3. Major General K. Mackay, interview, 10 October 1985.
4. Chiefs of Staff Committee directive of 20 January 1969, reproduced as appendix A to D. M. Horner, *Australian Higher Command in the Vietnam War*, Canberra, 1986; Mackay, interview, 10 October 1985.
5. Alan Stretton, *Soldier in a Storm*, Sydney, 1978, p. 200; Ministry of Defence, *The New Zealand Army in Vietnam, 1964–1972: A Report on the Chief of the General Staff's Exercise 1972*, Wellington, 1973, p. 53; Lieutenant General Sir Donald Dunstan, interview, 23 December 1985; Mackay, interview, 10 October 1985.
6. Dunstan, interview, 23 December 1985; Major General D. Vincent, address, Canberra, 27 November 1985.
7. Mackay, interview, 10 October 1985; Lieutenant General Sir Thomas Daly, interview, 26 November 1985.
8. These two diagrams are based on diagrams of later command structures in 'Briefing for COMAFV, Maj Gen R. A. Hay, MBE', March 1969, AWM 181, 'Herbicide Series', [HQAFV] Non-Registry, item DAQMG Briefs — DAQMG file no. 114.
9. Mackay, interview, 10 October 1985. Mackay does not recall being shown the Combined Campaign Plan but was kept fully informed at briefings.
10. Ibid.; Vincent, address, 27 November 1985.
11. Mackay, interview, 10 October 1985.
12. Ibid.
13. Ibid.
14. George Odgers, *Mission Vietnam: Royal Australian Air Force Operations, 1964–1972*, Canberra, 1974, p. 55. RAAF strength was 652.
15. Lieutenant Colonel J. F. McDonagh, 'Civil Affairs in Phuoc Tuy Province, South Vietnam 1967–68', *Army Journal*, August 1968; 'Briefing for COMAFV, Maj Gen R. A. Hay, MBE', AWM 181; Major General J. Whitelaw, interview, 28 April 1986.
16. Vincent, address, 27 November 1985; General Sir Arthur MacDonald, interview, 13 December 1985.
17. Phoenix was concerned with the identification and neutralization of leaders of the Viet Cong. MacDonald, interview, 13 December 1985; Major General Whitelaw, when Chief of Staff, HQ, AFV in 1970, directed the commanding officer of the AATTV to cut down involvement in the Phoenix programme: interview, 28 April 1986.
18. Ian McNeill, *The Team*, Canberra, 1984.
19. Brigadier O. D. Jackson, address to Chief of the General Staff Exercise, 1971.
20. For early concern about the minefield see AWM 181, [HQ1ATF], R569-2-26, item Operations — Particular — 1ATF Operation *Leeton*; Major General R. L. Hughes, interview, 30 October 1985; Vincent, address, 27 November 1985, and interview, 2 December 1985; Daly, interview, 26 November 1985.
21. Letter, Vincent to Military Assistance Command, Free World Military Assistance Organization, 1 August 1967, AWM 181, [HQ1ATF], item R569-1-55, Operations — General — Combined Campaign; Stretton, *Soldier in a Storm*, p. 215; Vincent, address, 27 November 1985; Dunstan, interview, 23 December 1985.
22. Hughes, interview, 30 October 1985; Daly, interview, 26 November 1985. The introduction of tanks is described in Major General R. N. L. Hopkins, *Australian Armour: A History of the Royal Australian Armoured Corps 1927–1972*, Canberra, 1978, pp. 250–2.

23. Vincent, address, 27 November 1985; *Canberra Times*, 24 July 1967, 13 February 1968.
24. Hughes, interview, 30 October 1985.
25. MacDonald, interview, 13 December 1985.
26. Hughes, interview, 30 October 1985; Dunstan, interview, 23 December 1985.
27. Major General C. M. I. Pearson, interview, 26 November 1985; MacDonald, interview, 13 December 1985.
28. MacDonald, interview, 13 December 1985.
29. Ibid.
30. Major General R. A. Hay, interview, 5 November 1985; Stretton, *Soldier in a Storm*, pp. 207, 208.
31. 'Briefing for COMAFV, Maj Gen R. A. Hay, MBE', AWM 181; signal, Austforce VN to Army Canberra, 24 December 1970, ibid., item 237/1/21.
32. Letter, Hay to Daly, 16 April 1969, DO letters, Major General R. A. Hay, MBE, from 1 March 1969 to 7 April 1970, AAAGV, AWM (unserialized).
33. Hay to Harry, 4 October 1969, ibid.
34. Hay, interview, 5 November 1985; Pearson, interview, 26 November 1985; Daly, interview, 26 November 1985; letter, Hay to Pearson, 24 July 1969, Hay, DO letters, AAAGV, AWM.
35. Hay, interview, 5 November 1985; McNeill, *The Team*, p. 349, claims that the advisers were still not happy with the arrangements at Pleiku.
36. Signal, CGS to COMAFV, 28 February 1970, CGS–COMAFV, 1 January 1967 – 28 February 1970, AAAGV, AWM; signal, COMAFV to CGS and CCOSC, 1 March 1970, CGS–COMAFV, from 1 March 1970, AAAGV, AWM.
37. Brigadier G. D. Solomon to author, 10 June 1986; Whitelaw, interview, 28 April 1986; letter, Whitelaw to Colonel J. R. Salmon, 20 October 1970, DO file, chief of staff, from April to November 1970, AAAGV, AWM.
38. Daly interview, 26 November 1985; letter, Vincent to Daly, 15 July 1967, Vincent papers; Vice-Admiral Sir Alan McNicoll, interview, 6 March 1986.
39. Letter, Major General C. A. E. Fraser to author, 10 August 1986.
40. Letters, Rosson to Fraser, 23 July 1970, and Fraser to Rosson, 1 August 1970, personal correspondence, from 1 July 1970 to August 1970, AAAGV, AWM.
41. The establishment of the Jungle Warfare Training Centre in Phuoc Tuy is discussed in detail in McNeill, *The Team*, chapter 16.
42. For a discussion of civic action policies see Frank Frost, *Australia's War in Vietnam*, Sydney, 1987, chapter 8, and Philip Ayres, *Malcolm Fraser: A Biography*, Melbourne, 1987, pp. 175–8; Daly, interview, 26 November 1985. General MacDonald has admitted that he did not take as much notice of civic action as he should have during his time as COMAFV: interview, 13 December 1985.
43. Dunstan, interview, 23 December 1985.
44. Ibid.
45. Ibid.
46. Ibid.
47. William C. Westmoreland, *A Soldier Reports*, New York, 1976, p. 258, quoted in Frank Frost, 'The Operations of the Australian Army in South Vietnam, 1966–1971: Political and Military Problems', PhD thesis, University of Sydney, 1976.

Phantom soldiers

Australian tunnellers on the western front, 1916–18

Beneath the western front Australian tunnellers fought a war of technological innovation which contributed significantly to the bloody battles in the trenches. Roy MacLeod unearths the neglected men of the Australian tunnelling companies.

About midnight on the 6th June we assembled, were given the zero hour, synchronised our watches and departed to our posts ... The artillery preparations which, for days, had been intense had died down and the night was comparatively quiet ... Suddenly, all hell broke loose. It was indescribable. In the pale light, it appeared as if the whole enemy line had begun to dance, then, one after another, huge tongues of flame shot hundreds of feet into the air, followed by dense columns of smoke which flattened out at the top like gigantic mushrooms. From some craters were discharged tremendous showers of sparks rivalling anything ever conceived in the way of fireworks.[1]

Thus, in language which today might suggest a tactical nuclear explosion on the German frontier, was recorded the greatest exploit ever conceived in military mining: the destruction of Hill 60, heralding the battle of Messines Ridge, and presaging the third battle of Ypres. 'We had staked', an Australian engineer remembered, 'our every effort and every thought for nearly two years for one glorious moment, and we had won: nothing else mattered, our task was over. It may be that one supreme moment comes in life to every man — ours came to us at 3.10 a.m. on 7 June 1917'.[2] In this fiery moment, a fierce, dirty, dangerous chapter of a war that exceeded in its fury all its predecessors in its application of science and technology to the purposes of destruction reached its critical climax. Nineteen mines, concentrated over 4100 metres along the foot of the Messines–Wytschaete ridge south of Ypres, opened a series of craters 15 metres wide, killing outright at least 700 men of Germany's 204th Division.[3] According to General von Ludendorff, the 'moral effect' of the explosions was 'simply staggering'.[4]

By the ironies that attend extravagant success, this British mining victory virtually ended the mining war.

