

# RAILWAYS IN THE GREEK AND ROMAN WORLD

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**B**ecause the Greeks and Romans, for all their inventiveness in other directions, are not widely acknowledged as builders of railways, the title of this paper may raise a few eyebrows. True, the ancient world was totally innocent of anything approaching the modern concept of the public railway, with passenger trains running to a timetable, pulled by locomotives, and on iron rails. None of these components was more than 60 years old when they came together for the first time in the Liverpool & Manchester of 1830. The basic concept of the railway, however, is very much more simple: a prepared track which so guides the vehicles running on it that they cannot leave the track. Within this fundamental definition we are dealing, before the late 18th Century, with the private railway, with rails essentially of wood or occasionally of stone, with carriage only of goods in vehicles propelled by horse or by man power, and with a variety of methods of guiding the wheels. Railways of this simple kind, though few, can indeed be traced back as far as the Greeks and Romans. While they have been studied to some limited extent by the classical archaeologist, the railway historian, with the honourable exception of Charles Lee, has paid them very little attention indeed.

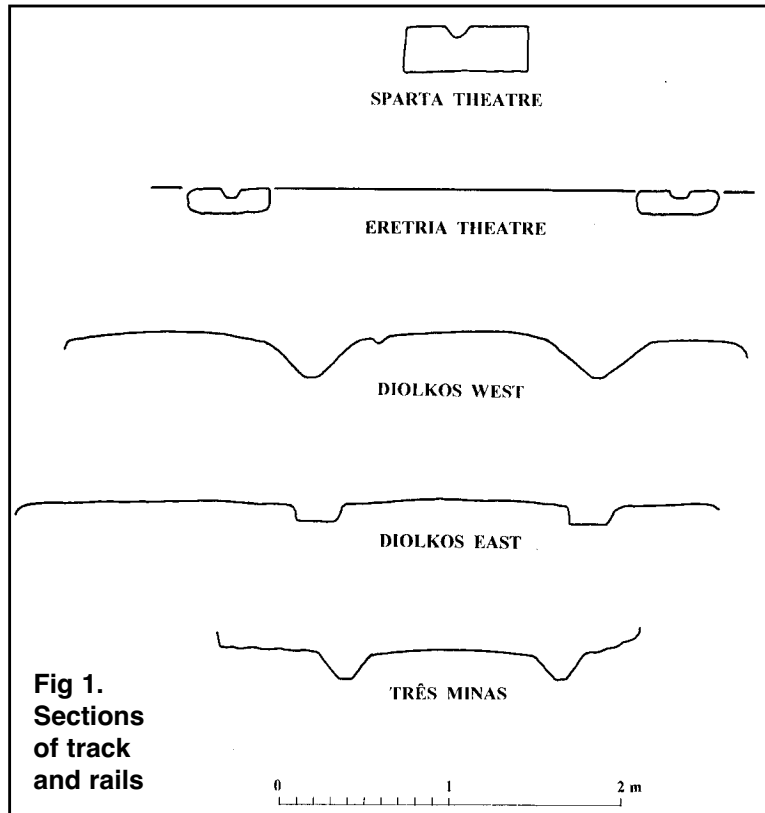
The railway began as a roadway deliberately provided with ruts to guide the wheels. Ancient road surfaces, where they can be seen today on the primitive mountain tracks of archaic, classical and Hellenistic Greece and on the enormous and technically far superior Roman network, frequently display ruts. It is necessary, but often difficult, to distinguish between those deliberately cut and those simply worn by traffic. Well-known examples of the latter are to be found in the streets of Pompeii. Almost equally famous are the rutways of Malta and Gozo. Although their date, purpose and method of formation are still disputed, the most likely explanation is that in the 6th Century BC the hard crust of the limestone which forms the islands was removed by cart to build up agricultural terraces, thus exposing the soft bedrock which the same carts rapidly wore down into ruts<sup>1</sup>. As an accidental modification to an ordinary roadway, such ruts can hardly qualify as a railway.

Nor are we concerned with those cases, quite common especially in Greek

areas and no doubt inspired by accidental ruts, where the channels were cut deliberately but only sporadically. They might help vehicles across or through outcrops of rock that obstructed ordinary roads or, as on a short stretch of the Roman road leading to the Little St Bernard Pass, serve like modern crash barriers to prevent vehicles leaving the road<sup>2</sup>. Such channels indeed represent deliberate guidance, if intermittent and only for short distances<sup>3</sup>. But by any logical analysis a railway surely has to be railed — that is, in these early days, deliberately rutted — throughout. Other instances, often thought to be ancient, are or might be of later date. Thus the deep channels in the Street of Tombs at Syracuse, long considered to be Greek, actually date from the 16th Century<sup>4</sup>. At the quarries at Vers in Provence, which supplied stone for the Pont du Gard, there are massive ruts which, because the quarries are still at work, might be post-Roman<sup>5</sup>.

