BMR Journal of Australian Geology & Geophysics, 10, 267-275

Cainozoic geology and geomorphology of the Wahgi Valley, central highlands of Papua New Guinea

C.F. Pain[1], C.J. Pigram[2], R.J. Blong[3] & G.O. Arnold[4]

The Wahgi Valley is a structural depression, between the Bismarck Fault Zone to the north and the Kubor Anticline to the south, which has been enlarged by erosional removal of northward-dipping sedimentary rocks on the northern flank of the Kubor Anticline. The geomorphic history of the area began when it became land about 35 Ma ago. The Wahgi Valley contains volcanic debris avalanche and lahar deposits in the west and fluviatile/lacustrine deposits elsewhere. The latter are dominated by undissected swamp and lake deposits in the west, and dissected fan and terrace deposits in the east. There is clear evidence of knickpoint retreat up the Wahgi River from the east, causing the fans to trench progressively from the east. Earlier interpretations of the evolution of the Wahgi Valley stressed drainage reorganisation, with reversal of a westerly flowing Wahgi River caused by damming by volcanics in the west, and capture in the east. Evidence from sediments, tephra, and landforms now suggests that reversal was probably restricted to the westernmost drainage, and any reversal of drainage occurred earlier than previously thought, perhaps 400 000 years ago.

Introduction

The highland valleys of Papua New Guinea originated in the Late Cainozoic with rapid uplift, extensive detachment tectonics, and Pleistocene volcanism (Dow, 1977). Many of the major rivers lie between high mountain ranges and traverse gently sloping infilled basin floors, as well as steeper gradients (Bik, 1967; Blong & Pain, 1976).

The Wahgi Valley has all the attributes of a typical highland basin. The upper reaches of the Wahgi River flow eastward for more than 50 km through an intermontane basin, between the Kubor and Bismarck Ranges, before entering the Wahgi Gorge southwest of Mingende (Fig. 1).

In this highlands environment, where tectonism and volcanism have played such an important role in landform development, drainage reorganisation has been relatively common. The often postulated reversal of flow in the Wahgi Valley is of particular interest because it involves a major highland river switching from the north-coast drainage of the Sepik catchment to the south-coast drainage of the Purari catchment.

Drainage reorganisation in the Wahgi Valley has been a topic of discussion since European man penetrated the area in the early 1930s. Michael Leahy, one of the first Europeans to enter the valley, was also the first to speculate on the prior existence of a lake in the area (Leahy, 1936). Rickwood (1955) went into more detail, suggesting that the late or post-Pliocene drainage was dictated by the main fold axes in the area. This drainage pattern, he suggested, was disrupted by vigorous Pleistocene volcanism, which led to capture of the eastern drainage of the Baiyer and Nebilyer Rivers by the Wahgi River. This resulted in deposition and swamp development in the upper Wahgi and Gumants basins. Rickwood contrasted the low gradient and broad, alluvium-filled valley of the Wahgi with the high gradient and narrow alluvium-free valleys of the Lai and Nebilyer Rivers. He also noted the rejuvenation of the Wahgi River as far upstream as Mingende (Fig. 1).

More recent work has added little to this basic story. Haantjens (1970) postulated a river flowing from the Wahgi valley into the Baiyer River, and suggested that the reversal took place in two steps — capture of the then upper Wahgi River in the east, followed by volcanic blocking in the west. However, it is equally possible that these events occurred either together or in the reverse order. Bain & others (1975) reiterated Haantjens, while Löffler (1977) and Pain (1978) reintroduced the idea first suggested by Rickwood (1955) that the Wahgi River may have flowed into either the Baiyer or Nebilyer Rivers, or both.

In this paper we present first an account of the late Cainozoic geology and the landforms of the Wahgi Valley area, and then return to the general question of drainage reorganisation in the context of over-all landform history and drainage pattern development.

Geology

The Wahgi Valley lies between two major structural units in the Papua New Guinea highlands, the Bismarck Fault Zone to the north, and the Kubor Anticline to the south. The Kubor Range is a Mesozoic horst (Pigram & Panggabean, 1984), which has been reactivated and uplifted perhaps as much as 5000 m since the Miocene to form the south side of the valley. Uplift along the Bismarck Fault Zone (Bain & others, 1975) on the north side of the valley produced the Bismarck Ranges. There is little geological evidence for the age of these movements within the Wahgi Valley. However, further east the major movements on the Bismarck Fault Zone postdate rocks of middle Miocene age.