After the 'mines of Messines', nowhere again in the struggles of the next eighteen months would either allied or German armies resume such underground enterprise. Equally striking was the success won by engineers from the empire. Of the eight tunnelling companies involved in the climax of Hill 60, two were Australian and one was Canadian, significantly out of proportion to their numbers along the front. For them, and for their British counterparts, June 1917 proved their finest hour. Yet, owing to the secrecy of their work, the precise nature of their achievement remained inaccessible for decades. With the publication of Bean's official history and some reminiscences, details of their existence and heroism became public knowledge, securing them belated honours among the glorious of the AIF. But even then and since, little has been said of the men and methods that won Australia this distinctive military honour.[5]

Who were the Australian tunnellers and what was the real measure of their achievement? Few cannot know that from the retreat before Mons to the break-out in 1918 the western front was virtually static — a war of costly attrition, barbed wire, deadly barrages and machine-gun fire. From the advance to the Aisne to the third battle of Ypres, the howitzer and the machine-gun were joined by the pick and spade as armies resorted to methods of siege warfare that had changed little since biblical times. With static war came also the creation of elaborate trench systems, adding fresh embellishments to the engineers' art. The new demands placed upon military engineers took them beyond their traditional experience in fortification, and towards the application of new scientific methods and techniques. Electric power, modern mining technology and new applications of the principles of geology and acoustics brought new disciplines into play, with consequences that would far outlast the war itself. Meanwhile, military mining — which depended upon expertise as well as courage — brought into focus a particular form of heroism, as men faced the risk of being overwhelmed by gas, blown to pieces or buried alive in a desperate war of nerves, electric wires and high explosives.

The mining war began with trench warfare itself, soon after the battle of the Aisne, when the opposing lines were drawn. In late 1914, the Germans took the lead by blowing up a portion of the British front in the Kemmel sector, and followed with underground work near Ypres; the British, at first far behind, had to work at a 'furious rate' to catch up.[6] The allies opened defensive mining operations as early as December 1914, when Royal Engineers drove galleries against the German lines. But in training and numbers these engineers were sorely pressed. Indeed, the total engineer force sent with the BEF amounted to no more than 6500 officers and men.[7] Rising to the occasion, in one of the heroic stories of a war in which British eccentricity was regularly set against German science, came Major (later Sir John) Norton-Griffiths, who toured the trenches in his private Rolls-Royce, and mobilized miners from the colliery districts of the north and Wales, and 'clay-kickers' from the London underground and the sewage authorities of England.[8]

The crater left by one of the explosions on Hill 60 on 7 June 1917 (AWM E1911).

The first British tunnellers arrived in France in February 1915; by March 1915, five companies had been formed by the simple expedient of rushing men from their British pits and tunnels into the trenches of Flanders, scarcely bothering with the niceties of uniforms or military drill. Their newly commissioned officers were frequently mining graduates of the Royal School of Mines at Camborne, and virtually all 'civilians in uniform'. Yet so necessary were these subterranean soldiers, and so vital the science of mine engineering, that GHQ requested more, and by the end of 1916 there were twenty-five British tunnelling companies, three from Canada and one from New Zealand; with the three companies from Australia and reinforcements, a total of 25 000 men.[9]

The conception of a separate and identifiable Australian contribution to the mining war has been credited to Lieutenant J. Thomson, a mining engineer of Western Australia. But it is T. W. Edgeworth David, professor of geology at Sydney University, who became popularly associated with the idea, and remained father to the deed.[10] While Australian engineers dug tunnels and set mines on Gallipoli, the lack of equipment precluded extensive operations. In October 1915,

Senator George Pearce, Minister for Defence, agreed to form a mining corps of two battalions of picked miners. Then Edgeworth David was commissioned major and placed in charge of the technical headquarters staff.

While these plans matured, J. A. Pollock, David's colleague and professor of physics at Sydney, began work in his university laboratory on a modified telephone for detecting faint sounds underground. This 'geotelephone' became one of Australia's first contributions to the scientific war. It also brought Pollock a commission as a captain in the new mining corps, and appointment to David's staff. To the 'fiery zeal of the crusader', as David later recalled, 'Pollock brought the heart of a boy rejoicing in the great adventure that now lay before him'.[11] In December, aged fifty, he joined David, aged fifty-eight, in active training at Casula Camp near Liverpool, New South Wales.

The mining corps — in David's words, 'the first thoroughly representative unit to be formed in Australia'[12] — was placed under the command of Lieutenant Colonel A. C. Fewtrell, a thirty-one-year-old mechanical engineer from Ipswich, Queensland, then a captain in the Australian engineers, and later to

become a distinguished chief engineer of the New South Wales railways.[13] The corps as formed consisted of a technical headquarters, and three companies each of about 400 men. The first was recruited from New South Wales, the second from Victoria and South Australia, and the third from Queensland, Tasmania and Western Australia, which could supply many 'thoroughly typical Western Australian miners, skilled at their calling and of sound physique'.[14]

Fewtrell was joined at Casula by his first fifteen officers on 2 February 1916. His headquarters included Captain Stanley Hunter, fifty-three, mining geologist from Mt Brighton, Victoria, and formerly of the Geological Survey of Victoria; and Captain James Shand, forty-six, an accountant from Epping. His medical officer was Rupert Heggerton, forty-two, a general practitioner from Murrumburrah, and his chaplain James Wilson, fifty-two, a Methodist from Melbourne. His first company commanders were Major John MacTaggart, forty-four, a civilian engineer from Drummoyne, followed by Captain (later Major) J. D. Henry and Major E. S. Anderson (1st ATC); Captain Victor West, forty-two, a mining engineer from Launceston, followed by Lieutenant (later Major) E. N. Mulligan (2nd ATC). The 3rd ATC was first led by Lieutenant (later Major) Leslie Coulter, and later by Lieutenant (later Major) Alexander Sanderson. The average age of Fewtrell's officers was thirty-five. A third of them were married, about half were from Victoria and a third were from New South Wales. There were on embarkation fifty-three officers, a cosmopolitan group of men who, like their British counterparts, had followed their profession all over the world.[15] Few of them, notably excepting Lieutenant (later Major) G. I. Adcock, twenty-one, a mining engineer from Bendigo who had been a staff trainee at Duntroon, had seen previous military service.

Among the junior officers were men of diverse backgrounds. Second Lieutenant Alexander Sanderson, a great-grandson of Henry Sanderson, who collaborated with George Stephenson in building the first railway in England, was educated in Perth and at the School of Mines in Otago, and had worked as a consulting engineer in coal collieries, gold and tin recovery plants, and timber concessions in New Zealand, the Philippines and the north-west of Australia before enlisting. He was assigned to the technical staff, with Pollock and Morse, until he arrived in France. Captain Henry Brown (later of the 3rd ATC) was educated at the South Australian School of Mines, and had worked for the Broken Hill Proprietary Company Ltd and four other mining companies by 1914. Lieutenant Joseph Hamilton was an articled surveyor in Fremantle, a worker on the rabbit-proof fence in Western Australia, and well known in the sports world — 'unbeaten in the quarter-mile championship in the Eastern goldfields'. Lieutenant Leslie (Jack) Coulter, a graduate of the Ballarat School of Mines, was an assistant surveyor with the Mount Lyell Mining Company at the outbreak of war. Captain R. V. Morse, thirty-one, educated at the Sydney Technical College, was a consulting electrical engineer with experience of refrigerating plants. In

1914, Lieutenant (later Captain) Oliver H. Woodward from Queensland (1st ATC) was on the staff of the Mount Morgan Mining Company in Papua, and Captain Arthur Hillman (1st ATC) was a railway engineer for the Western Australian government.[16]

Life at Casula Camp was memorably uncomfortable for men unused to military formalities. 'I am positive', Lieutenant Oliver Woodward, newly commissioned to the 1st Australian Tunnelling Company (1 ATC), muttered to his diary, that 'the genesis of the idea which ultimately led to the perfection of the mechanical robot was the outcome of the inventor studying the actions of a 2nd Lt. engaged in company drill'.[17] Indeed, the camp experienced at least one outbreak of civil war, when several thousand infantry struck against the camp authorities. However, they unsuccessfully sought the aid of the miners, and indeed, men from the 3rd ATC volunteered for guard duty.[18]

Their secret training included the use of the 'wombat' drill, a motor-driven auger, 8 inches (20.3 centimetres) in diameter, invented by Captain Hunter. As Woodward put it, the idea was 'to bore a hole under every trench, push in a torpedo carrying a charge of high explosive, fire the charge, hurl some hundred-weights of Huns into the air, and repeat the performance'.[19] Their drill also employed the newly invented 'push-pipe', sections of rod about 1.2 metres long and 7.6 centimetres in diameter, designed to be driven underground at a depth of about 2 metres by hydraulic jacks. To the initial sections fresh lengths were added, each containing explosives charges. In principle, as Edgeworth David explained, after 60 metres or so of pipe had been pushed across or under no man's land, the whole line of explosives could be detonated, instantly creating a crevasse, like a railway cutting, between British and enemy trenches.[20] With these techniques, and much practice, the miners were given the means of offensive war.

