pointed ends of the leaf (148).[15]

The willow leaf, in other words, served one of the same functions that the epicycle served in Europe. It is characteristic that, having taken a tack that in the West was prompted entirely by geometric reasoning, Shen's first resort should have been a familiar natural object with rich poetic connotations. Use of a pointed figure would hardly have survived a mathematical analysis of observational data, but this simile remained an offhand suggestion.

Another early outcome of Shen's service at the court was a series of proposals to redesign major astronomical instruments: the gnomon, which was still employed to measure the noon shadow and fix the solstices; the armillary sphere, with which angular measurements were made; and the clepsydra, used to determine the time of observations as well as to regulate court activities. Shen's improved versions of the armillary and the clepsydra apparently were not built until late 1073, after he had taken charge of the Di-

15. Translated above in Chap. II, Appendix C; see its Figure 9.

rectorate of Astronomy. The armillary at least was discarded for a new one in 1082, a casualty of his personal disgrace.

Shen's clepsydra proposals represent a new design of the overflow-tank type (Needham's Type B; III, 315–319, 325), but the most significant outcome of his work on this instrument was a jotting on problems of calibration. Day and night were by custom separately divided into hours, the length of which varied with the season. The time was read off graduated float rods, day and night sets of which were changed twenty-four times a year. Shen pointed out that this crude and inadequate scheme amounted to linear interpolation, "treating the ecliptic as a polygon rather than a circle," and argued for the use of higher-order interpolation (128).

The best armillary sphere available in the central administration when Shen first worked there was based on a three-hundred-year-old design "and lacked ease of operation" (150). Shen's most interesting improvement was in the diameter of the naked-eye sighting tube. At least from the first millennium B.C. a succession of stars had been designated the polestar until each strayed unacceptably far from the celestial pole, the still point in the sky about which the stars rotate in the course of a day and night. In the late fifth century A.D. Tsu Keng 祖暅 discovered that the current polestar, 4339 Camelopardi, rotated about a point slightly more than a degree away. This determination of the true pole was incorporated in subsequent instruments by making the radius of their sighting tubes 1.5 Chinese degrees (each of which is 360/365.25°). The nightly excursion of the polestar just inside the field of view thus provided a check on whether the instrument was pointing true north. Six hundred years later Shen found that the polestar could no longer be kept in view throughout the night. He gradually widened the tube, using plots of the polestar's position made three times each night for three months to adjust aim, until his new calibration revealed that the distance of the star from "the unmoving place at the celestial pole" was now slightly over three degrees (127; III, 262). Shen's successors followed him in treating the distance as variable. The relation of this secular change to what is now called the precession of the equinoxes remained unexplored. Aware of the periodic retrogradation of the lunar nodes, Shen also discarded the armillary ring representing the moon's path, which did not reflect this motion. It was never used again.

Calendar reform. On the accession of Shen-tsung in 1068, a new computational system was expected. The inability of the incumbent specialists to produce one left Shen with a clear mandate when he took over the Directorate of Astronomy in 1072. The situation became even more awkward when he could dislodge few of the timeservers already in the bureau, and was forced to bring in Wei P'u and others from outside the civil service in order to begin work on the calendar reform. It is not yet possible to tell what part of the work was done by Shen and what part by his assistants. Wei surely took responsibility for compiling the system as Shen became increasingly occupied elsewhere in government. Wei bore the brunt of fervent opposition within the bureau. He was even formally accused of malfeasance.

Shen knew that previous Sung astronomical systems had suffered greatly from reliance on old observations. He clearly conceived what new data were needed for the first major advance in centuries. Unabating opposition within the bureau and his own demanding involvements outside it limited the number of important innovations in his Oblatory Epoch (Feng-yuan 奉元) system. It was the official basis of calendar computation from 1075, the year of its completion, to 1094, a period very close to the average for systems of the Northern Sung. That the system was not used longer has little to do with its merits, since except in cases of spectacular failure, Sung astronomical systems changed as rulers changed. Shen's was replaced when the coming of age of Che-tsung began a new era. The immediate vicissitudes and long-term influence of three special features will give an idea of how historical actualities limited Shen's astronomical ambitions.

The boldest aspect of Shen's program was the attempt to predict the apparent positions of the planets—not merely their mean speeds and prominent phenomena—for the first time. The computational tools available did not permit this to be done with a few observations of stationary points, occultations, and maximum elongations. Shen and Wei therefore planned a series of observations of a kind not proposed in Europe until the time of Tycho Brahe, five centuries later: exact coordinates read three times a night for five years. Similar records were to be kept for the moon's positions, since previous Sung systems had still used the lunar theory of I-hsing, which after 350 years had accumulated considerable error. This program of observing was the most unfortunate casualty of the obstruction within the Bureau. Shen and Wei had no recourse but to produce a conventional planetary theory based mainly on old observations. They were able to correct the lunar error, but even this proposal provoked such an outcry that it could be vindicated only by a public demonstration using a gnomon (116).

A second issue was the central one of eclipse prediction. Previous attempts to add or subtract correction factors had shown the futility of tinkering. It was Wei P'u who "realized that, because the old eclipse technique used the mean sun, [the apparent sun] was ahead of it in the accelerated phase of its motion and behind it in the retarded phase." He therefore incorporated apparent solar motion into the eclipse theory (139). This had been done centuries earlier but abandoned.

A major obstacle in eclipse prediction, as well as in such workaday problems as projecting observations in equatorial coordinates onto the ecliptic, was the absence of spherical geometry. Shen's evolution of arc-chord-sagitta relations out of some inferior approximations for segment areas given in the arithmetical classics was a first step toward trigonometry. He made it possible in effect to apply sine relations and a fair approximation of cosine relations (301; III, 39, with diagram). The great remaining lack, as in planetary theory, was a mass of fresh observations on which to base new parameters. That this weakness could threaten the continuance of the system became clear in 1076, the year after it was adopted, when the failure of a predicted lunar eclipse to occur left Shen and his associates open to attack. Shen parried with a successful request that students in the Palace Library's Bureau of Astronomy be ordered to carry out his observational program "for three or five years" and to communicate the results to the original compilers. Whether this expedient could have bypassed the stalemate at the Directorate of Astronomy's observatory remains unknown, for in the next year Shen's impeachment aborted it.

In sum, the immediate outcome of the Oblatory Epoch calendar reform was undistinguished, and within half a century the official documents embodying it had been lost. It is impossible to be sure, for instance, to what extent Shen, after inventing arc-sagitta relations, had incorporated them. But enough information survived in proposals, reports, Shen's writings, and compendia of various sorts for his astronomical system to play a considerable part in the highest achievement of traditional Chinese mathematical astronomy, the Season-Granting (*Shou shih* 授時) system of Kuo Shou-ching 郭守敬 (1279). Kuo carried out a sustained program of observation using instruments that incorporated Shen's improvements. He took up Shen's arc-sagitta formula, greatly improving the cosine approximation, and applied it to the equator-ecliptic transform. Aware of Shen's emphasis on the continuous variation of quantities in Nature and his criticism of linear interpolation in clepsydra design, Kuo used higher-order interpolation to an unprecedented extent in his calendar reform.[16]

Shen recorded another scheme for reform of the civil calendar that was most remarkable for his time and place. It almost certainly occurred to him in the last decade of his life. The traditional lunisolar calendar was a series of compromises in reconciling two incommensurable quantities. The modern value for the tropical year is 365.2422 days, and that for the synodic month 29.53059 days, so that there are 12.3683 lunar months per solar year. The practical problem was to design a civil calendar with an integral number of days each month, and an integral number of months each year, in such a way that the long-term averages approach the astronomical constants. Hardly two of the roughly one hundred computational systems recorded in early China solved this problem in exactly the same way, just as there was endless tactical variety in other traditional societies, but the strategy was generally the same. Months of twenty-nine and thirty days alternated, with occasional pairs of long months to raise the average slightly. Intercalary thirteenth months were inserted roughly seven times every nineteen years. That comes to 0.3684 additional months per year, an excellent approximation.

By a millennium before Shen's time the calendar was more than adequate in these respects for every civil need, although attempts to further refine the approximation led to endless retouching. The rhythms of administration, and to some extent of commerce, were of course paramount in the design of the lunisolar calendar, despite pieties about imperial concern for agriculture. Chinese farmers did not need a printed almanac by which to regulate their activity. What they consulted was its notations of lucky and unlucky days. Division of the year by lunar months is, in fact, useless for agriculture, since the seasons that pace the farmer's work vary with the sun alone. The Chinese calendar also incorporated twelve equal divisions of the tropical year *(ch'i,* like the Babylonian *tithis)*, further subdivided into twenty-four periods with such names as Spring Begins, Grain Rains, and Insects Awaken. These provided a reliable notation for seasonal change in the part of northern China in which the series originated, but were useless elsewhere. They were included for their antiquity, not because they filled an agricultural need.

Shen's suggestion was a purely solar calendar, based on the twelve divisions of the tropical year (average 30.43697 days in his system) instead of on

16. An excellent biography is Li Ti 李迪, *Kuo Shou-ching* (Shanghai: Shang-hai Jen-min Ch'u-pan-she, 1966).

the lunation. The civil calendar would thus alternate months of thirty and thirty-one days, with pairs of short months as necessary to approach the average. This would provide truly seasonal months and at the same time do away with "that goitrous excrescence" the intercalary month. "As for the waxing and waning of the moon, although some phenomena such as pregnancy and the tides are tied to them, they have nothing to do with seasons or changes of climate; let them simply be noted in the almanac" (545). Shen was aware that because the lunisolar calendar went back to hoary antiquity "it is by no means appropriate to criticize it." He predicted that his discussion "will call forth offense and derision, but in another time there will be those who use my arguments." This proposal was in fact considered by later scholars the greatest blemish on Shen's astronomical talent. His posterity appeared in the mid-nineteenth century, with the even more radical solar calendar enacted for a few years by the T'ai-p'ing rebels.[17] His work was cited to justify more respectable proposals between that time and the adoption of the Gregorian calendar in 1912.

Configuration and Change

Despite Shen's exceptional interest across the board in mathematical quantity and his conventional fondness for numerology, the most obvious of his contributions to understanding the earth and its phenomena are qualitative. I group them below, for convenience, by modern category.