Let us rather concentrate on certainties. The Greeks were clearly familiar with the principle of the true railway on very short systems. The theatre at Sparta, as rebuilt about 30 BC, had a stage building that was only occasionally needed for performances. It was therefore not a fixture, but mobile: parked normally in a kind of carriage shed to one side and rolled into place when

required on multiple wheels running in three widely-spaced rows of channelled stone rails (section, Fig 1). It measured about 34m long by 8m wide<sup>6</sup>. Much the same arrangement also appears at the theatre at Megalopolis from the third century BC, where no trace was found of rails perhaps because they were of wood rather than stone<sup>7</sup>. The railway had another theatrical func-



**Fig 1.**  
**Sections**  
**of track**  
**and rails**

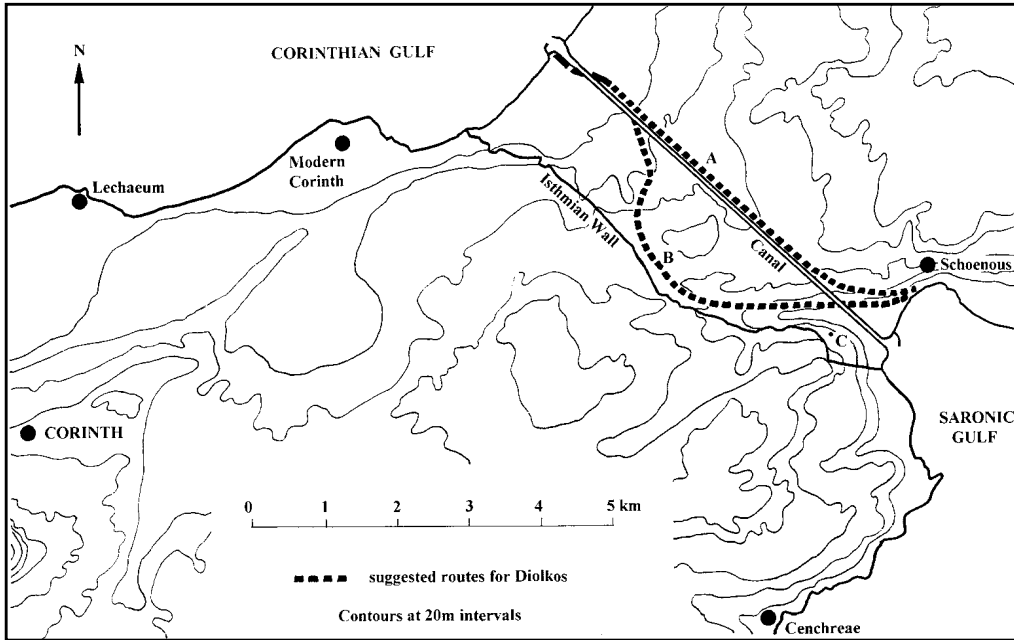
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tion. In highly-formalised Greek tragedy, scenes involving death were enacted off-stage. But the result might then be displayed, as in Aeschylus' 'Agamemnon'. A screech would be heard from behind the scenes, the doors in the stage building would open, and onto the stage would trundle a flat trolley carrying the corpse of the murdered king in his bath. To guide this trolley, the theatre at Eretria in Euboea had stone channel rails at 2.6m centres running across the stage from back to front (section, **Fig 1**)<sup>8</sup>. Even the automatic puppet theatre of Hero of Alexandria in the first century AD, a marvel of mechanical ingenuity, rolled under its own power onto a planked stage 'on which longitudinal channels are made by nailing down strips so that the wheels run in the channels'<sup>9</sup>. As railways, all these were of course ridiculously short. But they lead us on to two much longer examples, one Greek and one Roman.