By the time they had completed training, the mining corps knew they were too late for Gallipoli and that service in France lay before them. On 20 February 1916, the 'Miners' Battalion' of 1200 men, complete with Belgian boarhound mascot, received its official farewell with a march through Sydney's Domain.[21] They embarked from Woolloomooloo on *Transport A-38*, formerly the Blue Funnel line passenger ship *Ulysses*.

Their journey to the front was to prove an adventure in itself. First, the transport ran aground off Fremantle, causing some weeks' delay. The troops employed the time in further training, and Major MacTaggart, who fell ill, returned to Sydney. The troops proudly received a flag given them by the Kalgoorlie mining fraternity. At sea at last on 2 April, Lieutenant Adcock recalled, the officers, splendid in their first-class accommodation, read French primers and censored letters; while the men endured physical exercises, interspersed with lectures by Edgeworth David on Shackleton's Antarctic expedition, and no fewer than fifteen courts martial for minor infractions of discipline. Late in March, the restless troops were unwilling to stay aboard at Durban, but in April the tunnellers reached Alexandria. There a party of 120, wearying of life on board ship, rushed their

sentries and made for the centre of the city. Arrested by military police, they had nearly succeeded in tunnelling out of the local prison before their officers secured their release the following day.[22] With this, their first tunnelling campaign behind them, they left on board *Transport 81* (the *Ansonia*) for Malta, where they marched through the streets of Valletta, before zig-zagging across the Mediterranean. No wonder that the tunnellers' 'T' patch on their shoulders was unkindly rendered as 'T for tourists'.[23] After travelling by train through the pleasant late spring of the Rhône Valley and then through France, they arrived finally at their destination, Hazebrouck, on 8 May.

On reaching the front, the Australians were met by the realities of trench warfare. At first the British army had restricted tunnelling to defensive works against German mines, but in June 1916, just as the Australians arrived, General George Fowke, the redoubtable engineer-in-chief, persuaded army commanders to adopt offensive mining as an alternative to expensive frontal infantry attacks. In France the Australians found British mining operations directed by an inspector of mines (Brigadier, later Major General, R. Napier Harvey) at GHQ, and by a controller of mines at each of the three (later four) army headquarters. The Australians had thought they would work as companies distributed within the Anzac Corps. But the British argued that mining would never require the wholesale movement of a mining battalion to accompany infantry operations; accordingly, their corps organization was abandoned, and three separate companies were formed. In April 1916, each of the four British armies had between five and ten mining companies attached.[24] The first two Australian tunnelling companies were attached to the British Second Army, while the 3rd ATC went to the First Army.

Thirty men from each of the three companies were separated to form a new and unprecedented unit, the Australian Electrical and Mechanical, Mining and Boring Company — afterwards, and for obvious reasons, known as the 'Alphabetical Company'.[25] Some of the electrical plant the Australians brought with them at first drew laughter from the British mining units, which considered such machines absurdly impractical for active operations. However, when miners began to strike water and needed pumps, and put in tunnels of such length that extensive lighting was necessary, the Australians were found to have the only adequately equipped unit on the entire British front.

For the three tunnelling companies, the first week was spent receiving lectures from Colonel Stephenson on the organization of mining. For front-line training, sections of each company were sent to experienced British and Canadian units. On 27 May, scarcely a fortnight after their arrival, Australian units were in action. The three companies worked in geologically distinct sectors. In Belgium, to the north, there were sandy beaches; from Ypres to the La Bassée Canal there were layers of quicksand and blue clay; and from the canal to Loos, Vimy Ridge and the Somme, there was chalk. Chalk was easy but noisy to dig; clay proved difficult to dig, but could be dug more quietly.

The western front, June 1917.

Thanks in large part to the Australians, the British gradually recognized military mining as a science.[26] As the distance at which sounds of mining can be heard depends upon the nature of the earth through which the sound passes, the detection of enemy mines required detailed knowledge of the 'geological' front. From early 1915, the Germans had assigned a geological section to each of their armies, with responsibility for drilling wells, locating road metal and siting trench systems. It was believed that by early 1916 the Germans, who had certainly used geological knowledge to tactical advantage on the Russian front, had made complete geological surveys of their front in Flanders.[27] David was posted to GHQ, where he became senior adviser on geological matters to the entire BEF.

To improve the allies' scant knowledge of the geology of Belgium and of their unfavourable position in the salient, David provided a completely new foundation of geological reference.[28] Using drilling bores, soils and strata were identified. Calling on advice from Belgian geologists, some of the first scientific water tables in Europe were compiled, enabling many British trenches and dug-outs to be dug or re-laid before winter rains and rising water levels washed them away. In July 1916, David began a series of lectures on the geological strata of the British front to the first Army School of Mines; by early 1917, he was using coloured maps and vertical sections to show where quicksands prevailed, and where trenches and tunnels might safely be dug.[29] Within a

year, David had persuaded GHQ to seek reports from its mining geological staff before undertaking any new operation or siting artillery concentrations[30], and by 1918 printed geological maps, with co-ordinates replacing early drawings, were distributed through the controllers of mines and the chief engineers of the four armies to all divisional staffs.

If hand-boring machines are considered to have been the most important tools introduced into military mining during the war, the 'wombat' drill can claim a place of honour alongside French rotary drills and compressed air machines. But of far more lasting importance were the acoustical instruments used to locate enemy mining positions.[31] Sir Herbert Plumer, commander of the Second Army, appointed Captain Pollock (who heard of his nomination as a fellow of the Royal Society while still at sea)[32] head of a new mining school at Proven, near Poperinghe, within easy reach of Messines, where he established what David later called 'a military physics laboratory'. The school was not unlike that set up by Major W. L. Bragg (the young physicist who had shared with his father the Nobel Prize for physics in 1915) for sound-ranging at Montreuil, or that of the American engineers at Langres.[33] Despite Pollock's work in Sydney before embarkation, the listening apparatus brought by the Australians was not used at the front. Instead, as Woodward recalled, listeners were first given French 'water bottles' — rectangular canisters filled with water, with a standard microphone fitted to the top. By using two of these, one to each ear, the direction of sound could be fixed, and its origin traced by cross-bearings.[34] From these beginnings, technical advance was rapid.

At Proven, Pollock studied the transmission of sound waves through the earth, and tested the new measuring instruments and others devised by the physicist Charles Vernon Boys, and the seismologist, R. D. Oldham. One of Pollock's colleagues recalled his enthusiasm for measuring the binaural acuity of his new 'students', and his success in measuring the minimum period necessary for a locator to detect a sound. Apparently, he eventually discovered a young Russian who was so sensitive that he could point the geophone indicator in the direction of the sound as if he had *seen* the source of the sound itself.[35] In operational conditions, the improved French geophone was found superior to the Germans' Reiner, Edelmann and Siemens apparatus, and to the supersensitive machine made for the British by Western Electric. By November, the French geophone was in general use throughout the allied armies. Comparative trials of enemy methods, co-ordinated by the British since February 1916, were turned to good effect.[36] Later came a 'seismomicrophone', which transmitted sound from as many as fifty gallery faces to a central station in the rear. This reduced some of the risk of forward gallery listening, although it was of limited use where wires could be ruptured by shelling.[37] The best use of all these devices was relayed rapidly to the officers of new British tunnelling companies as they arrived in France and proceeded through the school.

Their final class-room, however, remained the trenches. In the twelve months following June 1916

there were three main mining offensives: the Somme in July 1916, Arras in April 1917, and Messines two months later. During 1916, at least 750 British mines and 696 German mines were exploded. From the summer of 1916 the principles of mine warfare developed rapidly. There was, in General Heath's phrase, 'nothing haphazard' in these mining manoeuvres. They quickly became 'a scientific form of warfare, calling for very careful measuring and plotting on the part of the officers in charge, and great skill in the silent, yet efficient, handling of their tools by the men'.[38] The mathematics of explosives charge and predicted 'crater size' became increasingly accurate, and mining tactics ever more devastating. Weekly reports by the tunnelling companies to the controllers of mines reached the inspector of mines, who kept available for Intelligence a remarkably clear view of the 'geological war' all along the front. Harvey monitored closely the 'scientific intelligence' arising from the occupation of German mining systems, and even commented on the origins of rock substances used in the construction of enemy pillboxes.[39]

All along the front, shafts were sunk at intervals of thirty to sixty metres, and drives laid underground towards German lines, connected by 'crosscuts', variously some twenty to thirty-six metres ahead of the British lines. These were regularly detected and repeatedly hit by *Minenwerfers* of fifty-four kilograms of high explosive.[40] To detect German countermining, listening posts were established at fifteen metre intervals. According to contemporary accounts, the typical gallery was 1.2 metres (four feet) high, 0.76 metres (two feet six inches) wide at the top, and 0.9 metres (three feet) at the bottom. Many galleries were over 120 metres long, giving over 132 cubic metres (5000 cubic feet) of earth to dispose of — silently![41] German raids undermined British saps, and vice versa, and 'listeners' on both sides were exhausted by the toil and the terror. As Heath recalled, it was often a race as to which side would get in its charge first, and the British were not always the winners.[42] Attack in flank was the favourite British technique, to blow in the enemy's galleries.