Magnetism. For more than a millennium before Shen's time, south-pointing objects carved from magnetite were used from time to time in ceremonial and magic. In 1044 a book on military arts recommended, as aids to pathfinding, objects cut from sheet iron and magnetized by thermoremanence. Shen took up the matter of needles rubbed against lodestone by contemporary magi, discussed floating and other mountings, recommended suspension, noted that some needles point north and some south, and asserted that "they are always displaced slightly east rather than pointing due south"—all in about a hundred characters (437; IV.1, 249–250). Noticing the

17. Kuo T'ing-i 郭廷以, *T'ai-p'ing t'ien kuo li-fa k'ao-ting* 太平天國曆法考訂 (Critical study of the calendrical methods of the T'ai-p'ing Heavenly Kingdom; Peking: Commercial Press, 1937, reprinted Taipei: idem, 1963); Lo Erh-kang 羅爾綱, *T'ien li k'ao chi t'ien li yü yin yang li jih tui-chao-piao* 天曆考及天曆與陰陽曆日對照表 (On the T'ai-p'ing calendar, with a concordance table for the lunar and Gregorian calendars; Beijing: San Lien Shu-tien, 1955).

result of what is today called magnetic declination depended not only on trials with a suspended needle but also on the improved meridian determined by Shen's measurement of the distance between the polestar and true north.[18]

Shen may have been anticipated by geomancers, who practiced a sophisticated proto-science of land configuration and siting, but the dates of texts on which such claims have been based are questionable. The use of compass needles in navigation is recorded shortly after Shen's death, and later descriptions provide enough detail to show that the twenty-four-point rose that Shen substituted for the old eight compass points (perhaps also under the stimulus of the better meridian, if not of geomantic practice) was widely adopted. He apparently was unaware of the polarity of magnetite itself, since in another article he explained the difference between north-pointing and south-pointing needles as "perhaps because the character of the stone also varies" (588; IV.1, 250).

Cartography. It has been conjectured that Shen was the first to use a compass in mapmaking, although traditional methods would have sufficed. Neither his early maps of Khitan territory nor the atlas of China completed in 1087 have survived to answer this question. But in an enclosure to the latter he did separately record bearings between points using his twenty-four-point compass rose. He also listed rectilinear distances rather than, as customary, distances along established routes. He called the use of distances "as the bird flies" ancient, but we have no earlier record. "Thus although in later generations the maps may be lost, given my book the territorial divisions may be laid out according to the twenty-four directions, and the maps speedily reconstructed without the least discrepancy" (575; III, 576). His great atlas included twenty-three maps drawn to a uniform scale of 1:900,000. The general map was ten by twelve Chinese feet. There is no evidence that the handbook outlasted the maps.

Three-dimensional topographic maps go back at least to Hsieh Chuang 謝莊 (421–466), who had a demountable wooden model carved, apparently on the basis of an ancient map. In 1075, while inspecting the Khitan border, Shen embodied information gathered from the commander and the results of his

18. Needham and Peter J. Smith, "Magnetic Declination in Mediaeval China," *Nature,* 17 June 1967, 1213–1214. See the historical table in *Science and Civilisation in China,* IV.1, 310. Declination in Shen's part of China at the time has been estimated as between five and ten degrees.

own travels in a series of relief maps. He had them modeled, for the sake of portability, in plastic media (wheat paste and sawdust until the weather turned freezing, then beeswax) on wooden bases. These were carried to the capital and duplicated in wood. The government thenceforth required similar models from other frontier regions (472; III, 580).

Shen regularly used both historical research and special on-the-ground surveys to solve such cartographic problems as tracing changes in watercourses (431). Typical of his ingenious topographic survey methods were those used in 1072 to measure the slope of the Pien Canal near the capital. He built a series of dikes in temporary, narrow parallel channels to measure incremental changes in water level (457; III, 577*).

Formation of the earth. In 1074, in the T'ai-hang 太行 mountain range (Hopei), Shen noticed strata of "bivalve shells and ovoid rocks running horizontally through a cliff like a belt. This was once a seashore, although the sea is now hundreds of miles east. What we call our continent is an inundation of silt. . . . This mud year by year flows eastward, forming continental land." A similar stratum had been observed long before by Yen Chen-ch'ing 顏真卿 (708–784), who vaguely suggested its origin in the sea; but Shen—whose duties had made him intimately familiar with the process of silting—opened a new line of investigation by proposing a cause (430; III, 604).

Probably on his southward drought survey earlier in the same year, Shen saw the Yen-tang 雁蕩 range (Chekiang), a series of fantastic rock formations "invisible from beyond the ridgeline [opposite], but towering to the sky when seen from the valleys. If we trace the underlying pattern, it must be that great waters in the valleys have attacked and washed away all the sand and earth, leaving only the great rocks erect and looming." His explanation proceeded to generalize the shaping role of erosion, and then to apply it to the hills that divide streams in the loess country of northwest China—"miniatures of the Yen-tang mountains, but in earth rather than stone" (433; III, 603–604).

Shen reported diverse contemporary finds of petrified plants and animals (373–374; III, 614–618). He remarked particularly on a stony formation he identified as originally a grove of interconnected bamboo roots and shoots, found dozens of feet below ground level at Yenan 延安 (Shensi). He knew from his military service there that the climate was too dry to grow bamboo: "Can it be that in earliest times [literally, 'before antiquity'] the land was lower and the climate moister, suitable for bamboo?" (373).[19] About a century later the great philosopher and polymath Chu Hsi (1130–1200), who knew Shen's jottings well and often extended ideas from them in his teaching, suggested that the stone of certain mountains was itself petrified silt deposits. But Shen's notion of prehistoric climatic change, like that of the reshaping of land by erosion, was not pushed further soon after his lifetime.

Atmospheric phenomena. Although Shen did not report important original discoveries of his own, he preserved a number of interesting observations not recorded elsewhere. Perhaps the most important is a vivid description of a tornado (385; translated in Holzman, "Shen Kua," 286). Modern meteorologists questioned its veracity until, in the first decade of the twentieth century, the Sikawei Observatory in Shantung reported phenomena of the same kind, previously thought restricted to the western hemisphere.

Shen transmitted an explanation of the rainbow by Sun Ssu-kung 孫思恭, an elder contemporary in the court who was also considered one of the best mathematical astronomers of his era. "The rainbow is the image [literally, 'shadow'] of the sun in rain, and occurs when the sun shines upon it." This sentence does not, as often claimed, adduce refraction (pinhole or mirror images were regularly called "shadows"; see 44). Sun's observations prompted Shen to determine by experiment that the rainbow is visible only opposite the sun (357). Later Chu Hsi, aware of Shen's account, added that by the time the rainbow appears "the rain *ch'i* has already thinned out; this in turn is because sunlight has shone on and attenuated the rain *ch'i*." *Ch'i* must mean vapor here; the notion of reflections off individual drops is hardly implicit. Shen also recorded the fall of a fist-sized meteorite in more detail and with less mystification than in previous reports. The particulars of its fall came from a careful account by another of Wang An-shih's associates. The object was recovered and exhibited, but Shen did not claim that he himself had observed that "its color is like that of iron, which it also resembles in weight" (340; III, 433–434).

Products of the earth. Shen's responsibilities with respect to fiscal policy gave him a detailed knowledge of important commodities, their varieties, and the circumstances of their production, as may be seen from his descrip-

19. Fu Daiwie observes that Shen did not consider these objects to be anything that could be called fossils in the modern technical sense. He understood them by applying the contemporary idea that one living creature metamorphoses into another (29–31).

tions of tea (208) and salt (50, 221, 224, 422). Inflammable seepages from rock had been known a millennium before Shen's time, and for centuries had been used locally as lamp fuel and lubricant. While Commissioner near Yen-chou in 1080-1081, he noted the blackness of soot from petroleum. Good ink was then made by burning pine resin, but Shen knew that North China was being rapidly deforested. He remarked that, in contrast with the growing scarcity of trees, "petroleum is produced inexhaustibly within the earth." He began an industry to manufacture the solid cakes of carbon ink used for writing and painting throughout China. The name Shen coined for petroleum is the one used today, and the source in Shensi province that he developed is still exploited. In the same article he quoted a poem of his that is among the earliest records of the economic importance of coal, then beginning to replace charcoal as a fuel (421; III, 609, partial).

Optical phenomena. Shen did not directly link his interest in image formation with his worldly concerns. The play of his curiosity over old artifacts, not the improvement of naked-eye astronomical instruments, motivated him.

In the canons of the Mohist school (ca. 300 B.C.) is a set of propositions explaining the formation of shadows and of optical images (considered a kind of shadow) in plane, convex, and concave mirrors. Most scholars believe that one proposition concerns pinhole images, although textual corruption and ambiguity make this uncertain. These propositions are in many respects physically correct, although very schematic. They do not presuppose rays of light.

Shen asked himself why a concave mirror forms an inverted image. He suggested that an "obstruction" (*ai* 礙), analogous to an oarlock, constricts the "shadow" to a shape like that of a narrow-waisted drum (more or less two cones apex to apex, the second constituting the inverted image). Like the Mohists, Shen clearly believed that inversion takes place *before* the image is reflected. He expressly likened the inverted image to that of a moving object formed on the wall of a room through a tiny opening in a paper window. Aware for the first time that there is a range of distances from a concave mirror within which no image is formed (that is, between the center of curvature and the focal point), he explained that this blank region, corresponding to the pinhole, is the locus of "obstruction" (44).[20] Shen's pinhole obser-

20. This jotting and the Mohist texts are translated in A. C. Graham and Sivin, "A Systematic Approach to the Mohist Optics," in S. Nakayama and Sivin (ed.), *Chinese*

vation was adventitious, but his approach to the burning-mirror settled the details by experiment.

Two other observations of optical interest are found under the rubric "Artifacts and Implements." The first, in the Sequel to Brush Talks, noted that when the ancients cast bronze mirrors, they made the faces just convex enough that, regardless of size, every mirror would reflect a whole face. By Shen's time this refinement had been abandoned and the reasoning behind the curvature forgotten, so that collectors were having the faces of old mirrors scraped flat (327; IV.1, 93).

The second jotting is the oldest record of a Far Eastern curiosity still being investigated: "magic mirrors," or, as Shen called them, "transparent mirrors." Shen described a bronze mirror with the usual smooth, polished face and an inscription integrally cast in relief on its back. When this mirror was used to reflect the sun onto a wall, the inscription appeared within the image. Shen cited with approval an anonymous explanation: "When the mirror is cast, the thinner parts cool first. The raised design on the back, being thicker, cools later and the shrinkage of the bronze is greater. Although the inscription is on the obverse, there are imperceptible traces of it on the face, so that it becomes visible within the light." He noted that this explanation is incomplete, because he had tried mirrors in his own and other collections that were physically indistinguishable from the "transparent" ones and found that they did not cast images (330; IV.1, 94*). His doubt was justified, although the approach taken by his informant was at least as good as those of some modern metallurgists.

Manipulation of the cooling rate can only accentuate the effect. The variation in thickness appears to be primarily responsible for the image in this sort of mirror, the most common among several types extant. Filing considerable bronze off the face of the mirror after casting is the key. This releases tensions in the metal and gives rise to slight deformations that produce the image.[21]

Science: Explorations of an Ancient Tradition (Cambridge, MA: MIT Press, 1973), 105–152.