Basement rocks

The Kubor Anticline is cored with Palaeozoic metamorphics and Triassic granodiorite (Bain & others, 1975), and is flanked by Upper Triassic, Upper Jurassic, and Cretaceous sediments. These sediments also occur on the north side of the Wahgi Valley, where they are deformed by the Bismarck Fault Zone, and intruded by Miocene intrusive rocks. Inliers of basement sedimentary rocks occur within the areas of the areas of both the Quaternary volcanic rocks and sediments (Fig. 1).

Quaternary volcanics

The Hagen Range, which rises to more than 3800 m a.s.l., at the western end of the Wahgi Valley, is a large pile of volcanic lavas, pyroclastics, and associated foot-slope deposits. This basaltic stratovolcano (with later andesitic flows) is made up of three coalesced cones aligned north-northeast (Mackenzie & Johnson, 1984). Volcanic breccia and lahar deposits also extend down the Nebilyer River, almost to the junction with the Kaugel River. The foot- slopes, which extend into the upper Wahgi Valley (Fig. 1), are composed of volcanic breccias, a massive volcanic debris avalanche (Blong, 1986), lahar deposits, and airfall tephras.

The whole of the Wahgi Valley has been covered with volcanic ash (airfall tephras) from a number of different sources. Most

[1]School of Geography, University of NSW.
[2]Division of Marine Geosciences & Petroleum Geology, Bureau of Mineral Resources, Canberra.
[3]School of Earth Sciences, Macquarie University.
[4]Gold Fields Exploration Pty Ltd, Canberra.

of the tephra units were apparently erupted from the Mount Hagen volcanoes, but some have come from the east, while others have come from the west (Pain & Blong, 1979). At many sites the tephras are well bedded, and mantle the underlying landscape, thus providing an important means of relative age control on the different geomorphic surfaces, which are discussed below (Table 1).

Lavas from the Hagen Volcanics have radiometric ages between 420 000 and 220 000 years (Loffler & others, 1980; Mackenzie & Johnson, 1984). The massive Mount Hagen debris avalanche occurred at least 80 000–100 000 years ago and probably more than 400 000 years ago (Blong, 1986). The uppermost tephra unit (Tomba Tephra) is older than 50 000 years, the limit of radiocarbon dating (Pain & Blong, 1979). The oldest lahar deposits are older than the lowermost tephra units, while others directly underlie Tomba Tephra. These age relationships are discussed further in the section on geomorphic history.

Quaternary fluviatile and lacustrine sediments

A wide range of Quaternary fluviatile sediments lies on the floor of the Wahgi Valley, extending up the larger tributaries of the Wahgi River (Figs 1, 2). The sediments consist of fanglomerates, lake deposits, flood-plain and terrace deposits, and swamp deposits, and have been named the Minj Group. The nature of the sediments in the valley allows them to be divided into four informal units, Qm_2–Qm_4.

Qm_1 consists of coarse polymictic conglomerate, pebbly sandstone, sandstone and siltstone, and laminated siltstone and mudstone with peat horizons. Coarser clastics, generally massive or poorly bedded, lie near the edges of the valley, while beds of finely laminated carbonaceous mudstone and siltstone are common towards the centre of the valley. This distribution is consistent with Qm_1 deposits being formed on alluvial fans that debouched into and periodically filled a transient lake and swamp environment. The intercalation of coarser sediments with beds of laminated siltstone, mudstone and peat suggests that alluvial fans periodically coalesced across the valley. In most exposures, Qm_1 deposits are strongly weathered, suggesting considerable antiquity.

Qm_2 deposits are similar, although perhaps slightly less weathered than Qm_1 deposits. The basis for the distinction between Qm_1 and Qm_2 deposits lies in the morphology of the fans they underlie (Fig. 3) (see below).