In 1917, the British blew 117 and the Germans 106 mines.[43] In each case, the tactical success attributable to offensive mining was conditioned by the limitations of combined operations between artillery, infantry and tunnelling. On the Somme, for example, five British and Canadian tunnelling companies were said to have participated 'successfully' in the Fourth Army's disastrous attack of 1 July 1916; but only nine mines were blown beforehand, and the enemy positions remained virtually intact. In April 1917, three British tunnelling companies attached to the First Army prepared eight mines, but blew only two, as an advance heavy artillery bombardment was thought sufficient preparation for the attack.

Australian reinforcements, raised during the summer, began arriving in August 1916.[44] In October, the new 4th, 5th and 6th tunnelling companies were absorbed into the first three. As their experience deepened during the spring of 1917, David's geological
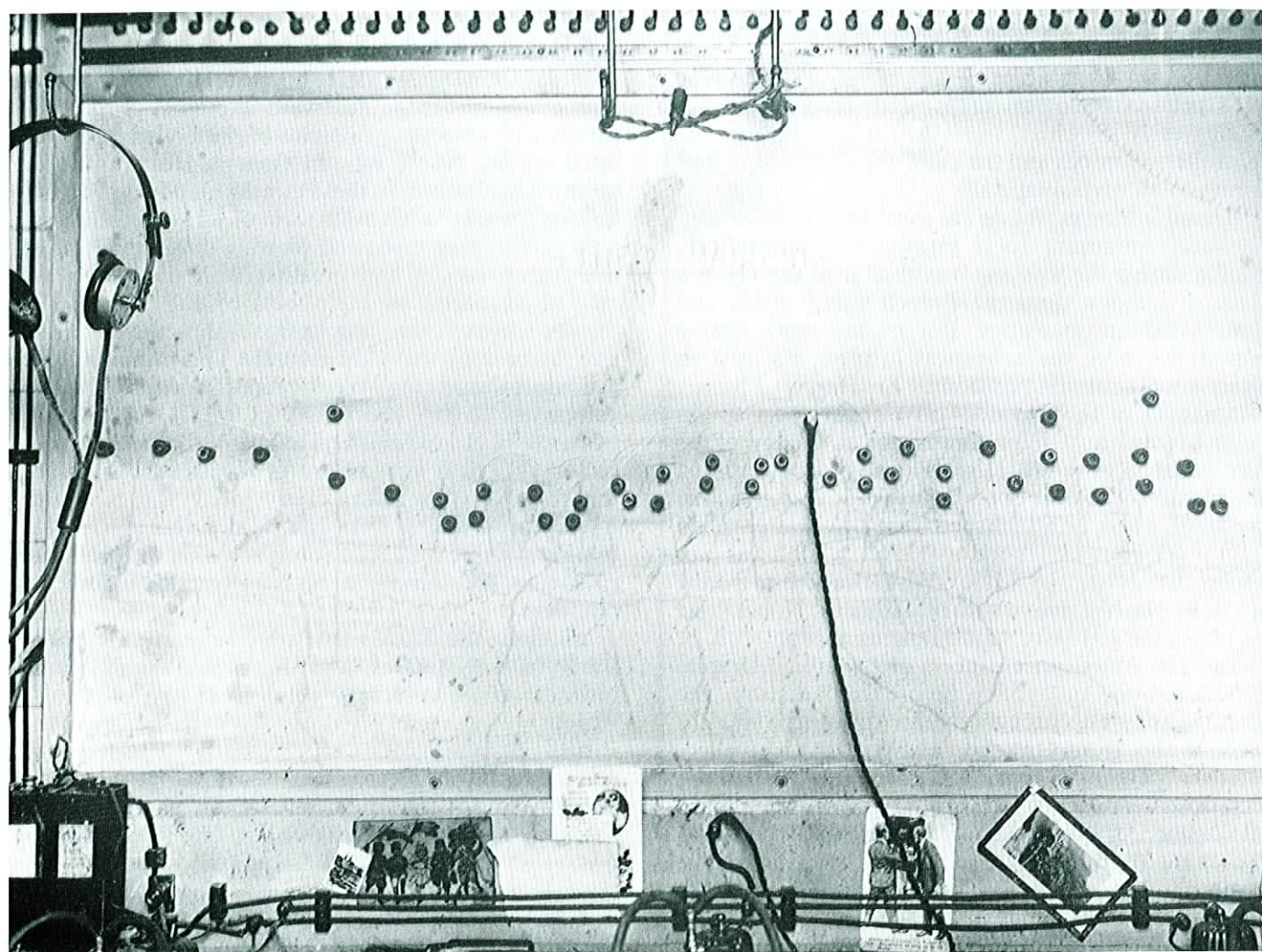
A listening board used by the 3rd Australian Tunnelling Company at Noeux-les-Mines, near Bethune, France (AWM E4904).

and engineering counsel prevailed, and offensive mining took on the job of slow, methodical digging, in patient parallel to the war of attrition being waged above ground. Keeping the miners supplied was a logistical triumph. In the three months January to March 1917, the 1st ATC required 135 000 sandbags, 62 new pumps, 3.5 tonnes of nails, 180 metres of suction hose, and 2 tonnes of corrugated iron. The men consumed 33 000 loaves of bread, 39 000 tonnes of preserved meat, 24 tonnes of vegetables, and 6000 litres of rum.[45] But it was not 'rum courage' that kept them there. More than once, the miners of the 1st ATC could claim that they had held their line against German attack. In July 1917, the 3rd ATC, fighting quite improperly as infantry at Hill 70 near Loos, captured an entire German mining system. Moving between corps, the Australians worked closely with other dominion troops, and many discovered imperial solidarity in their common adversity. When Woodward's section visited the dug-outs of the South African Scottish ('Dutchmen in Kilts', as he called them), he was moved to ask his diary, 'What is the secret of this great Empire of ours?'.[46] That the fight was 'ours' was never in dispute, although

the burden of sharing it, especially with the Americans and other allies, was not always seen to fall equally. Even the British were not above comment. 'If we had all Australians instead of Tommies', Lieutenant Adcock wrote to his parents in Gosford, 'we would be in Berlin in a couple of months'.[47]

While relieved by sections, the Australian tunnelling companies were destined never to leave the front. Thrusting new responsibilities on scarcely trained officers had a predictable effect. As R. V. Morse wrote his wife, 'No one except those who've had it, can realise what it means to work with a limited staff and with such difficulties and casualties'.[48] By February 1917, the 3rd ATC had lost four officers and seventy-one men, with eighteen men dying of illness. Casualties came in ones and twos, except during heavy offensives. The 2nd ATC lost 89 dead, including twenty at a single blow at Hill 70 in November 1916.[49]

Given their task, heroism was commonplace. In July 1916, Major Coulter, commanding the 3rd ATC, Captain Sanderson and five men were wounded during 'push-pipe' operations at Laventie, near Loos.

When a 'push-pipe' failed to explode, Coulter went out, under shrapnel and machine gun fire, and blew up the exposed portion of the 'push-pipe'. Later, when leads were cut by hostile shell fire, he went out to light the fuse further down the sap. Wounded, he refused to be removed until the 'push-pipe' had been exploded.[50]

For this he received the Distinguished Service Order. Sanderson, then thirty-five, received the Military Cross 'for conspicuous gallantry', showing 'great coolness and pluck under heavy shell fire'.[51] All this they bore lightly. 'One does not get much fun here', Sanderson wrote to Coulter in hospital, 'except in the work and risks one has to take. Taking them all round you could not get a finer lot of officers, NCOs, and men'.[52] In June 1917, Coulter, only twenty-eight, was killed on Hill 70 near Lens, when he joined his men with the 18th Infantry Brigade in heavy fighting at close quarters after gaining a German trench.[53] Sanderson received a bar to his Military Cross that day, and was promoted to major and command of the 3rd ATC.