21. For Chinese research see Julia K. Murray & Suzanne E. Cahill, "Recent Advances in Understanding the Mystery of Ancient Chinese 'Magic Mirrors': A Brief Summary of Chinese Analytical and Experimental Studies," *Chinese Science,* 1987, 8: 1–8. This report gives more attention to temperature than to surface deformation. I am also grateful for counsel to Prof. Mao Tseng-tien 毛增滇.

Productive Techniques and Materials

The technologies of Shen's time, like their European counterparts, were not cumulative and linked to science, but independent artisanal traditions transmitted from master to pupil. Shen left so many unique and informative accounts of ancient and contemporary processes among his jottings that Brush Talks has become a major source for early technology. Shen's interests in contemporary techniques can in most cases be linked to broad concerns of his official career; but the exceptional richness of his record bespeaks a rare curiosity, and the trenchancy of his descriptions a seriousness about mechanical detail unusual among scholar-officials. His notes on techniques that had been lost before his time reflect the application of this technical curiosity and seriousness to archaeology, which was just becoming a branch of antiquarianism in the eleventh century.

Most of Shen's cultured contemporaries keenly appreciated good workmanship, but saw no reason to notice the artisans responsible for it, except occasionally when condescending to them. Shen wrote about resourceful craftsmen and ingenious laborers with much the same admiration he gave to judicious statesmen. He never lost sight of the social distance between himself and members of the lower orders, but in his writing there is no snobbishness about the concert of hand, eye, and mind.

Contemporary techniques. The most famous example is Shen's account of the artisan Pi Sheng's 畢昇 (fl. 1041–1048) invention of movable-type printing. Shen described how ceramic types were carved and fired, and imbedded and leveled in a layer of resin, wax, and paper ash in an iron form. A second form was set up as the first was printed. As in woodblock printing, water-based ink was used. Since the porous, thin paper took it up readily, no press was needed. Shen also remarked, with his usual acumen, that the process could become faster than carving wood blocks only with very large editions (historians estimate the average printing of a scholarly book in the Northern Sung period at between fifty and a hundred copies). Unevenness of the surface and absorption of ink by the fired clay must have posed serious problems. The process was abandoned after Pi died, probably due to the lack of economic incentive that Shen noted. The long series of royally subsidized Korean experiments in the fifteenth century that perfected cast-metal typesetting still began with Pi Sheng's imbedding technique as described by Shen.

Whether he knew Pi is unclear, but Shen's nephews owned Pi's original font (307).[22]

Shen described several metallurgical processes. Especially interesting are the recovery of copper from a mineral creek by replacement of iron, a process then being carried out on an industrial scale to provide metal for currency (455; II, 267); two of the three steelmaking processes used in early China (56);[23] and a little-known cold-working method that the smiths of the Ch'iang people of western China used to make extremely tough steel armor (333). Water control techniques of which he records details include pound-locks with double slipways (213; IV.3, 351–352), piles for strengthening embankments (210; IV.3, 322–323), and sectional gabions for closing gaps after embankment repairs (207; IV.3, 342–343).

Ancient techniques. The concern for understanding ancient techniques began more than a millennium earlier, as commentators strove to understand everything mentioned in the Confucian and other classics. Exegesis remained an important activity in China, and the productive methods of golden antiquity were investigated with the same assiduity as anything else mentioned in its literary remains. Less than a century before Shen's time, for various reasons—among them the recovery of ancient artifacts in large numbers for the first time, the growth of collecting, and the elaboration of a conscious aesthetics—archaeology began to emerge from the footnotes, especially in monographs on ancient implements and ritual institutions. He was familiar with this literature and responded to it critically. Much of his writing in the "Artifacts and Implements" chapter falls squarely in this antiquarian tradition, drawing on the testimony of both objects and books.

Shen's vision of the past as a repertory of lost processes introduced an influential new theme. A constant concern in his writing was not only that the workmanship of the past be esteemed for its excellence, but also that the present be enriched through understanding what the practical arts had been capable of. Although his contemporaries generally believed that semidivine monarchs of archaic times had invented the arts that made civilization possible, in a letter Shen saw technology emergent for just the opposite reason: "How could all of this have come from the Sages? Every sort of workman and

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22. Translated by T. H. Tsien in *Science and Civilisation in China,* V.I, 201–202.

23. Translated in Needham, *The Development of Iron and Steel Technology in China* (London: The Newcomen Society, 1958), 33–34.

administrator, the people of the towns and those of the countryside: none failed to participate."[24]

Shen's remarks on magic mirrors are typical of his effort to understand lost processes. Another example is his reconstruction (and trial) of ancient crossbow marksmanship, interpreting a gnomic aiming formula in an ancient footnote with the aid of a graduated sight and trigger assembly that he examined after it was unearthed (331; III, 574–575). The most famous instance of Shen's use of literary sources to study techniques has to do with the remarkable modular system of architecture used in public buildings. The set of standard proportions is well known from an official compilation printed about a decade after Shen's death. By describing the earlier proportion system of the Timberwork Canon *(Mu ching* 木經), attributed to a great builder of about 1000 and already falling out of use, Shen demonstrated the antiquity of this art (299; IV.3, 82–83).

Medicine

Medicine, from at least the second century B. C., drawing heavily upon natural philosophy for its conceptual underpinnings, accumulated a classical tradition. Not only was each new treatise consciously built upon its predecessors, but a main goal of new work was restoring an understanding that medical scholars believed was deepest in the oldest writings. The revealed truth of the archaic canons was too concentrated for ordinary latter-day minds, who could hope to recapture it only as the culmination of a lifetime of study. Writers in the intervening centuries referred to the early classics as the ultimate source of significance, even while aware that empirical and practical knowledge had considerably advanced since antiquity. The continuous tradition of medical writing fitted new experiences into the old framework and, when necessary, constructed new frameworks in the spirit of the old. As government committees compiled and disseminated standard editions of the chief classics, the curing arts became more respectable as a field of study. Large numbers of men from the scholar-official class began to take up medicine, not in competition with those who made a living by it but as a means of self-cultivation allied to cosmology and occasionally useful. The initial motivations commonly were personal ill health and the desire to serve one's sick parents.[25]

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24. *Ch'ang-hsing chi, 19:* 53b.

25. Robert Hymes demonstrates conclusively for one affluent southeastern locality that "a permanent shift among elite families from exclusive concentration on

Shen, we have seen, began the study of medicine early, for the former reason. One of his two therapeutic compilations survives in altered form. Its preface is a long disquisition on the difficulty of adequate diagnosis and therapy, as well as on the proper selection, preparation, and administration of drugs. His criticisms of contemporary trends toward simplification remind us that the development of urban culture and the spread of education in Sung China had led to increased medical practice among ordinary people as well as study by the literati. As popular adaptations of elite medicine began to displace ritual folk therapies (at least in the cities), there were more half-educated physicians to be criticized by learned amateurs such as Shen.

Shen's most characteristic contribution was undoubtedly his emphasis on his own experience, unusual in a tradition whose literature in the Sung still depended heavily on copying wholesale from earlier treatises. Shen included only medical formulas the efficacy of which he had witnessed, and noted the circumstances in which most had succeeded. He precisely described many animal, vegetable, and mineral drugs. Although like other pharmacognostic scholars he had no interest in general taxonomic schemes, his concern for exact identification and for philological accuracy gave his critical remarks enduring value. Many were incorporated into later compilations on materia medica. Shen's writing also served as a stimulus to the work a few decades later of the great pharmacognostic critic K'ou Tsung-shih 寇宗奭 in his Dilatations on Materia Medica *(Pen-ts'ao yen i* 本草衍義, 1116).

Historians are still debating whether certain medical preparations from human urine collectively called "autumn mineral" *(ch'iu shih* 秋石) contain high concentrations of steroid and protein hormones. In Good Formulas Shen gives one of the earliest accounts, in the form of detailed instructions for two such preparations that he performed in 1061 (other accounts by contemporaries are harder to date).[26]

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the achievement of high office to a broader strategy focusing on local position" came only at the end of the N. Sung. "Not Quite Gentlemen? Doctors in Sung and Yuan," *Chinese Science,* 1987, 8: 9–76.

26. See Lu Gwei-djen and Needham, "Medieval Preparations of Urinary Steroid Hormones," *Medical History,* 1964, *8:* 101–121. Their claim that the oldest known formula goes back to 1025 (p. 111) is erroneous, so that Shen's account is the oldest extant. See Juan Fang-fu, "Shen Kua tui k'o-chi-shih ti yu i chung-yao kung-hsien—kuan-yü wo-kuo shih-i shih-chi ts'ung jen-niao t'i-chü hsing-chi-su ti chi-tsai 沈括对科技史的又一重要贡献—关於我国十一世纪从人尿提取性激素的记载" (Another important contribution by Shen Kua to the history of science and

Perhaps Shen's most famous writing on general medical matters is one in which he refuted the common belief that there are three passages in the throat. This belief was so general that three passages appear in the first book of drawings of the internal organs based directly on dissection (1045).[27] His supporting argument is not from independent dissection but from the principle of sufficient reason: "When liquid and solid are imbibed together, how can it be that in one's mouth they sort themselves into two throat channels?" He thus saw the larynx as the beginning of a network for distributing throughout the body the vital *ch'i* carried in atmospheric air, and the esophagus as carrying nutriment directly to the stomach cavity, where its assimilation begins. This was a significant increase in clarity as well as accuracy (480).

A passage that has been praised for its simple but beautiful language takes issue with the ancient principle that medicinal plants should be gathered in the second and eighth lunar months (when they were thought easiest to identify). In a few hundred characters it epitomizes the variation of ripening time with the identity and variety of the plant; the part used in therapy; the physiological effect needed for the application; altitude; climate; and, for domesticated medicinal plants, variation with planting time, fertilization, and other details of horticulture. The sophistication of this jotting (485) reflects not only increasing cultivation (exceptional before the Sung) but also

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technology. On records of the extraction of sexual hormones from human urine in our country in the eleventh century), in *I-hsueh hsin lun,* 219–230, esp. 225–227. For an analysis of Shen Kua's account, see Meng Nai-ch'ang 孟乃昌, "Shen Kua ho Li Shih-chen tui 'ch'iu shih' ti li-lun ch'an-shu 沈括和李时珍对秋石的理论阐述" (The theoretical expositions of Autumn Mineral by Shen Kua and Li Shih-chen), *Chung-hua i-shih tsa-chih* 中华医史杂志, 1987, *17.* 3: 187–188. Attempts to repeat Shen's preparations have failed to yield steroids. See the summary in H. T. Huang et al., "Experiments on the Identity of *Chiu shi* (Autumn mineral) in Medieval Chinese Pharmacopoeias," *Pharmacy in History,* 1990, *32:* 63–65.