Qm_3 materials occur in terraces in the Wahgi Valley, cut into Qm_1 and Qm_2 deposits (Fig. 3). They typically consist of polymictic conglomerate and sandstone, generally present as a veneer on erosional surfaces cut into the older Quaternary

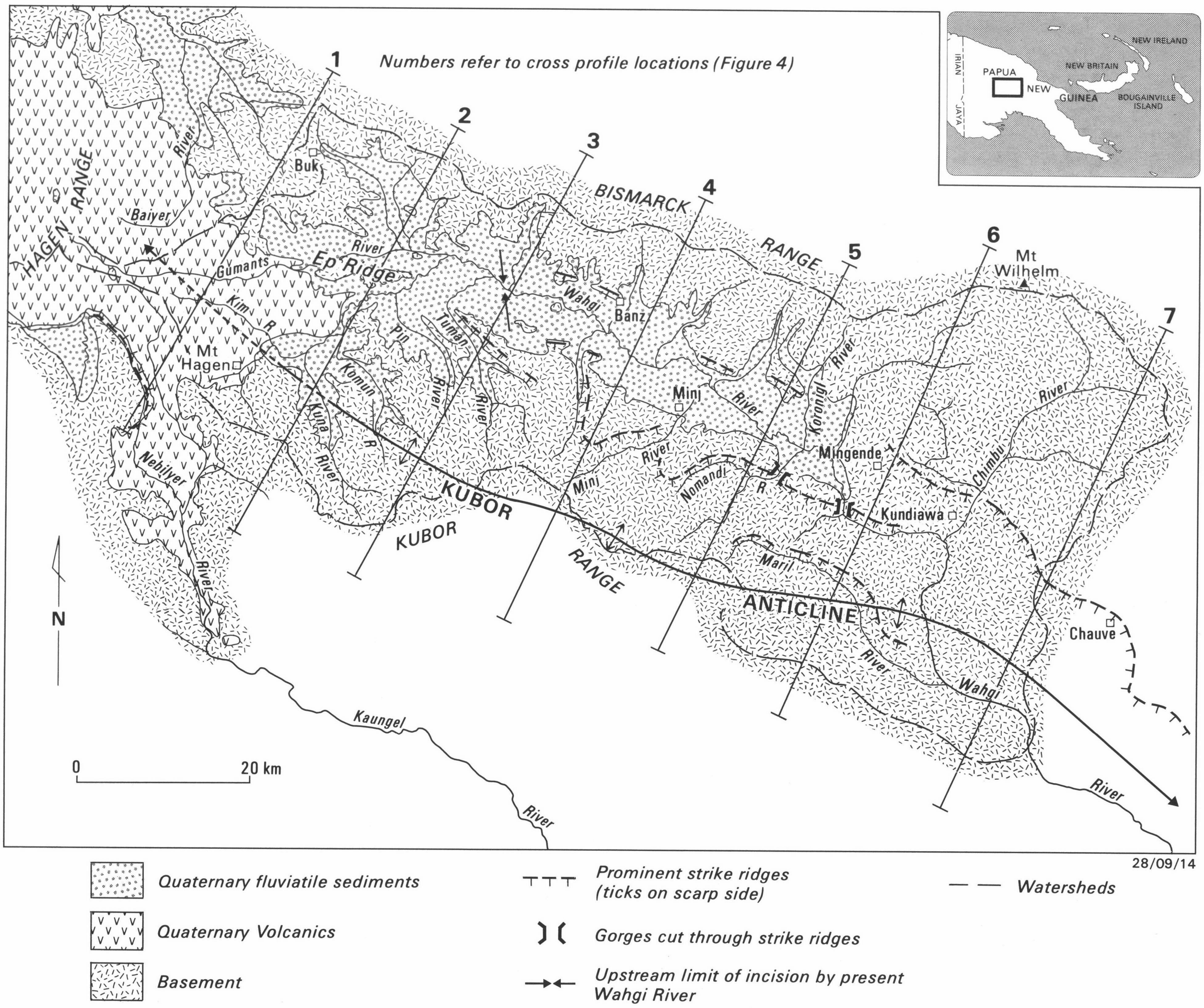

Figure 1. The Wahgi Valley, showing its location between the Bismarck Range and the Kubor Range, and some geomorphic features. Cross-section locations refer to Figure 4. For topographic details refer to Figures 4, 5, 7.

deposits. They are distinctly less weathered than the older deposits, and are a result of alluviation and subsequent down-cutting in the Wahgi River meander trench.