Possibly the best known story of incidental heroism was connected with Edgeworth David, who in September 1916 fell down a disused well-shaft he was using to study strata. As anxious soldiers pulled him up, severely injured, he asked them to pull slowly, so he could have more time to observe water levels in the shaft.[54] Meanwhile, all along the British front, the 'Alphabetical Company' led by Major Richard Morse was building pumping and power stations to drain flooded trench systems. By 1917, Morse's company was also carrying out all the electrical power work associated with 'forward mining' in the British sector. He helped standardize electrical supplies to 440 volts, making possible quick repairs, and developed engine rooms operating nine to twelve metres below the surface. For his services he received the Distinguished Service Order and a mention in dispatches; he lived to enjoy a prominent post-war career in electrical engineering and public works in Tasmania and New South Wales.[55] R. V. Morse's letters to his wife in mid-1916, preserved in the Australian War Memorial, recall the mateship of the miners and even chatty visits to the trenches by professional friends from civilian life. This was to be the 'place to show and develop manhood, which will be invaluable to the nation and [to] future generations'.[56] When, in July 1916, Oliver Woodward became the first tunnelling officer to receive the Military Cross for blowing up a sniper post, Morse saw his example inspiring our 'happy little family'. Woodward subsequently agreed — conquering, in his own words, 'Cowardice but not fear'.[57]

By November 1916, the miners had established a daily routine. Along the sectors belonging to the 1st and 2nd ATCs, miners sallied under no man's land with bombs and mobile charges of 13.6 kilograms of ammonal, sometimes being gassed by carbon monoxide or methane in the process. Canaries, it was reported, were in great demand. With their geophones, the miners meticulously recorded enemy movements. Switchboards were disconnected when shelling or rats cut their

Will Dyson
Australian tunnellers near Nieuport 1917
lithograph 77.5 × 52 cm
Australian War Memorial (2287)

wires, leaving listeners on their own. Casualties were heavy, but nervous stress, which no one measured, must have been worse. In the 2nd ATC, two officers were wounded by November, and two others suffered nervous breakdowns. The miners kept going on beef-tea and rum — 'of which', one officer confirmed, 'we had a plentiful supply'.[58]

Yet there were interludes. In March 1917 Major Adcock, the one military man in the 2nd ATC, who had earlier described himself in letters home as a 'mining manager', remarked that life was 'fast becoming a business rather than [an] adventure'. When he and the 2nd ATC moved to Nieuport in mid-1917, beginning offensive mining in what proved to be a short-lived attempt to outflank a German thrust against the Channel ports, Adcock looked forward to 'real' action. Alas, for him, disappointment again: the miners saw the same old routine. 'Shells count no more than tramcars and a fresh raid no more than a business trip.'[59] Whether inured to danger, or bored by the infinite patience expected of him, the war ceased for Adcock to be news.

But 'news' carried the miners' war home. A few Australian newspapers eagerly followed their miners underground. 'Willie Wombat', writing for the *Sydney Morning Herald*, told their story from September 1916 onwards, and his articles were syndicated in other capitals. Readers followed the heroism of Sergeant Jack

Stevenson from Queensland, awarded the Distinguished Service Medal, and Sappers R. Kerry (Victoria) and D. Reeves (South Australia), both awarded the Military Medal for defending their secret minehead against a German raiding party. The *Sydney Morning Herald* assured Australia that the miner was 'a man of the greatest importance in warfare'. It was also 'Willie Wombat' who extolled the initiative shown by Australians, who had done many other things, who had 'a greater and wider scope of practical knowledge', and who demonstrated repeatedly 'their quickness in adapting themselves to things as they find them and proving themselves all round men'.[60]

Nowhere was this adaptability better expressed than during the ten months of deadly secret underground preparations that led to the devastating blow of June 1917. 'The day, what a lot has been written about it', R. V. Morse wrote to his wife:

> The months of preparation and waiting ... the anxious watching of weather conditions, the secrecy of the time, then the trouble commencing as the enemy realises that you are preparing something for him and he pastes the roads ... with plenty of extra, the replacing of men and parts lost due to this, and as the time draws nearer, the worse it becomes.[61]

The man-made mound called Hill 60 was formed in the nineteenth century of spoil resulting from a nearby railway cutting. On top was rich loamy clay. Underneath lay seven metres of dry sand, separated from a layer of blue clay by two metres of quicksand. The military history of the hill dated from the early days of the war, and it had changed hands several times. The Germans regained the hill in May 1915, and increased its fortification during the following year.

From 1915, the struggle for control of the hill cost dearly. Only forty-six metres above the clay, it held the key to the entire Messines Ridge, and offered a spectacular view of Ypres. Deep mining operations began in August 1915 by a British tunnelling company, from eighteen metres behind the British front line. In January 1916, when GHQ gave mining a high priority underground efforts began in earnest. But owing to an almost chronic lack of co-ordination between miners, supporting artillery and advancing infantry, the British failed to break the German hold on the hill. In April 1916 the 3rd Canadian Tunnelling Company took over, and began a long effort to undermine the entire area. By July 1916, galleries leading to and under Hill 60 were in places finished, and charged with nearly 2400 kilograms of high explosive. In October, galleries under a neighbouring mound called the 'Caterpillar' were also mined with a further 31 500 kilograms of explosives.

At the end of October 1916, the Canadians were relieved by the 1st ATC. The Australians' task seemed initially one of maintenance, but after they had inspected the galleries, it was clear that far more work would be necessary. The British and Canadians had dug a sap — optimistically called the 'Berlin sap' — for 174 metres at 12 degrees from the horizontal, bringing them directly under the German forward trench. From

here, a drive of 45 degrees to the left led under the crown of Hill 60, and 45 degrees to the right led to the base of the 'Caterpillar'. But the Canadians, in avoiding the band of quicksand, had had to descend to a water-bearing level, and this had stopped their progress.

In fact, little was known of the actual geology of the area until David compiled data on the sedimentary strata and calculated the depths — between twenty-four and thirty-six metres — at which offensive galleries could be sunk without fear of striking water. With this information, the 1st ATC dug a vertical shaft twenty-seven metres deep, from which were run at angles three galleries (the 'Sydney', the 'Brisbane' and the 'Perth'), one 152 metres under the hill, a second 244 metres to the left under another German stronghold called the 'Snout', and a third 152 metres to the right, under the 'Caterpillar'. In the event, neither of the latter two were used as tactical calculations pointed to the critical significance of Hill 60.

In this sector, during the twelve months following July 1916, thirty-four British mines were fired and the Germans replied in kind along the chord of an arc reaching from Hill 60 to just east of Ploegsteert Wood. The Germans knew British mining was under way, and sought by artillery and camouflets (small underground charges) to find the Australian galleries leading to Hill 60. On May 15 they even succeeded in entombing two Australian 'listeners' for forty-eight hours. Miraculously, the tunnellers survived, and heard the creaking windlasses above the German shafts that gave away the enemy's intentions. Under the Hill 60 system, some eight kilometres of galleries had been dug, three or four metres each day and night, pumping engines never ceasing, under the glare of electric lights in underground gloom.[62] Yet, for seven months, the enemy failed to find the Australian tunnels.

From the beginning of May 1917, nine divisions of the Second Army, including Monash's newly arrived 3rd Australian Division, supported by more than two hundred heavy guns, began to concentrate on the southern sector of the Ypres salient. It was planned that three corps (9th, 10th, and 2nd ANZAC), with three divisions each, or 80 000 men, would attack the six divisions holding the hill. The infantry rehearsed their second attack several times while their officers consulted a vast wooden model of the ridge, set in a field behind the lines. On 3 June, a series of mines running along the ridge, then south from Wytschaete to Messines, was exploded by eleven firing teams. The single largest charge was 43 000 kilograms of ammonal, laid again at St Eloi, which had already suffered more than thirty British and German 'blows'. At last, opposite Hill 60, a firing party was assembled under Captain Woodward, with two officers, a sergeant and forty sappers. After repeated checks by Royal Engineers of the electrical leads that connected detonators to charges, the Australians did their own tests, using galvanometers to test the circuits and Wheatstone bridges to measure the resistance of the detonators. The Hill 60 and 'Caterpillar' systems, consisting of twenty-one mines, were linked through a single circuit, with a conventional exploder available as an emergency alter-
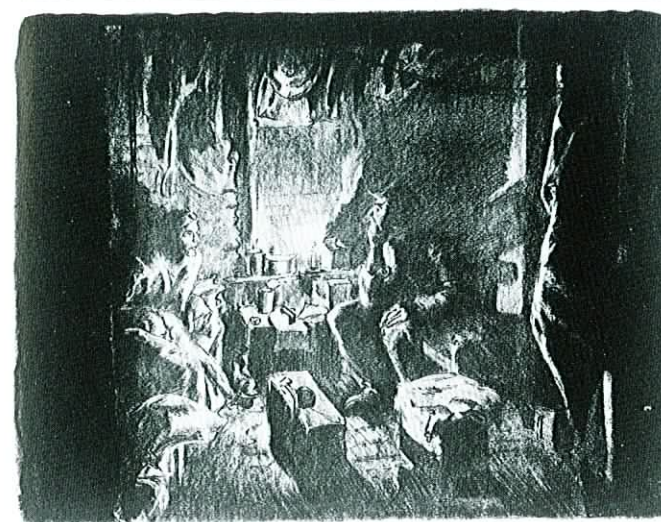
Will Dyson
Home comforts in the tunnels, Hill 60 *1917*
lithograph 52 × 77.5 cm
Australian War Memorial (2280)

native. In a series of sketches, Will Dyson, the war artist, commemorated these Australian efforts above and below ground.