27. Persons untrained in medicine dissected executed bandits in 1045 and recorded what was found under the direction of an enthusiastic amateur. A similar episode, meant to correct the earlier drawings, took place at the beginning of the twelfth century. There is no reliable account of either in any European language, but see Watanabe Kôzô 渡邊幸三, "Genson suru Chûgoku kinsei made no gozô rokufu zu no gaisetsu 現存する 中国近世までの五蔵六府図の概説" (A survey of extant Chinese anatomical drawings from before modern times), *Nihon ishigaku zasshi* 日本医史学雑誌, 1956, *7:* 88.

the integration of drugs from every corner of China into the expanding commercial network.

Conclusion

The Northern Sung was an important period in the history of every branch of science and technology because society was expansive and relatively open to talent, and the government increasingly invested in a broad spectrum of learning. Shen was not the first polymath this era produced. There was also Yen Su 燕肅 (fl. 1016), who designed an odometer and south-pointing chariot (in which a differential gear assembly kept figures pointing in a constant direction as the chariot turned), improved the design of the water clock and other astronomical instruments, and wrote on mathematical harmonics and the tides. In Shen's lifetime there was Su Sung 蘇頌 (1020–1101), who was paramount Grand Councillor during the last part of the reaction against the New Policies (1092–1093). Through the 1060's he played a major part in a large imperially sponsored compilation of materia medica, and in the editing and printing of ancient medical classics. In 1088 a group that he headed completed a great water-driven astronomical clock incorporating an escapement device. Their detailed description of the mechanism *(Hsin i-hsiang fa yao* 新儀 象法要) included the oldest star map extant in printed form, based on a new stellar survey. That Yen, Su, and Shen were all in the central administration is not surprising. The projects on which they were trained and those in which they worked out many of their ideas were of a scale that only the imperial treasury could (or at least would) support. What little is known about the career of another contemporary polymath, Shen Li 沈立, suggests that his narrower range of interests (in natural history, geography, water conservancy, etc.) reflects a career that evolved in provincial administration and moved to the capital late in life.[28]

28. The book on the astronomical clock has been studied and translated in Wang Ling et al., *Heavenly Clockwork* (Cambridge University Press, 1960). See Wang Chin-kuang 王锦光, "Sung-tai k'o-hsueh-chia Yen Su 宋代科学家燕肃" (Yan Su, a scientist of the Song dynasty), *Hang-chou ta-hsueh hsueh-pao* 杭州大学学报, 1979, 3: 34–38; Su K'o-fu 苏克福 et al. (ed.), *Su Sung yü Pen-ts'ao t'u-ching yen-chiu* 苏颂与本草 图经研究 (Studies of Su Sung and the Illustrated canon of materia medica; Changchun: Ch'ang-ch'un Ch'u-pan-she, 1991). The essays in the latter collection vary greatly in quality. The only study of Shen Li is "Pei Sung k'o-hsueh-chia Shen Li 北宋科学家沈立" (The Northern Sung scientist Shen Li), in Li Ti, *Chung-kuo k'o-hsueh chi-shu shih lun-wen-chi* 中国科学技术史论文集 (Collected essays on the

Breadth of interest alone does not explain Shen's importance for the study of Chinese scientific thought. Another aspect is his profound technical curiosity. Many of the phenomena he recorded were mentioned by others; but even when their descriptions were fuller, they usually treated their subject matter as a mere curiosity or an occasion for anecdote rather than as a challenge to comprehension. Above all, one is aware in Shen, as in many other great figures, of a special directness. A member of a society in which the weight of the past always lay heavily on work of the mind, he nevertheless often cut past deeply ingrained structures and assumptions. This was as true in his program of astronomical observations and his audacious solar calendar as in his work on government policies.

People in the Sung were aware that society had become much more complicated since antiquity. Questioning of precedent (in the name of a return to classical principles) was inherent in the New Policies. Shen's commitment to Wang An-shih's political program can only have made him more aware of the unceasing need to improve techniques and to achieve better results that had driven the best Chinese astronomers for centuries. Even given these predispositions and opportunities, Shen remains in many senses an atypical figure, even in his time and among his associates.

A modern scientist or engineer finds much familiar, not only in the way Shen went about making sense of the physical world, but also in the temper of his discourse, despite the ancient concepts he used. One comes away from his writings confident that he would see much of modern science as a culmination (not the only possible culmination) of his own investigations—more confident than after reading Aristotle, St. Thomas Aquinas, or Copernicus. But does Shen's special configuration of abilities and motivations suggest that a genetic accident produced, out of time, a scientific rationalist-empiricist of essentially modern type? To answer this question it is necessary to look at Shen's larger conception of reality, of which his scientific notions are only a part but from which they are inseparable.

The relation of scientific thought to reality. The sense of cumulative enterprise in mathematical astronomy did not imply the positivistic conviction that eventually the whole pattern could be mastered. Instead, from the earliest discussions on, the attitude was prevalent that scientific explanation—whether in terms of number or of abstract qualitative concepts, such as

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history of Chinese science and technology; Hohhot: Nei-meng-ku Chiao-yü Ch'u-pan-she, 1991), 73–83.

yin-yang—merely expresses, for human purposes, limited aspects of a pattern of constant relations too subtle to be understood. No one expressed this attitude more clearly than Shen. In instance after instance he emphasized the inability of secular knowledge to encompass phenomena: the reason for magnetic declination (437), why lightning striking a house can melt metal objects without burning the wooden structure (347), the way in which every constant and every mean value obscures continuous variation of every parameter (123). This and similar evidence amount not merely to an appreciation of the role of abstraction in science, but also to the steady conviction that abstraction is a limited process incapable of producing universal and fundamental knowledge. Nature is too rich, too multivariant, too subtle *(wei* 微). This limitation did not detract from the interest or worth of theoretical inquiry, and did not lead intellectuals to question whether learning could contribute to the satisfaction of social needs; but the ambit of rationalism in traditional scientific thought was definitely circumscribed.[29]

In this light Shen's explanatory metaphors, such as the willow leaf for variations in planetary speed and the oarlock and waisted drum for optical image inversion, become more comprehensible. He likened the variation in polarity of different magnetized needles to the fact that two species of deer shed antlers in opposite seasons (588; IV.1, 250), and so on. Geometric figures, numbers, and quantities were useful for computation but had very limited value, not so great as cogent metaphors from the world of sensual experience, in understanding its inherent patterns. We have already seen that numerology and mathematics were alternate means to the same goal.

Other kinds of knowledge. Did Shen believe that other ways of knowing complemented and completed empirical and theoretical investigation? Aside from its scientific aspects, Shen's thought has been so little studied that only some tentative suggestions can be offered.

Contemplation and disciplined self-examination were ancient themes in Confucianism. By Shen's time many learned people considered illumination to be a source of knowledge complementary to experience of the external world. The domestication and secularization of Buddhist and Taoist meditation were gradually leading to more introspective and less ritualistic ap-

29. I have studied this theme in "On the Limits of Empirical Knowledge in the Traditional Chinese Sciences" in J. T. Fraser et al., *Time, Science, and Society in China and the West*; for a revised version see below, Vol. II, Chap. IV.

proaches to self-realization. This tendency was later elaborated with great variety of emphasis and weight in the schools of neo-Confucianism.

To understand what part contemplation and meditation played in the thought of Shen Kua requires a clearer view than we now have of their practice and meaning in his time, of Wang An-shih's considerable influence on his intellectual development, and of his own attitudes as indirectly expressed in his literary remains. His interest in Taoist arcana seems to have peaked in his thirties. His public remarks express sympathetic interest in illuminationist (Ch'an, Japanese Zen) Buddhism. He stated in an autobiographical fragment that Ch'an meditation was one of the things to which he turned his attention after retirement. We can hardly overlook such enthusiasms if we hope to grasp his epistemology.

Teraji Jun 寺地遵 has demonstrated this point when examining how strong a factor in Shen's motivation and individuality was his belief in destiny and prognostication. In his commentary on Mencius, Shen spoke of the necessity for choosing what is true and holding to it, and called the rule of the heart and mind by sensory experience "the way of the small man." The basis of moral choice was an autonomous inner authority defined in an original way but largely in Mencian terms, a centeredness "filling the space between sky and earth," unquestionably linked with the self-reliance that marked Shen's own unhappy career.

It is not immediately obvious why someone who so valued individual responsibility should have been fascinated by fate and divination, the themes of whole chapters of Brush Talks. Shen did not view these enthusiasms as in conflict with his scientific knowledge. His delight in strange occurrences and his tendency to place matters of scientific interest under that rubric begin to make sense under the hypothesis that he accepted the odd, the exceptional, and the affront to common sense as a piquant challenge to understanding. Phenomena that seem to be unique turn out to be similar to something else somewhere or at some other time. As Fu Daiwie has put it, "Shen was carving out new classes of things in nature, subjecting them to his own classificatory grid."[30] Other phenomena deserve a place in the chapters on oddities because Shen cannot fathom their place in the cosmic schema, and the challenge remains to be met by someone else—without assuming that explanation is inevitable. In his hundreds of jottings on people, the person he chose to

30. Fu, 27.

praise is most often the one who did not do the obvious thing, even when it seemed the sound thing to do.

At one point Shen provided a thoroughly rational explanation of the relations between fate and prognostication. Certain people can of course know the future, he said, but it is a mistake to conclude that all matters are preordained. The vision of the future is always experienced in present time; the years in the interim also become simultaneous. One can do nothing to avoid an undesirable future so glimpsed. Authentic foreknowledge would have witnessed the evasive measures; a vision that failed to see them could not be authentic foreknowledge (350).

In addition to the visionary ability of certain minds, Shen pondered universally accessible methods of divination, which (he seems to have believed) do not describe the future or the spatially distant so much as provide counsel about them or aid thought about them. In one of his chapters, "Regularities Underlying the Phenomena," he explained why the same divinatory technique gives different outcomes when used by different people, and thus is not inherently verifiable. He quoted the Great Commentary to the Book of Changes to the effect that understanding is a matter of the clarity and divinity (in an abstract sense) within one's mind. This divinity is, for Shen's sources, the moral center of the individual. Because the mind is never without burdens that hinder access to its divinity, Shen reasoned, one's communion with it may take place through a passive mediating object or procedure (144, 145). The rituals of prognostication invoke the power of self-examination. Access to the future, whether by vision or by divination, is a perfectly natural phenomenon. It is related, on the one hand, to the moral faculties, which choose the future, and, on the other, to the sciences, which rationally comprehend the natural order as reflected in all sensory experience.

Thus introspection supplemented by divinatory procedures was a legitimate means to knowledge in Shen Kua's eyes, like painstaking observation and measurement of natural phenomena. He neither confused the two approaches nor attempted to draw a clear line between them. Nor was he inclined to compare the importance of these ways of knowing.