Qm_4 deposits consist of gravel, sand, silt, mud, and peat. In the eastern part of the Wahgi Valley they form typical flood-plain deposits, while in the west they underlie extensive swamps such as the North Wahgi Swamp (Fig. 2). Qm_4 deposits are currently being laid down in a variety of environments ranging from distributary fans, flood plains, and active meander belts to alluvial back swamps and organic-rich lakes. However, in some places Qm_4 deposits range back into the late Pleistocene. A sample of wood collected from a layer of silt, clay, and peat below 2.5 m of alluvial gravel and sand near the confluence of the Komun and Wahgi Rivers gave a radiocarbon age of $40\ 800^{+3100}_{-2200}$ years (SUA-1278). Similarly, late Pleistocene ages have been obtained from materials in the Kuk Swamp, and in the North Wahgi Swamp (Blong, 1972).

Landforms

Pigram and coworkers (personal communication), following Löffler (1977), divide the eastern part of the Wahgi Valley into six physiographic units. In this paper, their division is modified slightly to take into account the swamps and valley-fill areas in the western part of the valley. Moreover, landforms on basement rocks are not subdivided on our maps (Figs 1, 2).

Landforms on basement rocks

Landforms on basement rocks in the Wahgi Valley all fall into the general category of ridge and V-valley forms (Löffler, 1977). These landforms are generally of high relief, and have dense drainage patterns. Narrow ridges are separated from V-shaped valley floors by long straight or irregular valley side slopes. A distinctive feature of these landforms in some areas is the presence of prominent strike ridges (Figs 1, 4), formed on the sedimentary rocks that dip to the north, away from the Kubor Anticline. Where they occur south of the Wahgi River, these strike ridges have a marked effect on the direction of drainage, good examples being the Nomandi and Maril Rivers (Figs 1, 4). In most places where rivers cross these strike ridges, they do so through characteristic V-shaped gorges such as that on the Chimbu River near Kundiawa (Fig.). The Wahgi River itself leaves the Wahgi Valley and begins its gorge section by cutting through a strike ridge in Wahgi Group