The first is the famous Diolkos or railed way across the Isthmus of Corinth. For movement between the Corinthian and Saronic Gulfs it saved the long and dangerous sea journey round the Peloponnese, where Cape Malea had a sinister reputation for gales. A succession of rulers from 600 BC onwards dreamt of a canal through the Isthmus, but only the emperor Nero actually began one and, before giving up, did a great deal of work for which he has received little credit<sup>10</sup>; but Nero has always had a bad press. Nowhere is the ridge of the Isthmus less than 75m above the sea, a height which the Diolkos had to surmount and any canal had to cut through. The modern canal, on the same line as Nero's, was finished in 1893, having destroyed his works and some of the Diolkos in the process.

Canal and Diolkos naturally crossed the narrowest part of the Isthmus, less than 6km wide, well to the north-east of the city of Corinth, which had its own ports of Lechaemum and Cenchreae on either side (**Fig 2**, page 11). The western end of the Diolkos was excavated between 1956 and 1961 by Nikolaos Verdellis, who uncovered about 800m of more or less continuous track and traced about 1100m in all. His interim reports lack detail, and he died before publishing fully<sup>11</sup>. Only recently have Georges Raepsaet and Walter Werner re-recorded and published some of the missing detail<sup>12</sup>. Further tracing of the line is impeded by the modern canal and its spoil tips, but the straight continuation proposed by Raepsaet (A on **Fig. 2**) is hardly possible. It gives wicked gradients towards Schoenous, which is known to have been the eastern terminus, and reports of the 1880s and 1890s locate a stretch of the Diolkos, described as a 'tramway', south of the canal. This has not been found since, and is often assumed to have been at point C; but its site 'on top of the Isthmus' and just north of where the road from Kalamaki (Schoenous) to (modern) Corinth crossed the Isthmian Wall can only be at point B<sup>13</sup>. The route therefore swung south in search of gentler gradients, and its length was at least 8.5km (**Fig 3**, page 11).

Space forbids detailed debate of the problems which still surround the Diolkos. Archaic letters or monograms cut on many of the stones, interpreted



**Fig 2. The Isthmus of Corinth.** Base map from Raepsaet, 'Diolkos,' Fig 1.

**Fig 3. Diolkos looking east towards walls (1989).**

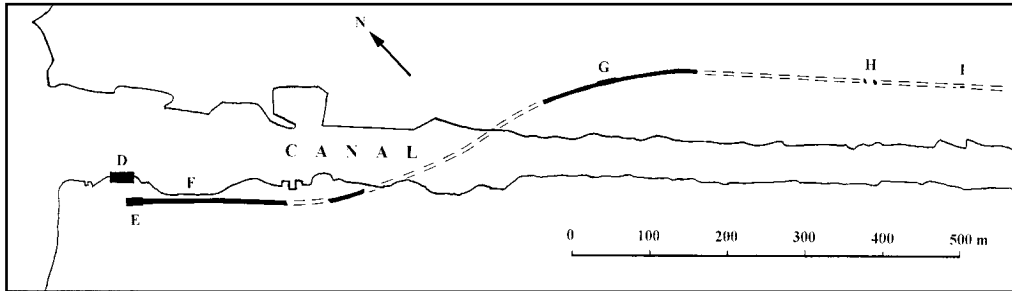
Courtesy of Dr John Prag.

by Verdelis as instructions to the operators (the ancient



equivalent of 'Whistle' signs?), are much more probably masons' marks. They, and associated pottery, date the Diolkos to the sixth century BC, in or after the time of Periander, tyrant of Corinth about 600 BC. Greek historians record eight occasions between 428 and 30 BC when it carried warships over the Isthmus. Two sources of Roman date, Strabo and Pliny, talk of it carrying boats (as opposed to ships) on waggons, and in AD 67 it was truncated and probably put out of use by Nero's canal works. After this we hear the name of Diolkos no

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**Fig 4. West end of the Diolkos.** Based on Verdelis, *Anaskaphe* (1960), Pin A.

more. Two reports of boats being hauled across the Isthmus in Byzantine times, in 873 and about 1150, most likely refer to a different and unrailed route<sup>14</sup>. The gradient on the known section steepens from about 1 in 70 at the west end to 1 in 30 where the line is lost. On the eastern side a direct course would involve about 1 in 12 but, as noted, an easier route is more likely.