Given this chilling prospect, the week ending 7 June was one of intense anxiety for Woodward's men. The week opened with a massive gas shelling along the Hill 60 sector. At last the day came. With prophetic irony, Plumer's chief of staff, Major General Sir Charles Harrington, reputedly told a press conference on 6 June that 'I don't know whether we are going to make history tomorrow, but at any rate we'll change geography'.[63] The New Zealanders remember the evening of 6 June as cool and sweet, after a sharp thunderstorm that afternoon.[64] The last Australians were not finally withdrawn from the saps until 2 a.m. on the morning of the 7th. As the men returned from their ghostly ritual, their pale faces gave no sign of the enormous shock they had prepared. Then, at 3.10 a.m., before (as Edgeworth David, quoting from the *Rubaiyat of Omar Khayyam*, recalled) the 'phantom of false morning died', just nineteen of the twenty-one mines laid, representing nearly 450 000 kilograms of high explosive, went off at split-second intervals. In David's words, 'Nineteen gigantic red roses sprang suddenly from the ground and as their crimson petals fell apart flames of all colours of the rainbow ending in brilliant white towered upwards'.[65]

Brigadier Harvey, inspector of mines, wrote of the 'gorgeous sheet of flame', and of a scene which 'baffle[d] description'.[66] Philip Gibbs, the official war correspondent, spoke of witnessing 'the most diabolical splendour I have ever seen'. Others spoke of doors thrown open, as from a set of colossal blast furnaces.[67] The countryside was illuminated by a red light, and sounds of the explosion were reported as far away as London.[68] 'Where some of us stood watching, aghast and spellbound by this burning horror, the ground trembled and surged ... Truly the earth quaked'.[69] Paintings by François Flameng and Paul Nash vividly

captured the event. It was the greatest series of simultaneous explosions in history.[70] Woodward later marvelled at the technical sweetness of it all. 'The tongues of flame shot upwards', he recalled, 'then seemed as if they would roll towards our lines and consume their creators'. Pillars of cloud succeeded the pillars of fire, and before these died away, 'the most tremendous, and possibly the most perfect barrage of the war was laid down by our artillery'.[71] Over 2400 guns and howitzers — one gun to every seven metres of front — opened fire. Nearly six million shells were fired that day.[72]

As David later recalled, 'nineteen German strongholds had been demolished in the twinkling of an eye'.[73] By first light, hundreds of German soldiers were staggering blindly, or crawling on their hands and knees, groping in confusion as their trench system disappeared. By the end of the day, ten thousand Germans were reported missing. The British took 7354 prisoners, many dazed.[74] Along the 9.5 kilometres of Messines Ridge to the north, the 60th and 70th Brigades moved forward. The New Zealand division captured Messines, and the 16th and 36th Irish Divisions captured Wytschaete. For a time, the Ypres salient ceased to exist as the line straightened south and east of Hill 60, from near Zillebeke to Frélinghien.

The damage was complete. As von Ludendorff later recalled, 'no sound of underground work on the part of the enemy could be heard at our listening posts'.[75] Evidence suggested that faulty judgement by the commander of the German geologists had misled the German *19th Army Corps* and Crown Prince Rupprecht.[76] It was later reported that twelve German army geologists based at Lille had been paraded on the morning of 7 June and denounced for assuring the high command that the German positions could not be cratered. According to the story relayed by David to Harvey, those German geologists under forty years of age were sent to front-line units as punishment, and those over forty back to Berlin.[77] German military mining ended. Within months, the Second Army's School of Mines also closed, and Pollock moved to Farnborough to study problems of flight.[78]

During the following months, as the British initiative ebbed, the Germans retook part of the ridge and Messines changed hands several times before it was finally captured by the British 30th, 31st and 34th Divisions on 29 September 1918. For the rest of 1917, the tunnelling companies were employed in building vast new dug-outs and roads — duties similar to those of field companies and pioneer battalions — and in helping the newly arrived American engineers. In the summer, the 2nd ATC moved to Nieuport on the Belgian coast to attempt the almost impossible task of tunnelling in the sand dunes, to forestall a German attack across the Yser canal.[79] There the war artist Will Dyson caught the tunnellers in the sand. In September, Oliver Woodward won a first bar to his Military Cross, and a second in November when he led his company into action behind tanks at the Oise. Following the German offensive in March 1918, the Australian tunnellers served as infantry and as corps troops for

other armies, moving forward rapidly after the German retreat in August, defusing booby traps and land mines ahead of the allied advance.[80] Members of both the 1st and 2nd ATCs were in the line at the armistice.

In September 1918, the units, now twice reinforced, counted their losses. By the end of the war, the 1st ATC had lost 67 killed (5 officers and 62 men), 166 wounded and 37 invalided, of their total assigned strength of 1220. Of the 1313 who served in the 3rd ATC, 6 officers and 74 men had been killed, 290 wounded, and 205 were lost through sickness. In all, casualties represented 24 or 44 per cent of men embarked. This was less than the 66 per cent average of casualties for the AIF as a whole[81], but all three ATCs had been continuously in the fighting for over two years, forming closely cohesive groups, and they felt their losses deeply. Morse's 'Alphabetical Company' had lost many of its original band, although final casualty lists do not survive. Death and accidental injury continued until the very end, as defensive tunnelling proceeded through October 1918. But for many, at least the men of the 1st ATC, their finest moment had come long before, on that early morning in June 1917.

Today, two of the largest craters in the St Eloi district are privately owned fish ponds and swimming pools. The Hill 60 and Caterpillar craters are still visible, preserved as they were in 1918, looking like disused quarries amid rich Euro-farmers' fields. Near them, bisected by the principal rail line between Ypres and Comines, lies the Australian Tunnellers' Memorial.

Was the effort of Hill 60 worth the cost? The *Sydney Morning Herald* greeted the news of Hill 60 as 'A Proud Day for Australia', no less than one of the 'great days in our history'.[82] It was for their 'typical Australian' qualities of endurance and fortitude that the miners' praises were sung. Few knew or appreciated the significance of the part played by Australian leadership and intelligence in geology, and in electrical and mining engineering along the thirteen kilometre front.

The tunnellers' victory was short-lived. Tactically, Hill 60 demonstrated the benefits of mining, and the wisdom of scientific deep mining of a type Australians could do well. But for an attack to succeed, co-ordination between the fighting arms to a degree the allies had not yet mastered was needed. By August, any illusion of a breakthrough in Flanders had been dispelled when the main British assault of twelve divisions became mired in the mud of Passchendaele, and allied casualties exceeded 300 000 men.

Strategically, mining could never be more than one option, and an expensive one at that, depending for its success entirely on reasonably static conditions and known terrain. In retrospect, the Australians at Hill 60 witnessed not so much the beginning of a new age of high explosive warfare as the end of the ancient art of siege craft. A decade later, the inspector of mines, lecturing at Chatham, argued that no future war would see the same kind of offensive mining. With increasing air power, accurate artillery, and other 'bolts from above', the 'bolt from below [was] far too slow' and, of course, could not be readily adapted to the conditions of a rapidly moving front.[83] As with other aspects of offensive and defensive warfare, the advantage was passing quickly to those who could add science to courage. At the end of the war, General Rawlinson of the Fourth Army thanked the Australian tunnellers for their diligence, gallantry and skill, but also for 'the scientific methods which they have so thoroughly learned and so successfully applied'.[84] The science and apparatus of acoustic detection, and the experience of 'geological intelligence', would open new technological prospects in geological research, petroleum exploration, and ultimately in seismic monitoring of nuclear tests. For the moment, however, it was the bravery, comrade-ship and imperial loyalty of nearly 4000 Australians that were uppermost in the memories of those at home.

The end of war did not end the duties of the miners and their engineer-officers, however. The tunnellers advanced first into Germany, and then returned to Belgium, removing delayed-action German mines, something which the French in their sector preferred to let German prisoners do. In January 1919, leave was granted to many of the men. Woodward went to visit the London office of his previous employers, the Mount Morgan Gold Mining Company. To London also went Captain Albert Morris of Richmond, New South Wales, and the 3rd ATC, who enrolled in the associateship course at the Royal School of Mines. Possibly the most decorated surviving tunnelling officer was Alex Sanderson, one of only six to win a second bar to his Military Cross — in July 1917, for showing 'conspicuous gallantry' during a raid on enemy trenches, 'reconnoitering and destroying the enemy's mining system . . . blowing in two dug-outs and very largely contributing to the success of the operation'[85] — and the Distinguished Service Order in 1918. In March 1919, he took eight months' leave from his unit at Tournai to do civil engineering work with Parry, Blake and Parry of Westminster, and to prepare himself for the associateship of the Institution of Civil Engineers. Edgeworth David was promoted to lieutenant colonel just before the armistice, becoming at last equal in rank to his counterpart in the American army, Colonel Brooks. In early 1919, he went with the occupying forces to Cologne, where he viewed the vast German military machine still intact. A different future beckoned to Lieutenant (now Major) Adcock, for whom the army by 1918 had become no more than the 'antics of muddle-headed officialdom and self-seeking smooth bores'.[86] He married a Belgian girl he had met on leave, went to the post-war school of chemistry at Charleroi, and entered the perfume industry.