The complementarity in Shen's attitudes toward knowledge parallels another in the external world of his work. Computational astronomy and divination of various kinds (including judicial astrology) were equally weighty functions carried out by the central government on the emperor's behalf. Both kinds of activity supported his charisma. An important memorial of

Wang An-shih (1072) implies that the marriage of scientific activity and imperial ritual is indispensable to government: because the monarch acts on behalf of the natural order *(t'ien* 天), he must understand it in order to safeguard the empire and strengthen the loyalty of his subjects. Ritually expressed awe of that order, without knowledge, is not enough. Teraji has acutely pointed out that this is precisely the political justification for Shen's research, and the reason that conventional bureaucratic technicians, concerned mainly with maintaining ancient practices, were not what Wang wanted.[31]

Confucianism and science. Attempts in both East and West to construct a historical sociology of Chinese science have in large part been built around a contrast between Confucianist and Taoist convictions. The values of the Confucian elite are often described as oriented toward stasis, hierarchy, bureaucracy, and bookishness. These characteristics are seen as perennially in tension with the appetite of socially marginal Taoists for novelty and change, their tendency to contemplate Nature and the individual in it as a system, and their fascination with techniques, which kept them in touch with craftsmen and made them willing to engage in manual work themselves. I examine this set of assumptions elsewhere.[32] For the moment what matters is how relentlessly this discussion has treated both ideologies as collections of vague, free-floating abstractions.

Sociology is about groups of people. Doctrines are germane to sociology to the extent that their effect on what groups of people do, or on how they form, can be demonstrated. Generalizations about people who accept a certain doctrine have no significance unless such people can be shown to acted as a group, or at least so to have identified themselves. In ancient China, whether the use of an idea reflects an intellectual commitment, or merely conventional language, is very much to the point.

The term "Confucian" is used indifferently even by specialists to refer to a master of ceremonial, a professional teacher of Confucian doctrines, a philosopher who contributes to their elaboration, someone who attempts to live by Confucius' teachings, any member of the civil service, any member of the gentry regardless of ambition toward officialdom, or any conventional per-

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31. *Hsu tzu chih t'ung chien ch'ang pien* 續資治通鑑長編 (Unabridged draft of the Sequel to the Comprehensive Mirror for Aid in Government, presented to the throne 1168; 1881 ed.), *236:* 16b.

32. Vol. II, Chaps. VI, VII.

son (since it was conventional to quote Confucian doctrines in support of conventional behavior). A "Taoist" can be anyone from a hereditary priest ordained by the Heavenly Master to a retired bureaucrat of mildly unconventional tastes living on a city estate. Either group, by criteria in common use, includes people who would make opposite choices on practically any issue. This being so, the proposition "Taoists were more friendly toward science and technology than Confucians" reduces to "Educated individuals who hold unconventional sentiments are more inclined to value activities unconventional for the educated than are educated people who hold conventional sentiments." That tautology is sociologically vacuous and historically uninteresting.

Unease of this sort is probably the most obvious outcome of reflection on Shen Kua's career. By sentimental criteria he can be assigned to Confucianism, Taoism, or Buddhism, to suit the historian's tastes.[33] He was a member of the elite, a responsible official, a writer of commentaries on several of the Confucian classics, and a user of the concepts of Confucius' successor Mencius to explore the depths of his own identity. He spoke well and knowledgeably of Buddhism. He practiced arcane disciplines, such as breath control, that he called Taoist.

As for his allegiances, Shen was prominently associated with a powerful but shifting group of politicians whose backgrounds were generally similar to his own. Social stasis and institutional fixity were impediments to their aims in reshaping government. At the same time, the new balance of power toward which they strove was more authoritarian than the old. Underlying their common effort was an enormous disparity of motivation, from the well-intentioned (Shen) to the indefatigably manipulative and corrupt (Ts'ai Ch'ueh).

Were these Confucians more or less Confucian than their Confucian opponents? Wang An-shih, the leader of the New Policies clique, earned enduring stature for his commentaries on the classics and his thought on ca-

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33. Two essays in Anonymous, *Ju-Fa tou-cheng yü wo kuo ku-tai k'o-hsueh chi-shu ti fa-chan* 儒法斗争与我国古代科学技术的发展 (The struggle between Confucianism and Legalism and the development of science and technology in our country in ancient times; Peking: K'o-hsueh Ch'u-pan-she, 1974), 118–140, portray Shen as a Legalist and a relentless opponent of Confucianism. This odd idea was prominent in the "anti-Confucius anti-Lin Piao" campaign of the Cultural Revolution. See "Shen Kuo, the Legalist, and his Scientific Achievements," *Scientia sinica,* 1974, *17:* 717–728.

nonic themes. His followers seem to have found inspiration in the classics as often as their enemies and as those who avoided taking a political position. This is not to say that everyone understood the Confucian teachings in the same way. The latter were not, from the viewpoint of intellectual history, a set of tightly linked ideas that set fixed limits on change; rather, they were a diverse and fragmentary collection of texts reinterpreted in every age. They were understood differently by every individual and group who looked to them for guidance when coping with problems of the moment.

The major commentaries, which attempted to define the meanings of Confucian teachings philologically and didactically, carried enormous authority. Governments repeatedly attempted to make one interpretation orthodox. The administration of Wang An-shih, for instance, originated an important practice by requiring that candidates for the imperial examinations memorize his annotations. But the urge to pin down meanings was always in conflict with precisely what made these books classic. Their unlimited depth of significance depended more on what could be read into them than on precisely what their authors had meant them to say. That depth made them applicable to an infinity of human predicaments and social issues, unprecedented as well as perennial. Late neo-Confucian philosophers striking out in new directions demonstrated again and again how little the bounded intellectual horizons and social prejudices of the ancient canons' authors limited what may be drawn from them.

In other words, the Confucian canon had the influence it did because it set down patterns of thought that, over the centuries, educated people used and redefined in working through new quandaries, justifying action and inaction. Arguments against the New Policies often cited the classics as a pattern for static social harmony and willing subordination. Shen used them to argue for flexibility in social relations and for greater receptivity toward new possibilities than was usual in his time. Either as a social institution or as an ideology, Confucianism is too protean and thus too elusive a base for generalizations about the social foundations of science and techniques in China.[34]

Institutions also changed constantly, but at least they were tangible entities. No one seeking the motors of technical change is likely to succeed without scrutinizing them. Historians are often distracted from such scrutiny by

34. Kidder Smith, Jr., et al. illustrate this point nicely in *Sung Dynasty Uses of the I Ching* (Princeton University Press, 1990).

musings on whether Taoism predisposed anyone and everyone to scientific research, or whether neo-Confucians were capable of "rational analysis."[35]

It is only sensible to consider institutions when tracing the social connections of science. Very little is known about how scientists were educated in the Northern Sung period. In Shen's case we can see a pattern that certainly was not unique. He was, so far as we know, self-educated in astronomy, but with many learned associates to draw upon. In medicine and breath control he probably received teaching in the traditional master-disciple relationship. Defined in the ages before printing enabled access to large collections of books, this relationship involved the student's memorizing the classics that the teacher had mastered. This verbatim transmission of a text was supplemented by the teacher's oral explanations. The relation was deepened by ceremonial formality; the master took on the obligation to monitor the disciple's moral as well as intellectual growth, and the disciple accepted the responsibility of becoming a link in an endless chain of transmission. Schools were largely communities of masters and disciples.[36] The scale of government-sponsored elementary schools in the provinces was small in Shen's youth. Such schools began to compete with private academies only in the New Policies period. The two sorts together did not serve more than a small minority of youth.

In the central government, by the eighth century there were small schools to train technical functionaries. The masters, usually several in number, were officials representing the bureau that the disciples were being trained to staff. The schools for medicine and astronomy could not lead to the top of gov-

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35. On the latter point, see a recent argument that neo-Confucians, because of "their lack of interest in experimentation . . . were unable to examine their incorrect premises" about physical phenomena. This paper does not define "neo-Confucian." It mentions Shen but does not notice the trenchancy of his critical reasoning on such matters. Nor does it observe how often in early modern Europe avid experimention was combined with inability to examine incorrect premises. Charles E. Hammond, "The Interpretation of Thunder," *Journal of Asian Studies*, 1994, *53*. 2: 487–503, citing 498. Aside from these generalities, Hammond does well to correct the tendency among historians of an earlier generation to read a scientific mind-set into every correct description.

36. I have examined these relationships, defined in the third and second centuries B.C., in "Text and Experience in Classical Chinese Medicine," in Don G. Bates (ed.), *Knowledge and the Scholarly Medical Traditions* (Cambridge University Press, 1995).

ernment, but guaranteed steady advancement between minor sinecures. Very few of the important physicians or astronomers of traditional China began in these schools.

In the absence of evidence to the contrary, there is no reason to believe that Shen Kua ever attended a school of any sort, nor does that make him untypical. His early education by his mother, his training in medicine by an obscure physician and others who remain unknown, and his catch-as-catch-can studies of most other matters, do not set him apart from his contemporaries. With no knowledge of particulars one cannot even guess how his personal style in technical work was formed. But to say that we are ignorant is not to say everything. The intimate relations of master and teacher and the isolation of the autodidact were themselves important institutions in the Northern Sung, institutions of a sort that did not discourage the emergence of unforeseen abilities in the small number of people who had the opportunity to be educated. Shen did not have to cope with a standard curriculum, for better or worse. If we are searching for the decisive curriculum of technological practice, it is necessary to look outside the realm of education.

The civil service and the sciences. One institution above all others influenced the mature ideas and attitudes of intellectuals, namely the bureaucracy. This was even true of those who did not belong to it. What can be said about its influence on science and technology in the life of Shen Kua? First, like every bureaucracy, it depended upon science and technology. It supported both sorts of activity on a scale otherwise unattainable, and unimaginable in Europe at the time. Shen's curiosity, experience, and skills were so largely shaped by the civil service that it is absurd to ask what he would have become had he lived as a country gentleman or a Taoist priest. On the other hand, as elsewhere, technicians were further from the priorities of the state than administrators. The responsibility of the former was to provide the emperor and his administrators with wealth and other tools for the realization of policy. Specialist positions in the sciences and in engineering did not often serve as the beginnings of great careers.

Shen's epoch was pivotal in this respect as in many others. By the New Policies period a career stream for economic experts had been established. It could assimilate people who combined technological acumen with fiscal skills, and carry them to the central councils of the empire. Shen's early technical feats were performed in general administrative posts, but his special talents came to be valued and he rose quickly through formal and informal structures. It is not irrelevant that his management of the Directorate of Astronomy was never more than a concurrent position. His attempt to combine an effective voice in the shaping of change with a presence at the frontiers of knowledge ended in personal disaster. He was ruined by men of his own faction, apparently for his political seriousness and naïveté. His astronomical work was rendered futile by subordinates because of his demand that they do their jobs. The bureaucracy was not neutral; it was a two-edged sword.