**Fig 4** shows the known section, the stretch north of the canal being mostly on military land. We will look later at the western terminus at D and at the so-called ramp at G. The last point known is at I. The first 600m from the west end, as far as the 'ramp', comprise a paved roadway, 3.4 to 6.0m wide, of hard *poros* limestone with parallel grooves of shallow V section at about 167cm centres (5ft 6in) and varying in depth from almost nothing to 20cm (section, **Fig 1**). Some shallow subsidiary grooves that might be taken as turnouts prove, when they are in pairs, to be of wider gauge. All these grooves are usually interpreted as the result of wear; but the marked and surely deliberate camber of the paving between them suggests, rather, that the wheels were meant to follow those lines. As we shall see, moreover, the paving at the 'ramp' and the loading bay, though undoubtedly traversed by vehicles, shows no grooving at all, which suggests that the wheels did not generate significant wear. These grooves, then, were apparently original and deliberately cut. East of the 'ramp', however, the V-shaped grooves are replaced by rectangular ones, up to 30cm wide and 10cm deep and at the slightly narrower centre-line gauge of about 157cm, although wheels intended for the V-grooves would still fit within them. Part if not all of this section is not original, since the paving incorporates the re-used capital of a 5th Century column. The rectangular grooves are certainly cut deliberately, and in places are patched with cement which implies a Roman date.

Between the two sections is the 'ramp': two low parallel walls along the line of the track, rising to 40cm in height, and now 15m in length but originally twice as long. The paving beside and between them is innocent of grooves, but on top of the walls are several diagonal wear marks from ropes, and a few holes. Raepsaet interprets the 'ramp' as a transfer point where a ship was moved from a road vehicle on the west to a railway vehicle on the east, and

postulates capstans off to the sides — hence the rope marks — to power the operation. The reason for the transfer here, he suggests, was the change from a gentle to a steeper gradient. While his thinking is logical enough, the thinking he ascribes to the Greeks is not: why have a different vehicle confined solely to the 600m at the western end, with all the bother of a transfer? To understand these features it seems more helpful to remember the long life of the Diolkos — at least six centuries — during which time the arrangements were surely modified, and extensive repairs re-using some original material were certainly made. Might it not be that the V-grooves represent the original phase, while the rectangular grooves are a later relaying or recutting with, so to speak, different rails? Were the grooves omitted at the ‘ramp’ because the vehicle would straddle, and be guided by, one of the walls? Were the ropes and capstans to power not a transfer, but haulage? Further east again, Verdalis exposed a short section of paving (H), very narrow, of different construction but re-using old stones, and with no grooves at all. Could this be yet another relaying, from late in the Diolkos’ life when it was no longer a railway proper but a plain road with grooves surviving here and there? Definitive answers to such questions can not yet be given.

The fact remains that for some if not all of its career the Diolkos was a railway within our definition. More debatable is what it carried<sup>15</sup>. The word means a ‘haul-over’, and the standard view is that it was a portage-way for ships, which is undoubtedly what the ancient literature suggests. But it must be remembered that the Greek historians, our major source, were concerned with military rather than commercial matters. The portage of warships, though it certainly took place on occasion, seems largely irrelevant to the main purpose of the Diolkos. Until the fourth century BC the standard, and largest, warship was the trireme. Thucydides tells us that in 428 BC the Spartans had to build slipways to pull their triremes out of the water onto the Diolkos. The strong implication is either that there were no slipways before, or that the original slipways were too small; and that therefore the Diolkos was not originally built for triremes, or even perhaps for ships at all. The practical difficulties would be considerable. An empty trireme weighed 25 tons, and was 34m long on the waterline and 5.5m in beam<sup>16</sup>. It would take a great deal of effort, whether from oxen or men, to haul it up to the summit and lower it down again. True, it had a large crew — some two hundred men — who could supply the motive power. But it seems unlikely that warships, or at least larger warships, were portaged as a matter of course. Clearly the crossing by a Roman fleet in 102 BC, inaccurately hailed by the general in charge as an event ‘never attempted before and never to be contemplated hereafter’, was by that time a rarity.

The same, and more, applies to merchant ships, which by the 4th Century BC were commonly of 70 to 150 tons burden and 6 to 9m in beam<sup>17</sup>. Unlike warships, they were not built for lightness and were not designed to be hauled out of the water; and their crews, relatively speaking, were small. With that kind of

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tonnage, their cargo would necessarily be unloaded for the portage and taken across separately. Indeed one wonders whether owners would be happy to submit their ships — their major investment — to the stresses and strains of an overland journey on cradles, and to the risk of overturning. Consider the top-heaviness of a deep and tubby hull 6 or 9m wide perched on wheels 1.6m apart. It has been argued forcibly, and (to me) convincingly, that the craft which undoubtedly were hauled regularly across were small boats rather than ships, that even their cargoes were carried across separately, and that when a ship arrived at one end, the norm was to take the cargo across in waggons and load it onto a different ship at the other end.