By the armistice, a kind of official amnesia had begun to overtake the miners' operations. Morse reflected on his 'phantom war'. 'Very few folk did know us outside the mining world and high authority, as our existence depended on our secrecy', he mused. 'It didn't take long for our engine room to disappear after the enemy got its location.'[87] For him and other professionals, the end brought unequivocal relief. Woodward confessed to his diary, 'We were as men who had completed a task which was abhorrent to us'.[88]

The tunnellers' return to Australia was long delayed. Not until 16 March 1919 were the men at last repatriated. David returned to Sydney on 25 April, to an enthusiastic response from local journalists.[89] His Distinguished Service Order in 1918 was followed by a Knighthood of the British Empire in 1920. The rest of the men sighted Rottnest Island on 6 May, and Victorians and Tasmanians disembarked at Port Phillip nine days later. On 18 May, after a separation of three years and eighty-seven days, the New South Wales contingent met their families at Woolloomooloo. For the officers, at least, return to civilian life meant an end to 'amateur soldiering'. The task of reporting their exploits fell unevenly. The 1st ATC had an unofficial historian in O. H. Woodward, but the 2nd ATC had none. The 3rd ATC rested content with an epigram-matic unit diary; the 'Alphabeticals' had only an 'appreciation'. After several years had elapsed, many surviving officers and men joined the ranks of the Tunnellers' Old Comrades Association, which met annually in Britain, with branches in the dominions, from 1927 to the outbreak of war in 1939. Edgeworth David — 'the Grand Old Man' — and J. A. Pollock returned to their class-rooms at Sydney; others returned to careers in mining and engineering. For the Australian public, the 'phantom war' underground would become a sleep and a forgetting. But for those who saw the vision, the tongues of flame at Hill 60 burned brightly in their memories of the Great War. As symbols, their awesome craters remain, no less today cradles of remembrance before the prospect of a nuclear-free Europe.