The civil service provided a form for great projects in science and technology. It practically monopolized certain disciplines, such as mathematical astronomy, observational astrology, and cartography. Printing gave it the wherewithal to determine much of the content of elementary technical education, as in medicine and mathematics. A man of Wei P'u's genius, who had not had the opportunity to enter the bureaucracy by a regular route, was looked down upon and deliberately frustrated. Had Shen himself chosen to be a mere technician, his incumbency in the Directorate of Astronomy might have been sufficient to protect him from personal attack. He would have had more time but less power. It would be rash indeed to speculate that his calendar reform would have succeeded. But there is a larger issue.

Gentlemen were generalists by upbringing. Shen's mind was shaped for the civil service, as were those of his ancestors and peers, by an early education centered in moral philosophy and letters. Only a superficial knowledge of technical matters—arithmetic and so forth, the canonical Six Arts—was expected of youths like him. The development of depth in thought and work was left to his own proclivities. This situation was not very different from that of the British gentleman of some decades ago.

Shen's growing responsibilities in fiscal affairs were the one aspect of his career that clearly encouraged him to draw coherence out of his varied experiences and studies. For this reason and others of which we are still ignorant, the great breadth of his knowledge was accompanied by enough depth to let him write important monographs and, even through his brief jottings, to reshape Chinese understanding of certain phenomena. But distraction is a theme that runs through his writings: promising studies laid aside; endless skirmishes to defend administratively measures that spoke for themselves technically and strategically; pathbreaking proposals negated by political setbacks. Regardless of his capacity for technical depth and his willingness to find his way to it, the sheer busyness of his career blocked his way. The works of his final leisure, however valuable, were all superficial in form. Was this the result of habit, of distance necessitated by disillusion, or of a style appropriate for chatting with one's brush and ink slab in a silent garden? Of all three, no doubt.

What, then, was responsible for Shen Kua's personality? We do not know the answers to all sorts of prior questions. The greatest difficulty comes in learning what these questions should be—in isolating the important issues, in coming to terms with the paucity and partiality of the sources, and in doing justice to a rich mind that, despite its absorption in a quest that belongs to all peoples and all eras, partook fully of its time and place. It is not a matter of mechanically juxtaposing the usual factors: intelligence, subjectivity, philosophical convictions, social background, career, experiences. We have already seen how problematic the last three are. The most conspicuous traits of Shen's consciousness were open curiosity, mental independence (without the intolerance for disagreement that was a great limitation of Wang An-shih), sympathy for the unconventional, ambition, loyalty, and consciousness of his place in the world. The first four are considered marks of promise among technical people today, although one often meets great scientists who lack one or more of them. Were these characteristics in Shen due to heredity, to early experiences and education, or to influences encountered in adult life? This is another example of the sort of question that bars understanding; surely Shen was the sum of all these and more. The secret of his uniqueness will not yield itself to historical method, however powerful, unless it is applied with imagination, artifice, and awareness of the springs of human complexity.

Attitudes toward Nature. When examined closely, attitudes toward Nature in the late eleventh century become as elusive as attitudes toward Confucian humanism. The richly articulated philosophic vision of man in harmony with his physical surroundings could not prevent the deforestation of northern China, virtually completed a generation after Shen's death. One cannot even speak of the defeat of that vision in an encounter of ideas; there was none. What happened? The most obvious part of the answer is that the people who were chopping down the trees for timber and charcoal were not the people who were seeking union with the ineffable cosmic Tao. That social difference was of too long standing, however, to explain the crescendo of exploitation in the Northern Sung. The coincidence of that fateful shift with the rise of large-scale industry and market networks is again obvious enough.[37] What needs to be explained, rather, is the survival of the naturalist ideal until modern times.

The dilemma emerges clearly in the attitudes of Shen Kua and Wang An-shih toward their natural environment. The orientations that pervade Brush Talks are in most respects the same as those of literati thinking about Nature a millennium earlier. Philosophical pigeonholes are largely beside the point. Some "Confucians" thought about Nature a great deal, and some, convinced that human society is the sole proper object of reflection and action, as little as possible. The notions of heaven and earth they drew on were, on the whole, the ones common to all Chinese who could read and write. Nature was an organismic system, its rhythms cyclic and governed by the inherent and concordant pattern uniting all phenomena.

With that in mind, it comes as a shock to see Shen's definition of salt in a memorial of 1077: "Salt is a means to wealth, profit without end emerging from the sea."[38] This was not a slip, nor is it difficult to find philosophical precedents. Shen expected wealth from Nature to pay for the expanding fiscal functions of the state. That mattered, because he briefly held supreme responsibility for those functions. He recommended—on the basis of his own early accomplishments—encouraging extractive industries and manufactures, and mobilizing labor for land reclamation, in order to increase the wealth of the state. In that respect he was faithful to the priorities of Wang An-shih. This is a far cry from the senior cadre in China in the 1960's designing a campaign to convince farmers that Nature is an enemy to be conquered, tamed, and remolded to social ends. But neither is it the pastoral ideal.

Why this discrepancy between Nature as the ideal pattern to which man adjusts, and Nature as an exploitable resource? Why does Shen seem not to be conscious of the contradiction? The research has yet to be done, but Shen Kua's career, considered in the round, suggests a working hypothesis. Such

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37. See the series of papers by Hartwell: "A Revolution in the Chinese Iron and Coal Industries during the Northern Sung, 960–1126 A.D.," *Journal of Asian Studies*, 1962, *21:* 153–162: "Markets, Technology, and the Structure of Enterprise in the Development of the Eleventh-Century Chinese Iron and Steel Industry," *Journal of Economic History*, 1966, *26:* 29–58; "A Cycle of Economic Change in Imperial China: Coal and Iron in Northeast China, 750–1350," *Journal of the Economic and Social History of the Orient*, 1967, *10:* 102–159.

38. *Hsu tzu chih t'ung chien ch'ang pien*, 280: 17b–21b.

notions as yin-yang, the Five Phases, and certain related ideas associated with the Han commentaries on the *Book of Changes,* are sometimes called hindrances to an autochthonous scientific revolution in traditional China. This is, of course, an elementary fallacy.[39] The old Chinese world view had much in common with cosmological ideas (the four elements and so on) universal among the educated in Europe until the seventeenth century, ideas that readily faded away as Aristotelianism withered. Historically speaking, Chinese organismic naturalism was not a rigid framework of ideas that barred change; rather, it was the only conceptual language available for thinking about Nature and communicating one's thoughts, *new or old,* to others. Like any language, it imposed form and was itself malleable. Its historical possibilities were less a matter of original etymology or definition than of the ambiguity and extensibility that let people in later ages read new and often drastically changed import into old words. There is no true paradox in appeals to the harmony of man and Nature by Shen and others before and after him who favored the exploitation of Nature in the interests of the state. Although such activist thinkers stretched the old pattern of understanding, its fabric remained seamless. Their definition of what they wanted could not transcend it. Only the more desperate urgencies of another time could finally stretch it until it tore.

Bibliography

Primary sources

The best attempt at a complete list of Shen's writings is in an appendix to Hu Tao-ching's 胡道靜 standard ed. of Brush Talks, *Meng ch'i pi t'an chiao cheng* 夢溪筆談校證 (Brush Talks From Dream Brook, a Variorum Edition, hereafter *Chiao cheng;* Shanghai: Chung-hua Shu-chü, 1956; rev. ed., 2 vols., Peking: idem, 1960), 1151–1156. There are forty titles, including lost works mentioned in early writings about Shen. Some titles belong to parts or earlier versions of larger writings. Ch'en Teng-yuan 陳登原 has suggested that the high rate of attrition was due to the campaign of Ts'ai Ching 蔡京 (1046–1126), virtual dictator during the revival of the New Policies in the first quarter of the twelfth century, to obliterate the literary remains of his predecessors as well as their enemies. See Ch'en's *Ku-chin tien-chi chü-san k'ao* 古今典籍聚 散考 (A study of the collection and dispersal of classical writings in ancient and

39. This and other fallacies are analyzed in Chap. VII below.

modern times; Shanghai: Hai-wai T'u-shu Ch'u-pan-she, 1936), 54. Six of Shen's books are extant, although only two appear to be substantially unaltered, and considerable fragments of four others exist. Those of scientific interest are described below:

1. *Meng ch'i pi t'an* 夢溪筆談 (Brush Talks From Dream Brook), written over the greater part of Shen's retirement and possibly printed during his lifetime. It includes 587 jottings.

Brush Talks was first quoted in a book dated 1095. Originally it consisted of 30 ch. (*chuan* 卷). All extant versions, descended from a xylograph of 1166, follow an unknown prior editor's rearrangement into 26 ch. The editor of the 1166 reprint noted a number of errors that he could not correct for want of variants. One copy of the 1166 version survives in Japan. A reprint of 1305 has been reproduced as *Yuan k'an Meng ch'i pi t'an* 元刊夢溪筆談 (Peking: Wen-wu Ch'u-pan-she, 1975).

There are two sequels, *Pu pi t'an* 補筆談 (Supplement to Brush Talks, 91 jottings), listed in most early bibliographies as 2 ch., but rearranged in the 1631 ed. into 3 ch. with some alteration of order, and *Hsu pi t'an* 續筆談 (Sequel to Brush Talks, 11 jottings in 1 ch., mostly on literature). Hu suggests that both sequels were edited posthumously from Shen's notes. There is even stronger evidence for this hypothesis than he adduces, for some articles appear to be rejected drafts of jottings in Brush Talks (cf. 588 with 437, 601 with 274).

The practically definitive ed. of Brush Talks and its sequels, and in many other respects the foundation of later studies, is the 1960 Hu Tao-ching recension. It includes a carefully collated and corrected text with variorum notes and modern (but occasionally faulty) punctuation, based on all important printed versions beginning with that of 1495 and on five previous sets of variorum notes. It also provides exegetic and explanatory notes and generous quotations from documents concerning Shen, from his other books, from the reflections of other early writers on his subject matter, and from modern Chinese (and to some extent Japanese and Western) scholarship. Appendixes include thirty-six additional jottings or fragments that have survived only in the writings or compilations of others; all known prefaces and colophons; notes on eds. by early bibliographers and collators; a chronological biography; a list of Shen's writings; and an index to names and variant names of all persons mentioned in Brush Talks (a tool still very rare in Chinese publications). Hu also published a 1-vol. version of the text with minimal apparatus as *Hsin chiao cheng Meng ch'i pi t'an* (Brush Talks, newly edited; Peking: Chung-hua Shu-chü, 1957). He summarized foreign scholarship up to the late 1970's in "Meng ch'i pi t'an tsai kuo-wai 梦溪笔谈在海外" (Brush Talks abroad), *Shu-lin* 书林, 1979, 1: 14–17. For a retrospect see his *"Meng ch'i pi t'an chiao cheng* wu-shih nien 梦溪笔谈校正五十年" (Fifty years of the variorum ed.), *Tu shu* 读书, 1979, 4: 120–125.