At the western terminus there is indeed a large sloping slipway (D, Fig 4) where boats and even ships could be hauled out of the water. Alongside it is a loading bay (E), 19m long, 6m wide and once maybe 1.5m deep, rebuilt in the late fifth century from some earlier structure. Its floor is paved but without grooves. This slipway and bay, both (with one undatable exception) innocent of inscribed letters, were probably the work of the Spartans in 428 BC and would allow boats or heavy loads to be slid onto cradles. But just to the east (F) there is also what looks like a quay alongside the Diolkos, apparently original because its stones are profusely inscribed with letters, where ships could moor for loading or unloading more ordinary cargoes. Given the wide extent of Greek trade, the cargoes in question might be almost anything; and when they were in small units like bales or amphorae they could be carried easily enough by pack animal or cart. There was indeed an earth road on either side of the paved route. But at least in the earlier days of the Diolkos there was certainly a considerable traffic in large blocks of marble from east to west, up to several tons apiece, and in large timbers from west to east, the sort of heavy commodities for which a railway would be particularly valuable.

It is probably no coincidence that the century when the Diolkos was built saw not only large masonry come into fashion for prestige buildings, in stones commonly of 10 tons and sometimes much more, but also the invention of the cranes, capstans and block and tackle necessary to handle them<sup>18</sup>. The Greeks became adept at transporting such huge stones long distances from the quarry to the building site. Inscriptions record specially-built roads and massive vehicles. Stones for Epidaurus, which had to travel by sea, were rolled on and off ships. Eight-ton stones for Eleusis were pulled by 37 yoke of oxen from the Pentelic quarries 40km away, and Raepsaet thinks that the word *hyponomoi* in these inscriptions refers to Diolkos-type grooves for the wheels to run in, though none have yet been found on the ground<sup>19</sup>.

Being in Corinthian territory, the Diolkos can only have been built by Corinth, which prospered mightily from its position controlling north-south traffic into the Peloponnese and east-west traffic across the Isthmus<sup>20</sup>. But the Diolkos was not built for trade to and from the city of Corinth which, with its two ports, lies well to the south. It was built, rather, to encourage, and to prof-

it from, merchants who traded across the Isthmus between the Aegean and western Greece and were willing to pay the haulage costs and tolls which, we may be quite sure, Corinth charged. And when a character in Aristophanes' *Thesmophoriazusae* is stripped of his female disguise and his great phallus is exposed which comic actors wore on a belt, he tries to hide it by swinging it round from front to back. The watching women exclaim, 'You've got an isthmus, man: you're shunting your cock up and down it more often than the Corinthians!<sup>21</sup>' which makes it quite clear that traffic on the Diolkos was frequent and regular; and as such it must have been essentially commercial, not merely naval. The Diolkos, therefore, was not only a true railway, and quite a long one, but also a public railway, open to all comers on payment: a concept that did not recur, to the best of our knowledge, until around 1800. Its example can in no way have influenced the public railway of the Industrial Revolution; but there is little new under the sun.

## MINE RAILWAYS

Let us move on to an instance where continuity can not be ruled out. The industry of the ancient world that was carried out in the largest units was mining, and above all Roman gold mining in north-western Spain and Portugal. By any standard, these mines were big business. One such, started in the first century AD, is Três Minas in Portugal, with two vast opencast pits each 400m or so in length and linked to the surface outside by low-level adits for drainage and the removal of waste and ore. One adit, the Galeria dos Alargamentos, is 150m long. The *alargamentos* of its name are widenings as if for vehicles to pass; and wherever the floor has been cleared, parallel channels, again of V-section, have been found cut into the rock at a gauge of about 1.2m (section, **Fig 1**)<sup>22</sup>. Within our definition, they form a railway. One swallow does not make a summer; but while the Diolkos, in its scale and purpose, was probably unique, it would be very surprising if at Três Minas we had lit on the only mine railway of the ancient world. Quite apart from other gold mines in Spain and Portugal, those of Transylvania are obvious candidates for the possession of railways, as is Dolaucothi in South Wales which certainly followed Spanish practice in other respects. For all we know, too, instead of being cut in the rock, the rails might sometimes have been built up of wood and left few traces behind.