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Endnotes

1. 'Tunneller', 'Messines', *Tunnellers' Old Comrades Association (TOCA) Bulletin*, no. 5, 1930, p. 23.
2. Ibid., p. 23.
3. J. McD. Royle, 'An Explosion Like an Earthquake', *TOCA Bulletin*, no. 14, 1939, p. 27.
4. General Erich von Ludendorff, *My War Memories, 1914–1918*, London, 1920, pp. 428–9.
5. The principal British accounts of tunnelling are the semi-official history by W. Grant Grieve and Bernard Newman, *Tunnellers: The Story of the Tunnelling Companies, Royal Engineers during the World War*, London, 1936, which was written on behalf of the Tunnellers' Old Comrades Association, and the official volume, *The Work of the Royal Engineers in the European War, 1914–1919: Military Mining*, Chatham, 1922, published by the Institution of Royal Engineers. A more popular and readable account, with illustrations, is Alexander Barrie's *War Underground*, London, 1962. None of these, however, were intended to give a detailed account of dominion efforts. There are a few individual British unit accounts, of which one of the best is H. W. Graham, *The Life of a Tunnelling Company, being an Intimate Story of the Life of the 185th Tunnelling Company, RE, during the Great War, 1914–1918*, Hexham, 1927.
6. Major R. V. Morse, 'War Mining Notes from the Western Front', *Journal of the Institution of Engineers, Australia*, 1, 1920, p. 480; 'Notes made on a visit to 3 ATC at Noeux-les-Mines, on February 23, 1918', AWM 27, box 8. An interesting parallel may be drawn between German initiatives and British responses in the 'geological' war in late 1914, and the 'chemical' war from the spring of 1915.
7. Major General Sir Gerard Moore Heath, 'The Work of the Royal Engineers in the Great War', *Proceedings of the Institution of Civil Engineers*, vol. CCX, pt II, 1919–20, p. 56. By the armistice the number had risen to over 322 000.
8. R. N. Harvey, 'Lt. Col. Sir John Norton-Griffiths, Bt.', *TOCA Bulletin*, no. 5, 1930, pp. 12–15; cf. Barrie, *War Underground*, 'Prologue'. Norton-Griffiths's revealing 'mole diaries' for 1915 are filed in PRO: WO 158/129.
9. E. J. Pryor, 'Tunnelling in the First World War', *Royal School of Mines Journal*, no. 8, 1959, p. 26; H. Standish Ball, 'The Work of the Miner on the Western Front, 1915–1918', *Bulletin of the Institution of Mining and Metallurgy*, 28, 1918–19, p. 191; Heath, 'The Work of the Royal Engineers . . .', p. 60; Grieve and Newman, *Tunnellers*, pp. 108–10; 'Historical Record of the 3rd Australian Tunnelling Company', AWM MSS 78, p. 3.
10. *Sydney Morning Herald*, 21 February 1916; R. N. Harvey, 'Lt. Col. Sir Tannatt William Edgeworth David, KBE, CMG, DSO, DSc, FRS', *Royal Engineers Journal*, December 1934, pp. 616–19, reprinted as 'Memoir on Lt. Col. Edgeworth David', *TOCA Bulletin*, no. 9, 1939, pp. 9–13; Royle, 'An Explosion . . .', p. 23. David's wartime career is discussed by his daughter in M. E. David, *Professor David: The Life of Sir Edgeworth David*, London, 1937, pp. 210–65.
11. T. W. Edgeworth David, 'Prof. Pollock's War Service', *Hermes*, vol. XXVIII, no. 2, August 1922, p. 80.
12. 'Mining Corps', *Mining and Engineering Review*, 8, 1916, p. 118; 'Australian Expeditionary Force Mining Corps', ibid., pp. 142–4.
13. *Sydney Morning Herald*, 1 January 1917; *Reveille*, 1 November 1950, pp. 34–5.
14. 'Historical Record of the No. 6 Australian Tunnelling Company', AWM MSS 78, p. 8.
15. Ball, 'The Work of the Miner . . .', p. 190.
16. Unit roll books, 3rd ATC, AWM 9/68/6; 'Notes . . . on a visit to 3 ATC . . .'.
17. O. H. Woodward, *The War Story of O. H. Woodward, Captain 1st Australian TC, AIF*, privately printed, 1919.
18. 'Historical Record of the 3rd Australian Tunnelling Company', AWM MSS 78, p. 1.
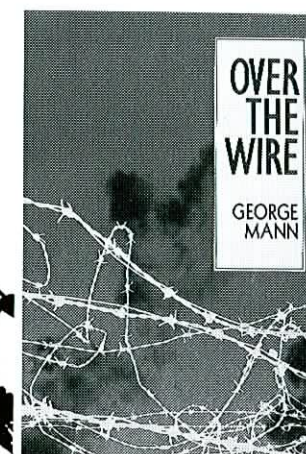
19. Woodward, *War Story*, p. 10. For a description of the 'wombat' drill, see the *Sydney Morning Herald*, 2 May 1919.
20. David, 'Prof. Pollock's War Service', p. 82.
21. *Sydney Morning Herald*, 21 February 1916.
22. David, 'Prof. Pollock's War Service', p. 81.
23. Letter, Adcock to his parents, 10 October 1916, AWM 2DRL 123.
24. Harvey, 'Norton-Griffiths', p. 9; 'Secret: Allocation of Australian Companies', 13 April 1916, AWM 27, box 8.
25. For the work of this extraordinary company, which well merits a study of its own, see 'Appreciation of work done by Australian Tunnelling Co's and the Aust. E & M, M & B Coy', AWM 27, box 8. See also AE & MMB weekly reports, 10 October 1916 – 29 June 1917, PRO: WO 158/133.
26. Cf. Grieve and Newman, *Tunnellers*, pp. 6–7.
27. Harvey, 'Norton-Griffiths'; cf. the Germans' celebrated victory at Tannenberg and the Masurian Lakes in 1914 where over 80 000 Russians were driven into impenetrable swamps following Hindenburg's careful use of geological advice. Captain Walter Kranz had urged the German government before the war to create an army geological corps. An estimated 75–150 geologists were thereafter appointed, against the allies' three to eight: see W. Cross, 'Geology in the World War and After', *Bulletin of the Geological Society of America*, 30, March 1919, pp. 168–70. However, the German geologists were not given commissions as officers, and as enlisted men were probably underrated by their military superiors. Sound-ranging, mapping survey, and other 'scientific' units in the German army were treated similarly. The allies, and notably the Americans, customarily gave their scientists officer rank.
28. On Edgeworth David's contribution, cf. Professor J. S. Ames, 'Science at the Front', *Atlantic Monthly*, January 1918, and H. F. Cleland, 'The Geologist in War Time — Geology on the Western Front', *Economic Geology*, vol. XIII, no. 2, 1918, pp. 145–6. See also David's own records in the David papers, University of Sydney, and in 'Geological Records', PRO: WO 158/133.
29. 'Report to Inspector of Mines, Capt. Hills' account of advice from Dr. Van Straelen, Belgian Army', PRO: WO 158/133; 'Historical Record of the 3rd Australian Tunnelling Company', AWM MSS 78, p. 5.
30. David to inspector of mines, 10 June and 28 October 1917, PRO: WO 158/133.
31. Alfred H. Brooks, 'Military Mining in France', *Engineering and Mining Journal*, 109, 1920, pp. 606–10.
32. Pollock to Threlfall, 5 March 1916, Threlfall papers, MS 347, Birmingham City Library.
33. For important parallel developments in sound-ranging and survey, as different aspects of the 'acoustics war', see Sir Lawrence Bragg *et al.*, *Artillery Survey in the First World War*, London, 1971, esp. pp. 31–40.
34. Woodward, *War Story*, p. 37.
35. 'Professor J. A. Pollock, FRS', *Nature*, 110, 9 September 1922, p. 360.
36. 'Mining Notes', no. 36, 3 August 1916, and no. 1, 1916, Imperial War Museum 76/113/1.
37. Heath, 'The Work of the Royal Engineers . . .', p. 62.
38. Ibid., p. 61.
39. 'G.H.Z.: Weekly Summaries, Inspector of Mines', PRO: WO 158/133; also see PRO: WO 158/33 and WO 158/154. For characteristic 'geological intelligence', see 'German Mining Officer's Diary, captured at Fricourt, July 1916', AWM 25, 985/10.
40. Letter, Adcock to his wife, 12 November 1916, AWM 2DRL 123.
41. 'Work of Engineers in the Field', *Engineering and Mining Journal*, vol. 104, no. 1, 1917, p. 9.
42. Heath, 'The Work of the Royal Engineers . . .', p. 61.
43. Ball, 'The Work of the Miner . . .', p. 215.
44. Unit Embarkation Nominal Rolls 1914–1918, AWM 8.
45. 'Capt. J. D. Henry's Quarterly Report', March 1917, PRO: WO 95/489.
46. Woodward, *War Story*, p. 37.
47. Letter, Adcock to his parents, 24 October 1916, AWM 2DRL 123.
48. Letter, Morse to his wife, 1 October 1916, AWM 12/11/819.
49. *Anzac Memorial: Soldiers & Sailors, Officers and Men of the Australasian Imperial Expeditionary Forces, died on service and missing from August 4th, 1914 to February 8th, 1917*, Sydney Returned Soldiers' Association, 1917, p. 222; Sanderson notebook, AWM 3DRL 7048.
50. R. D. Williams (comp.), *World War I: British and Foreign Orders and Decorations to Australia 1915–1922*, vol. 4, p. 657 (held in Research Centre, AWM).
51. Ibid., vol. 2, *Military Crosses to Australia from 1915–1920*, p. 136.
52. Letter, Coulter to his wife, 1 August 1916, AWM 1DRL 219.
53. 'Historical Record of the 3rd Australian Tunnelling Company', AWM MSS 78, pp. 26–7. Four Military Medals were won by tunnellers on Vimy Ridge in 1916, three more after Messines, and some fifty altogether.
54. The story is variously told. Cf. 'Celebrities of the AIF: Lt. Col. Sir Edgeworth David', *Reveille*, 1 July 1938, pp. 8–28, and David, *Professor David*, pp. 235–7.
55. Cf. Morse, 'War Mining Notes . . .', p. 480; *Sydney Morning Herald*, 28 January 1925; *Transactions of the Institution of Engineers, Australia*, 6, 1925, pp. 376–8.
56. Letter, Morse to his wife, 11 and 25 June 1916, AWM 12/18/819.
57. Woodward, *War Story*, p. 45.
58. Letter, Adcock to his parents, 12 November 1916, AWM 2DRL 123.
59. Letters, Adcock to his parents, 4 March and 26 July 1917, ibid.
60. *Sydney Morning Herald*, 16 September, 15 and 30 November 1916, 18 April and 6 June 1917.
61. Letter, Morse to his wife, 20 September 1917, AWM 12/11/819.
62. The desperate speed and appalling conditions under which the men worked are vividly recounted by Leon Wolff, *In Flanders' Fields: The 1917 Campaign*, London, 1961, pp. 107–13. Wolff seems unaware that the exploits he describes were largely those of Australians.
63. Wolff, *In Flanders' Fields*, p. 116.
64. New Zealand Expeditionary Force, *Official History of the New Zealand Engineers*, Wanganui, 1927, p. 133.
65. David, 'Prof. Pollock's War Service', p. 81.
66. Rose E. B. Coombs, *Before Endeavours Fade*, London, 1983, p. 59.
67. Barrie, *War Underground*, pp. 257–9.
68. Wolff, *In Flanders' Fields*, p. 120.
69. *Sydney Morning Herald*, 12 June 1917.
70. Wolff, *In Flanders' Fields*, p. 111.
71. Woodward, *War Story*, p. 98.
72. *Sydney Morning Herald*, 14 June 1917.
73. David, 'Prof. Pollock's War Service', p. 83.
74. Barrie, *War Underground*, p. 260.
75. von Ludendorff, *My War Memories*, pp. 428–9.
76. Wolff, *In Flanders' Fields*, p. 110. The history of the 204th (Württemberg) Division suggests that the professional German engineer in charge of surveying in the sector, Lieutenant Colonel Füsslein, lacked the mining experience of the Australians, and had instead to make do with improvised infantry arrangements. He was caught off-guard, and was perhaps overconfident of his success in monitoring British movements. See 'A German Account of the Loss of Messines Ridge and adjoining sectors in June 1917', AWM 27, box 8. According to Siegfried Passarge, who served as a consulting geologist with the German *Fourth Army*, the decision to place the four German geologists serving that sector under the authority of Füsslein was contested. The geologists proposed to counter the British drives by digging in much the same way the Australians were doing, beginning about 780 metres behind their front. This would have brought them under the British galleries. However, Füsslein took no notice of his geologists' advice, and continued to sink shafts immediately behind the German front-line trenches. This meant the Germans had to work through the quicksand above the clay — noisy work that gave the British below clear warning of their intentions. See Passarge, *Aus Achtzig Jahren: Eine Selbstbiographie*, Hamburg, Institut für Geographie und Wirtschaftsgeographie, Universität Hamburg, 1957, pp. 451–2.
77. Harvey, 'Norton-Griffiths', p. 12. This story is corroborated by the transcription given in AWM 27, box 8, 443. Passarge, *Aus Achtzig Jahren*, p. 452, adds that his later report on the incident to the German high command exonerated the geologists, whose advice the commanding engineer had rejected.
78. Pollock's aeronautical work was later described by David in the *Sydney Morning Herald*, 6 May 1919.
79. War diaries of the 2nd ATC, PRO: WO 95/491.
80. 'Summary of Work of Controller of Mines, Second Army and Staff', March–November 1918, Royal Engineers Library, Chatham. For subsequent activities of the Tunnellers, see C. E. W. Bean, *The Official History of Australia in the War of 1914–1918*, vol. V, *The Australian Imperial Force in France during the main German offensive, 1918*, Sydney, 1937, pp. 245, 427, 432, 479, and vol. VI, *The Australian Imperial Force in France during the allied offensive, 1918*, Sydney, 1942, pp. 503, 948.
81. Ernest Scott, *The Official History of Australia in the War of 1914–1918*, vol. XI, *Australia during the War*, Sydney, 1937, appendix 7; C. E. W. Bean, *Anzac to Amiens: A Short History of the Australian Fighting Services in the First World War*, Canberra, 1946, p. 532.
82. *Sydney Morning Herald*, 14 June 1917.
83. R. N. Harvey, 'Military Mining in the Great War', *Journal of the Royal Engineers*, December 1929, pp. 537–43.
84. 'Company Orders, 1 ATC', 14 October 1918, PRO: WO 95/489.
85. Williams, vol. 2, *Military Crosses to Australia from 1915–1920*, p. 350.
86. Letter, Adcock to his parents, 3 February 1918, AWM 2DRL 123.
87. Letter, Morse to his wife, 5 May 1914, AWM 12/18/819.
88. Woodward, *War Story*.
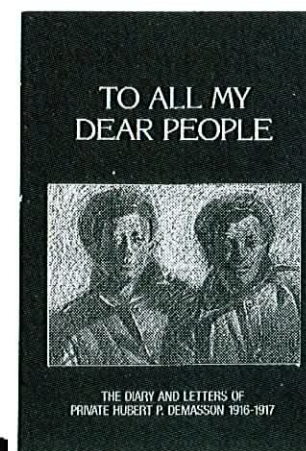89. *Sydney Morning Herald*, 25 April and 2 May 1919.