Hu Tao-ching's unflagging labors in China and Yabuuchi Kiyoshi's 薮内清 and Joseph Needham's broad use of Brush Talks in their publications have made Shen's name generally familiar to historians of science, but one can hardly discern a scholarly industry forming around him. Several of Yabuuchi's pertinent publications are gathered in *Sô-Gen jidai no kagaku gijutsushi gijutsushi* 宋元時代の科学技術史(History of science and technology in the Sung and Yuan periods; Kyoto: Kyôtô Daigaku Jimbun Kagaku Kenkyûsho, 1967). Teraji Jun 寺地遵, "Shin Katsu no shizen kenkyû to sono haikei 沈括の自 然研究とその背景" (The natural investigations of Shen Kua and their background), *Hiroshima Daigaku Bungakubu kiyô* 広島大学文学部紀要, 1967, *27.* 1: 99–121, is a notable attempt at an overview. Sakade Yoshinobu's 坂出祥伸 positivistic discussion of Shen's use of theory, "Shin Katsu no shizenkan ni tsuite 沈括の自然観について" (On Shen Kua's conception of Nature), *Tôhôgaku* 東方学, 1970, *39:* 74–87, contains a number of stimulating insights. The only study of comparable breadth since 1975, discussed in n. 10 above, is Joël Brenier et al., "Shen Gua (1031–1095) et les sciences," *Revue d'histoire des sciences,* 1989, *42:* 333–351.

There have been a couple of useful partial commentaries: Hu & Chin Liang-nien 金良年, *Meng ch'i pi t'an tao tu* 梦溪笔谈导读 (Reader's guide to Brush Talks; Chengdu: Ba-Shu Shu She, 1988), with vernacular notes; Jean François Billeter, "Florilège des *Notes du Ruisseau des réves (Mengqi bitan)* de Shen Gua (1031–1095)," *Asiatische Studien,* 1993, *47.* 3: 389–451. Partial translations into modern Chinese include Li Ch'ün 李群, *Meng ch'i pi t'an hsuan tu. Tzu-jan k'o-hsueh pu-fen* 梦溪笔谈选读。自然科学部分 (Selected readings from Brush Talks. Sections on natural science; Peking: K'o-hsueh Ch'u-pan-she, 1975); Chung-kuo K'o-hsueh Chi-shu Ta-hsueh 中国科学技术大学 (Chinese Science and Technology University) et al., *Meng ch'i pi t'an i chu. Tzu-jan k'o-hsueh pu-fen* 梦溪笔谈译注。自然科学部分 (Brush Talks, translated and annotated. Sections on natural science; Hofei: An-hui K'o-hsueh Chi-shu Ch'u-pan-she, 1979). The former book contains 86 jottings, and the latter 138, chosen from the more than two hundred on science and technology.

2. *Hsi-ning Feng-yuan li* 熙寧奉元曆 (The Oblatory Epoch astronomical system of the Splendid Peace reign period, 1075), lost, but listed in a Sung bibliography as 7 ch. This was the official report embodying Shen's calendar reform. The usual arrangement provided lists of constants and step-by-step instructions for computation, with tables as needed, so that a clerk with no knowledge of astronomy could calculate the complete ephemeris. Since a *Hsi-ning Feng-yuan li ching* 曆經 (Canon of the Oblatory Epoch Astronomical System . . .) in 3 ch. is separately recorded, the remaining 4 ch. may have been, as in other instances, an official evaluation *(li i* 曆議) outlining the observational basis of the system and reporting on trials of its accuracy. The Sung standard history also records a ready reckoner *(li ch'eng* 立成) in 14 ch., containing tables and other aids to calculation, and a detailed explanation of the mathematics with worked-out examples *(pei ts'ao* 備草) in 6 ch. The great student of ancient astronomy Li Jui 李銳 (1765–1814) gathered surviving fragments of the basic document under the title *Pu hsiu Sung Feng-yuan shu* 補修 宋奉元術 (Restoration of the Sung Oblatory Epoch techniques), in *Li shih i shu* 李氏遺書 (Posthumous works of Mr. Li, printed 1823). Three proposals of 1074, in which Shen outlined his designs for armillary instruments, clepsydras, and gnomons, survive in the Sung history *(Sung shih* 宋史, Chung-hua Shu-chü 1977 ed., *48:* 954–965).

3. *Liang fang* 良方 (Good medicinal formulas), a work of 10 or 15 ch. compiled during Shen's retirement. In the Sung (probably ca. 1126) it was combined with various medical formulas recorded by the greatest literary figure of Shen's time, Su Shih 蘇軾 (1036–1101), a moderate but influential opponent of the New Policies. The conflation is called *Su Shen nei-han liang fang* 蘇沈內翰良方 (Good medicinal formulas by the Han-lin Academicians Su and Shen), often referred to as *Su Shen liang fang.* The most broadly based text is that in the *Chih pu-tsu chai ts'ung-shu* 知不足齋叢書 collection and modern reprints descended from it. One copy of an illustrated Ming ed. still exists. Shen's original compilation was lost sometime after 1500. There is some overlap between ch. 1 of *Su Shen liang fang* and jottings in ch. 26 of *Meng ch'i pi t'an.*

Hu has reconstituted Shen's *Liang fang,* so far as it can be done, by separating out the part of *Su Shen liang fang* written by Su. See "Su Shen nei-han liang fang Ch'u Shu p'an 苏沈内翰良方楚蜀判" (Sorting out the medicinal formulas in Good Formulas by Su and Shen), *She-hui k'o-hsueh chan-hsien* 社会科学战线, 1980, 3: 195–210, and Wu Tso-hsin 吴佐忻, "*Su Shen liang fang* i-wen hsi 苏沈良方佚文析" (Analytical study of lost texts from Good Formulas by Su and Shen), *Chung-hua i-shih tsa-chih,* 1982, *12.* 4: 257.

A lost collection of medicinal formulas in 20 ch., *Ling yuan fang* 靈苑方 (Formulas from the Holy Garden), is quoted in Sung treatises on materia medica. Hu Tao-ching has shown that it was written before *Liang fang* (*Chiao cheng*, 830–831). See the comparison between Good Formulas and medical jottings in Brush Talks, 880–882.

4. *Meng ch'i wang huai lu* 夢溪忘懷錄 (Record of longings forgotten at Dream Brook), 3 ch., compiled during Shen's retirement. It incorporates a lost book on mountain living written (or at least begun) in Shen's youth and entitled *Huai shan lu* 懷山錄 (Record of longings for the mountains). His retirement to Dream Brook satisfied his early longings, hence the title of the later collection. It was lost soon after his death. The only well-known excerpts, in the *Shuo fu* 說郛 collection, are on implements useful to the well-born mountain dweller, but Hu Tao-ching in a recent study has shown that the book was plausibly classified by early bibliographers as agricultural. Hu has also collected all known fragments. See Hu, "Shen Kua ti nung-hsueh chu-tso *Meng ch'i wang huai lu* 沈括的農學著作夢溪忘懷錄" (Shen Kua's agricultural work Record of Longings Forgotten), *Wen shih* 文史, 1963, 3: 221–225; Hu & Wu Tso-hsin, "*Meng ch'i wang huai lu* kou-ch'en—Shen Ts'un-chung i-chu kou-ch'en chih i 梦溪忘怀录钩沉一沈存中佚著钩沉之一" (Record of Longings Forgotten recovered. Shen Kua's lost works reconstituted, 1), *Hang-chou ta-hsueh hsueh-pao* 杭州大学学报, 1981, *11*. 1: 1–16.

5. *Ch'ang-hsing chi* 長興集 (Collected Literary Works of [the Viscount of] Ch'ang-hsing), originally 41 ch., almost certainly a posthumous compilation. This book includes prose, poetry, and administrative documents prized for their language. It also contains important astronomical documents and sources for Shen's intellectual formation, in particular his commentary on Mencius (*Meng-tzu chieh* 孟子解) in ch. 23. By ca. the fifteenth century, when the book was reprinted in *Shen shih san hsien-sheng wen chi* 沈氏三先生文集, only 19 ch. of the Sung version remained. *Ssu pu ts'ung k'an* 四部叢刊 reproduces this ed. The ed. of 1718 contains an additional 3 ch. collected from other sources, but was very carelessly edited; see Teng Kuang-ming 邓广铭, "Pu-hsu-yao wei Shen Kua chin-shang t'ien hua—Wan-ch'un wei ping fei Shen Kua hsing-chien hsiao k'ao 不需要为沈括锦上添花—万春圩并非沈括兴建小考" (No need to gild the lily for Shen Kua; the Myriad Springs Embankment system was not built by him), in *Shen Kua yen-chiu* 沈括研究 (Studies of Shen Kua, compiled by the Seminar on Sung History of Hangchow University; Hangchow: Che-chiang Jen-min Ch'u-pan-she, 1985), 16–26. Hu Tao-ching has supplemented this source by gathering Shen's poetry from

a wide range of sources in *Shen Kua shih tz'u chi ts'un* 沈括诗词辑存 (Collection of Shen Kua's extant poetry; Shanghai: Shang-hai Shu-tien, 1985).

Translations

A high standard for translation has been set in the complete, annotated Japanese translation by the History of Science Seminar, Institute for Research in Humanities (Jimbun Kagaku Kenkyûsho), Kyoto University: Umehara Kaoru 梅原郁 (ed.), *Bôkei hitsudan* 夢渓筆談(Brush Talks, 3 vols.; Tôyô bunko 東洋文庫, 344, 362, 403; Tokyo: Heibonsha, 1978–1981). Not the least of this publication's many virtues is a detailed index. Translations into modern Chinese are sprinkled through Chang Chia-chü 张家驹, *Shen Kua* (Shanghai: Shang-hai Jen-min Ch'u-pan-she, 1962). The only book in any Western language that translates more than a few examples of Shen's writings is Joseph Needham et al., *Science and Civilisation in China,* 7 vols. projected (Cambridge University Press, 1954–), esp. in vols. III–IV. The translations are generally accompanied by more contextual information than is usual in Chinese publications. Occasionally the English version is extremely free, as when "Meng ch'i" is translated "Dream Pool." A representative selection of English translations will be included in a sourcebook of Chinese science that I am compiling.

Secondary Literature

Bibliography and biography. *Shen Kua yen-chiu* 沈括研究, 322–336, provides a bibliography of studies from 1926 to 1983. Earlier sources in Chinese are cited in Hu's *Chiao cheng* or in the footnotes to the biographies.