Três Minas raises an obvious and fascinating question. When railways appear, or reappear, in the late Middle Ages, they are found in precisely the same context: in metal mines, underground except for a few yards outside the adit mouth, with small trucks pushed by hand. The only difference is that whereas the Três Minas grooves are cut in the rock, the later rails are made of wood. They come at first in two forms<sup>23</sup>. The best-known and ultimately the most widespread type is the guide-pin *hund*, to give it its German name, with a pin projecting downwards to engage in the slot between the two parallel



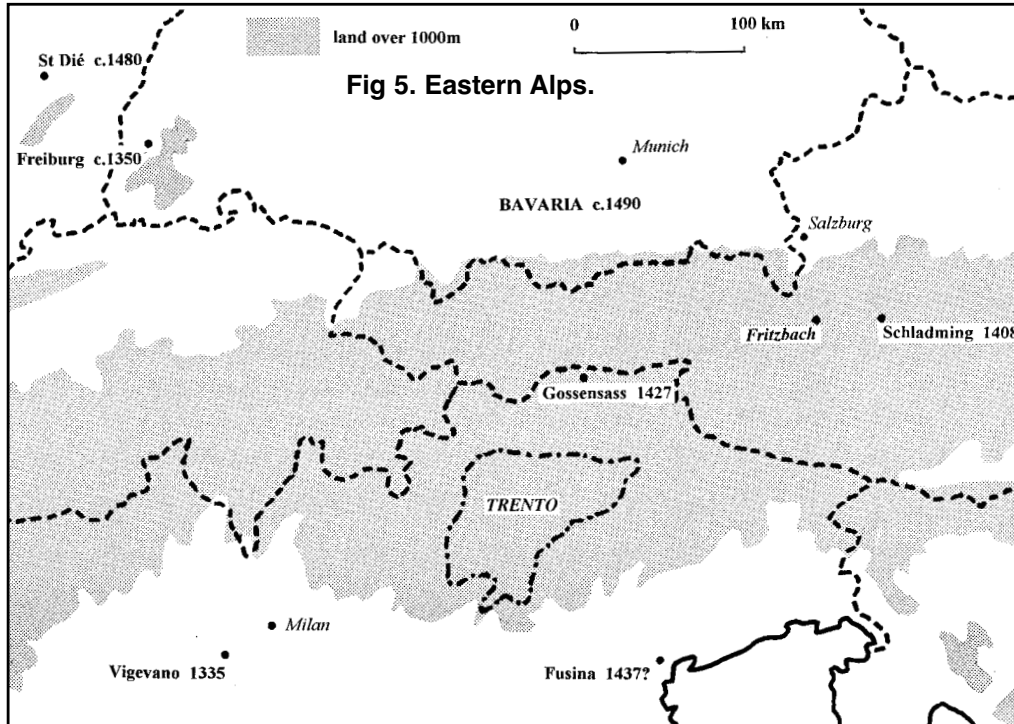
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planks that form the rails. Our earliest firm evidence for the type is a manuscript illumination of about 1480 from St Dié in the Vosges. The other and apparently earlier form of medieval railway was the channel or angle rail, of which our first certain illustration is a triptych, also of about 1480, from Gossensass, a silver-lead mine on the Brenner Pass<sup>24</sup>. Also from Gossensass comes the earliest written record yet found of the *hundstösser*, the *hund*-pusher, in 1427; while from Schladming near Salzburg comes a reference in 1408 to *gestänge*, rails. In a scene in a stained-glass window in the cathedral of Freiburg im Breisgau, dedicated in about 1350 by a local mine owner, a miner is pushing what appears to be a waggon, and it is not at all impossible that it ran on grooved rails.

Nor were such rails limited to mines. An incline at Fusina for moving boats from the River Brenta to the lagoon near Venice latterly boasted wheeled cradles guided by raised stone kerbs, though whether these were present when it was first built in 1437 we cannot be sure. The channel rail also features in military engineering. A drawing from the so-called Anonymous of the Hussite Wars, compiled probably in Bavaria and now dated between 1486 and 1492, shows a truck of spoil for building a rampart and indisputably running on channel rails. A century and a half earlier, in 1335, Guido da Vigevano, who hailed from near Milan, had described a wheeled siege tower. It was to cross the moat of a town under attack on two massive beams: 'let two channels be made on the two beams by fastening two pairs of laths upon them<sup>25</sup>.'

It is perfectly possible that there was no connection between Roman and medieval mine railways, that the same response to a common need was made completely independently. But a continuity cannot be ruled out either, and this possibility deserves closer investigation. Just where might the railway have survived? Not, one suspects, in Spain or Portugal, where medieval and even post-medieval mining was not noted for its technology. It might conceivably have survived in the Byzantine and subsequently Serbian mines of the Balkans, where the ubiquitous German miners, who moved into the area in the 13th Century, might have found it and disseminated it<sup>26</sup>. In this kind of way the force pump, well known to the Romans, was forgotten in the West, preserved by the Byzantines, and returned to the West in the 15th Century.

The most plausible area, however, is the Alps, and especially the Tirol and the eastern Alps. All the 14th and 15th Century railways mentioned above centre on this area, either in the mountains themselves or on their fringes (**Fig 5**, page 17). While this concentration may of course be coincidence, there were factors here that favoured survival. There was considerable Roman mining in the region, and better evidence than elsewhere for a continuity of mining into the Middle Ages, with miners continuing to beaver away in their mountain fastnesses largely insulated from the political upheavals around them<sup>27</sup>. And two particular facts do suggest that the mines of the eastern Alps acted as a preservative for Roman ideas. First, the Roman mining laws known from an



inscription at Aljustrel in Portugal bear a distinct resemblance to the earliest known medieval mining laws, promulgated in 1185 by the Archbishop of Trento, which is in the South Tirol. The possibility has long been recognised of some sort of continuity of mining law<sup>28</sup>. Secondly, it has only recently been realised that in their gold mines in Spain and Portugal and at Dolaucothi the Romans used water-powered stamps for crushing ore<sup>29</sup>. These re-emerge into our ken, after a gap of almost a thousand years, in 1135 at the gold mine of Fritzbach im Pongau just south of Salzburg, which belonged to the abbey of Admont. By 1200 there were also water-powered stamps in the silver mines of Trento<sup>30</sup>. The deduction is obvious: if Roman mining law and Roman mining technology in the form of ore stamps did survive in the eastern Alps, might not the Roman mine railway have done so too?

All this takes us deep into the realm of speculation. I emphatically do not claim a continuity of mining railways as a fact, because independent invention is perfectly possible. In any event, to prove such a continuity would be exceedingly difficult, because our understanding of the broad history, let alone the technology, of mining between the Romans and the late Middle Ages is still woefully defective. Nonetheless it is worth asking — and at this stage it can be no more than an unanswered question — whether the continuous and unbroken lineage of the railway may go back very much further than we thought: beyond the Middle Ages to Rome and ultimately to archaic Greece around 600 BC.