Chang's biography is the fullest and most accurate account of Shen's life, and pays attention to the whole range of his work. It is generally critical in method, but sometimes careless. Like other Chinese accounts of its period, it is severely positivistic, patronizing toward "feudal" aspects of Shen's mentality, and inclined to exaggerate his empathy with the common people. Another work of interest by Hu Tao-ching, overlapping to some extent the preface to his ed. of Brush Talks, is "Shen Kua ti cheng-chih ch'ing-hsiang ho t'a tsai k'o-hsueh ch'eng-chiu-shang ti li-shih t'iao-chien" (Shen Kua's political tendencies and the historical conditions bearing on his scientific accomplishments), in Li Kuang-pi 李广壁 and Ch'ien Chün-yeh 钱君晔, eds., *Chung-kuo li-shih jen-wu lun-chi* 中国历史人物论集 (Essays on Chinese historical figures; Peking: San Lien Shu-tien, 1957), 330–347. Its summary of scientific and technical achievements in the Northern Sung period from 960 to ca. 1100 is especially useful. Li Kuang-yü 李光羽, *Shen Kua* (Nanking: Chiang-su Ku-chi Ch'u-pan-she, 1983), is a brief popular biography without references.

In addition to discursive biographical studies, Shen's life has been the subject of four chronologies *(nien-p'u* 年譜), an old form that lists individual events year by year along with related data. The fullest in print (although obsolete in some respects) is Chang Yin-lin 張蔭麟, "Shen Kua pien nien shih chi 沈括編年事輯" (A chronicle of Shen Kua), in *Ch'ing-hua hsueh-pao* 清華學報, 1936, *11:* 323–358. The one appended to Hu Tao-ching's *Chiao cheng,* 1141–1156, is especially handy because of its references to jottings and to sources cited in the book's notes. The most up-to-date and accurate chronology is the concise one at the end of the Umehara translation. Hu Tao-ching, in his colophon to the 1960 ed. of Brush Talks, remarked that his own book-length chronology was in the press, but it has not yet appeared.

Yabuuchi Kiyoshi, Japan's leading historian of science, has provided a characteristically reflective discussion of the historic circumstances of Shen's career in "Shin Katsu to sono gyôseki 沈括とその業績" (Shen Kua and his achievements), in *Kagakushi kenkyû* 科学史研究, 1958, *48:* 1–6. Rejecting the prevalent tendency to prove Shen's greatness by citing anticipations of European science and technology, Teraji Jun has made a fruitful and original effort to grasp the inner coherence of his thought and work. The essay cited above influenced the present article's conclusion.

The first European introduction to Shen's life was Donald Holzman, "Shen Kua and his *Meng-ch'i pi-t'an,"* in *T'oung Pao* (Leiden), 1958, *46:* 260–292, occasioned by the Hu's 1956 ed. of Brush Talks. In addition to providing a critical and well-proportioned biographical sketch, Holzman paid more attention to Shen's humanistic scholarship than did any other author discussed in this section. He also considered some of the evidence for Shen's position in the history of science, but reached no conclusion. He tended to ask whether Shen's ideas are correct from today's point of view rather than what they contributed to better understanding of Nature in the Sung. I am working on a full-length intellectual biography. A reliable and compendious introduction to the New Policies is James T. C. Liu, *Reform in Sung China. Wang An-shih (1021–1086) and his New Policies* (Cambridge, MA: Harvard University Press, 1959).

Studies of work. The first modern study of any aspect of Shen's interests, largely responsible for the attention paid him by Chinese educated in modern science, is Chu K'o-chen 竺可桢, "Pei Sung Shen Kua tui-yü ti-hsueh chih kung-hsien yü chi-shu 北宋沈括對於地學之貢獻與記述" (Contributions to and records concerning the earth sciences by Shen Kua of the Northern Sung period), in *K'o-hsueh* 科學, 1926, *11:* 792–807. Chu's erudite and broadly conceived article has influenced much of the later writing on the subject. Many observations on Shen's scientific and technical ideas are distributed through Needham et al., *Science and Civilisation in China,* as well as through the topical studies by leading Japanese specialists in Yabuuchi, *Sô-Gen jidai no kagaku gijutsu shi. Shen Kua yen-chiu* contains 17 articles on diverse aspects of his work.

A concise survey of Shen's positive contributions by a great historian of mathematics is Ch'ien Pao-ts'ung 钱宝琮, "Shen Kua," in Seminar in the History of the Natural Sciences (ed.), *Chung-kuo ku-tai k'o-hsueh-chia* 中国古代科学家 (Ancient Chinese scientists; Peking: K'o-hsueh Ch'u-pan-she, 1959), 111–121. The articles in Ch'ien (ed.), *Sung Yuan shu-hsueh-shih lun-wen-chi* 宋元数学史论文集 (Essays in the history of mathematics in the Sung and Yuan periods; Peking: idem, 1966) study Shen's most noteworthy problems.

There is no recent investigation in depth of Shen's astronomical activities, but Juan Yuan 阮元, *Ch'ou jen chuan* 疇人傳 (Biographies of Mathematical Astronomers, 1799; reprint, Shanghai: Commercial Press, 1935), *20:* 238–243, provides a good technical description of what were traditionally considered Shen's most important contributions.

Although physics was not a discrete body of knowledge in traditional China, it is an obvious theme for positivistic studies. Notable are Wang Chin-kuang 王锦光, "*Meng ch'i pi t'an* chung kuan-yü tz'u-hsueh yü kuang-hsueh ti chih-shih 梦溪笔谈中关於磁学与光学的知识" (Knowledge of magnetism and optics in Brush Talks), *Che-chiang Shih-fan Hsueh-yuan hsueh-pao* 浙江师范学院学报, 1956, 2: 57–67, and Li Ti 李迪, "Shen Kua tsai wu-li-hsueh-shang ti kung-hsien 沈括在物理学上的贡献" (Shen Kua's contributions to physics), *Wu-li hsueh-pao* 物理学报, 1975, *24:* 231–236. Li has also explored Shen's meteorological interests in "Shen Kua tui ch'i-hsiang hsien-hsiang ti chi-shu yü yen-chiu 沈括对气象现象的记述与研究" (Shen Kua's records and studies of meteorological phenomena), *Ta ch'i k'o-hsueh* 大气科学, 1977, 2: 159–161.

For a general view of Shen's medical knowledge see Juan Fang-fu 阮芳赋, "Shen Kua yü i-yao-hsueh 沈括与医药学" (Shen Kua and medicine), in *I-hsueh hsin lun* 医学新论 (New discussions of medicine; Harbin: Hei-lung-chiang K'o-hsueh Chi-shu Ch'u-pan-she, 1984), 230–240. Hsia Nai 夏鼐, "Shen Kua ho k'ao-ku-hsueh 沈括和考古学" (Shen Kua and archaeology), *K'ao-ku* 考古, 1974, 5: 277–289, reprinted in Hsia, *K'ao-ku-hsueh ho k'o-chi shih* 考古学和科技史 (Archaeology and the history of science and technology; Peking: K'o-hsueh Ch'u-pan-she, 1979), 15–28, 139–141, and Synnøve Vinnsrygg, "Time in Archaeological Thought: China and the West," in *Time, Science, and Society in China and the West* (ed. J. T. Fraser, N. Lawrence, & F. Haber; The Study of Time, 5; Amherst: University of Massachusetts Press, 1986), 225–240, elucidate Shen's remarks on ancient techniques.

Rulan C. Pian, *Sonq Dynasty Musical Sources and Their Interpretation* (Cambridge, MA: Harvard University Press, 1967), esp. 30–32, uses and evaluates the substantial portion of Brush Talks devoted to music. Ts'ai Bin-mou 蔡宾牟 & Yuan Yun-k'ai 袁云开, *Wu-li-hsueh shih chiang-i. Chung-kuo ku-tai pu-fen* 物理学史讲义。中国古代部分 (Lectures on the history of physics. Ancient China; Peking: Kao-teng Chiao-yü Ch'u-pan-she, 1985), 130–134, provides a more technical discussion typical of Chinese textbooks. Useful for Shen's aesthetic ideas is Liu Ch'i-lin 刘启林, *Meng ch'i pi t'an i-wen pu chiao chu* 梦溪笔谈艺文部校注 (A critical, annotated study of the parts of Brush Talks on arts and letters; Harbin: Hei-lung-chiang Jen-min Ch'u-pan-she, 1986), which elucidates ch. 14 and 16–18.

Robert M. Hartwell, in an unpublished study, relates Shen's ideas concerning economic theory, the circulation of money, and similar topics, to traditions of thought on these subjects. Hu Tao-ching has published a most interesting study of Shen's military ideas: "Shen Kua chün-shih ssu-hsiang t'an yuan. Lun Shen Kua yü ch'i chiu-fu Hsu Tung ti shih-ch'eng kuan-hsi 沈括军事思想探源。论沈括与其舅父许洞的师承关系" (The sources of Shen Kua's military thought. The master-disciple relation of Shen Kua and his uncle Hsu Tung), *She-hui k'o-hsueh* 社会科学, 1980, 6: 120–124.

Retrospect

This essay, like that on Wang Hsi-shan in Chapter V and another on Li Shih-chen, was commissioned by Charles C. Gillispie for the *Dictionary of Scientific Biography.* This is not, as the length of this article makes clear, a conventional dictionary, but rather an attempt to sum up the state of understanding of its field ca. 1970 in the form of extended biographies. The essay was printed in vol. XII (New York: Charles Scribner's Sons, 1975), and reprinted for a Sinological readership as "Shen Kua: A Preliminary Assessment of his Scientific Thought and Achievements" *Sung Studies Newsletter*, 1977 (published 1978), *13:* 31–56.

The relations of science to other aspects of Chinese culture had long intrigued me; Shen's polymathic activities and interests offered an ideal focus. I was surprised to find no intellectual center uniting them. I recognized—slowly, because I did not expect it—that his technical interests were consistently shaped by his experience as a civil servant. His frequent breakthroughs in understanding owe a great deal, of course, to his brilliance and curiosity. But, like a large proportion of historical innovations, they frequently came from juxtaposing insights that did not conventionally fit together. He was able to do this because of his remarkable breadth of experience. What nurtured such connections, I believe, was his responses to a dizzying sequence of challenges, at the same time professional and personal. They arise from his piece of the action, as Vannevar Bush put it, during the tumultuous political transition that I have sketched above.

There have been a good many publications on Shen Kua since 1975. Some of this work has suggested fresh insights into one aspect or another of his writing, summarized in this revision. Most research on Shen has remained textually oriented. None has prompted a fundamental reevaluation of his life or work. I have added to the bibliography a number of recent monographs, and several books on wider topics that facilitate studying Shen and his time.