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## NOTES

- 1 Rowland Parker and Michael Rubinstein, *The Cart Ruts of Malta and Gozo* (Gozo, 1984).
- 2 Raymond Chevalier, *Roman Roads* (1976), fig 18.
- 3 There is a sizable literature, eg, W Kendrick Pritchett, *Studies in Ancient Greek Topography, Part III (Roads)* (Berkeley, 1980); John van Laun, 'Rutways in the Mediterranean - a preliminary inventory', *Railway & Canal Historical Society Tramroad Group Occasional Papers*, 64 (1990); A Caillemer, 'Les voies à rainures chez les anciens', *Congrès Archéologique de France*, 46 (1879), pp 277-88; M Bulle, 'Geleisestrassen des Altertums', *Sitzungsberichte der bayerischen Akademie der Wissenschaften, phil-hist Abteilung*, Jahrg 1947 Heft 2; Leonhard Franz, 'Alte Geleisestrassen in Tirol', in *Festschrift zu Otto Stolz* (Innsbruck, 1951), pp 133-46.
- 4 Albert de Rochas, 'Les rainures des chemins antiques', *La Nature* 26 Aug 1905, pp 207-8; and Charles E Lee, *The Evolution of Railways* (2nd ed, 1943), p 4, both assume a Greek date. For their real period, Alta Macadam, *Blue Guide Sicily* (5th ed, 1999), p 269.
- 5 Illustrated in Jacky Granier, *The Pont du Gard* (Monaco, 1989), p 4.
- 6 Heinrich Bolle, 'Das Theater zu Sparta', *SBAW, phil-hist Abteilung*, Jahrg 1937 Heft 5.
- 7 Plan in Margarete Bieber, *The History of the Greek and Roman Theater* (Princeton, 1961), fig 276.
- 8 Andrew Fossum, 'The Eiskykema in the Eretrian Theater', *American Journal of Archaeology*, 2nd series, 2 (1898), pp 187-94.
- 9 *Automatopoeica* 2. 2.
- 10 B Gerster, 'L'Isthme de Corinthe, tentatives de percement dans l'Antiquité', *Bulletin de Correspondance Hellénique*, 8 (1884), pp 225-32.
- 11 The main publications by Nikolaos M Verdilis are: 'Der Diolkos am Isthmus von Korinth', *Mitteilungen des deutschen archäologischen Instituts, Athenische Abteilung*, 71 (1956), pp 51-9; 'Die Ausgrabungen des Diolkos während der Jahre 1957-1959', *ibid*, 73 (1958), pp 140-5; 'Anaskaphe tou Diolkou', *Praktika tes Archaiologikes Hetaireias* (1960), pp 136-43; 'Anaskaphe tou Diolkou', *ibid* (1962), pp 48-50.
- 12 Georges Raepsaet, 'Le Diolkos de l'Isthme à Corinthe: son tracé, son fonctionnement', *BCH*, 117 (1993), pp 233-61 with plans of the main section; Walter Werner, 'The largest ship trackway in ancient times: the Diolkos of the Isthmus of Corinth', *International Journal of Nautical Archaeology*, 26 (1997), pp 98-119 with plans of the western end. Werner seems not to have read some of the main publications that he cites.
- 13 Karl Baedeker, *Griechenland* (Leipzig, 1883), p 220 and Greece (2nd ed, Leipzig, 1894), p 237, followed by J G Frazer, *Pausanias's Description of Greece*, 3 (1897), p 5.
- 14 Ancient sources listed in Raepsaet, 'Diolkos', p 233 n1; add Livy XLII 16. 6 and P A Joubert, *Géographie d'Édrisi*, 2 (Paris, 1840), p 123.
- 15 The main discussions of the traffic and mode of operation are R M Cook, 'The Diolkos', *Journal of Hellenic Studies*, 99 (1979), pp 152-3; R M Cook, 'A further note on the Diolkos', in *Studies in Honour of T B L Webster*, eds J H. Betts, J T Hooker and J R Green, 1 (Bristol, 1986), pp 65-8; Brian R MacDonald, 'The Diolkos', *JHS*, 106 (1986), pp 191-5.
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- 17 Lionel Casson, *Ships and Seamanhip in the Ancient World* (Princeton, 1971), pp 171, 183.
- 18 J J Coulton, 'Lifting in Early Greek Architecture', *JHS*, 94 (1974), pp 1-19.
- 19 A Burford, 'Heavy Transport in Classical Antiquity', *Economic History Review*, 2nd series, 13 (1960), pp 1-18; Georges Raepsaet, 'Transport de tambours de colonnes du Pentélique à Eleusis au IV<sup>e</sup> siècle avant notre ère', *L'Antiquité Classique*, 53 (1984), pp 101-36.
- 20 For the background, see J B Salmon, *Wealthy Corinth: a history of the city to 338 BC* (Oxford, 1984).
- 21 The word translated as 'shunt' is *dielkein*, to haul over, the verb corresponding to *diolkos*.
- 22 Jürgen Wahl, 'Três Minas: Vorbericht über die archäologischen Ausgrabungen im Bereich des römischen Goldbergwerks 1986/87', in *Montanarchäologie in Europa*, eds Heiko Steuer and Ulrich Zimmermann, Sigmaringen (1993), p 139. I am indebted to Dr Paul Craddock for information and to Prof Gerd Weisgerber for the loan of photographs.

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- 24 *Der Anschnitt*, 25.6 (1973), p 1.
- 25 A Rupert Hall, 'Guido's *Texaurus*, 1335', in *On Pre-Modern Technology and Science: Studies in Honor of Lynn White, Jr*, eds Bert S Hall and Delno C West (Malibu, 1976), p 24.
- 26 Speros Vryonis, 'The Question of the Byzantine Mines', *Speculum*, 37 (1962), pp 1-17.
- 27 Siegfried Pirklbauer, 'Die Rechtsentwicklung des Salzburger Bergbaus', *Der Anschnitt*, 23.6 (1971), pp 20-4.
- 28 G R Lewis, *The Stannaries* (New York, 1908), pp 65-70; John U Nef, 'Mining and Metallurgy in Medieval Society', in *Cambridge Economic History of Europe*, eds M Postan and E E Rich, 2 (Cambridge, 1952), pp 451-6.
- 29 M J T Lewis, *Millstone and Hammer: the Origins of Water Power* (Hull, 1997), pp 106-10.
- 30 Bradford B Blaine, 'The Enigmatic Water-mill', in Hall and West, *On Pre-Modern Technology*, 169; Nef, 'Mining', 461.