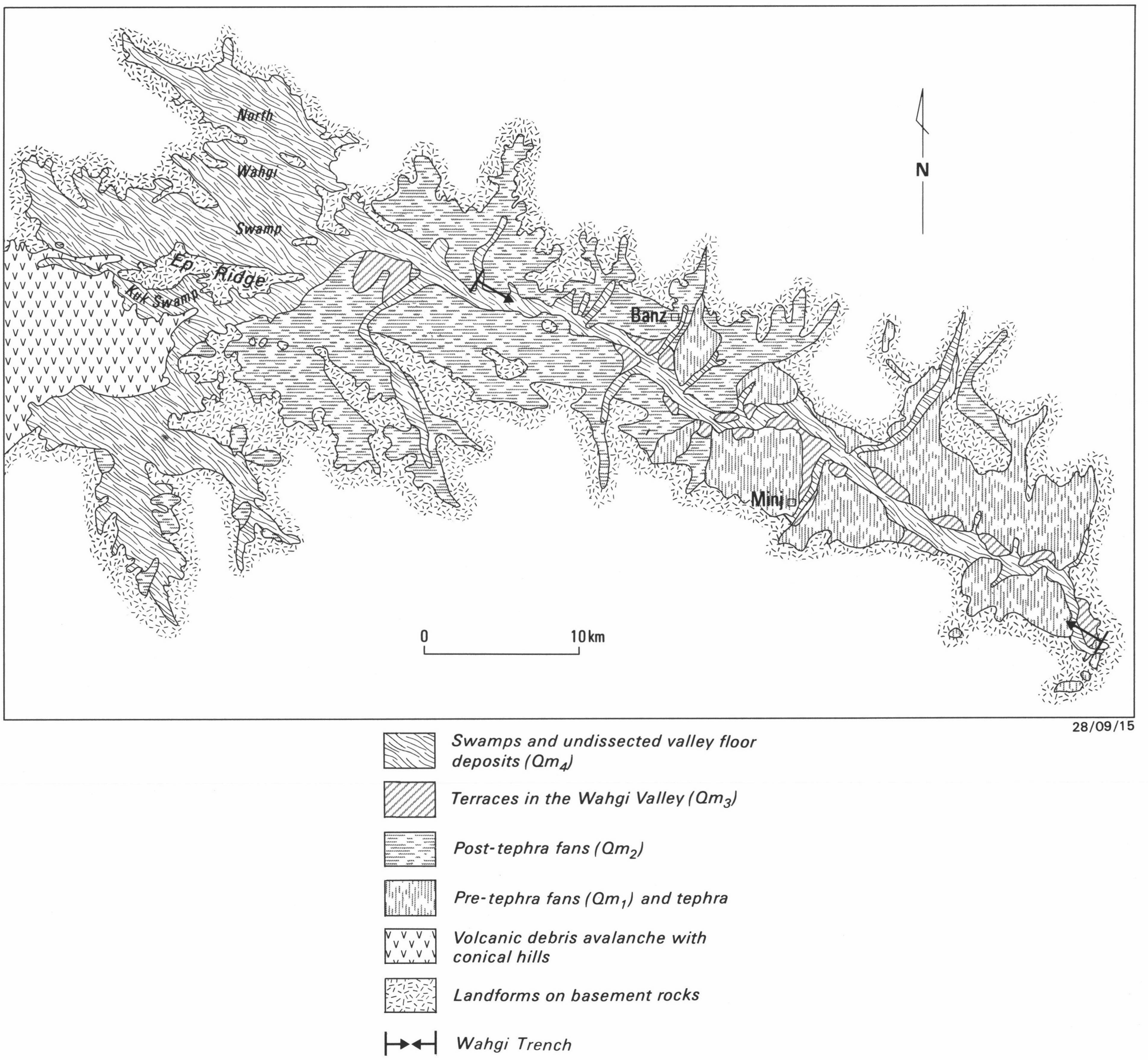

Figure 2. Landforms of the Wahgi Valley, showing the distribution of the major Quaternary landform units and their associated bodies of sediment.

rocks. In the absence of control by strike ridges, drainage patterns are generally dendritic.

Volcanic landforms

A description of the landforms of the Hagen volcanic complex can be found in Mackenzie & Johnson (1984). The upper part of the complex, which lies within the catchment of the Gumants River, a major tributary of the Wahgi River, consists of segments of smooth constructional surfaces separated by relatively shallow, steep-sided stream valleys. These surfaces fall towards a broad area of volcanic foot-slopes, which includes both the northern and southern divides of the Wahgi Valley (Figs 1, 5). The foot-slope area northwest of Mount Hagen town consists of gently sloping, generally smooth foot-slopes with streams incised only a few tens of metres. However, the eastern part of the foot-slope area is underlain by a debris avalanche with numerous low conical hills ranging up to 60 m high (Fig. 2). These hills continue beneath the Quaternary swamp and alluvial sediments of the Kuk Swamp and, probably, western portion of the North Wahgi Swamp (Blong, 1986).

Fans

Fans in the Wahgi Valley fall into two broad groups, based on their degree of dissection, and on the presence or absence of a cover of tephras (Fig. 2). The pre-tephra fan surfaces are underlain by Qm_1 deposits, while the post-tephra fans are made up of Qm_2 deposits (Fig. 3).

Table 1. Tephra units of the Papua New Guinea Highlands, and selected deposits from the Wahgi Valley.

Western (Tari-Mendi)	Central (Mendi-Minj)	Eastern (Minj-Kainantu)
	Qm_2, Qm_3, Qm_4 deposits	
Tomba Tephra	Tomba/Bune Tephras	‘upper’ tephra
	Balk Tephra	Balk Tephra
	Kiripia Tephra	‘middle’ tephra
	Kebaga Tephra	
Ambulai Tephra	Ambulai Tephra	Ambulai Tephra
	‘basal’ tephra	‘basal’ tephra
	western Qm fans	
Wanabuga Tephra	Wanabuga Tephra	Wanabuga Tephra
		eastern Qm fans
w_1	Turuk Tephra	
w_2	Togoba Tephra	
w_3		
w_4	undifferentiated ‘western’ tephras	
w_5		
	Hagen debris avalanche	

Notes: 1. Formal tephra names, where ‘tephra’ is capitalised, are from Pain & Blong (1976). ‘upper’, ‘middle’ and ‘basal’ tephras are described in Pain & Wood (1976). Other tephra units are from unpublished work by C. Pain.
2. Column headings refer to geographical location, and not to the sources listed in Pain & Blong (1979).

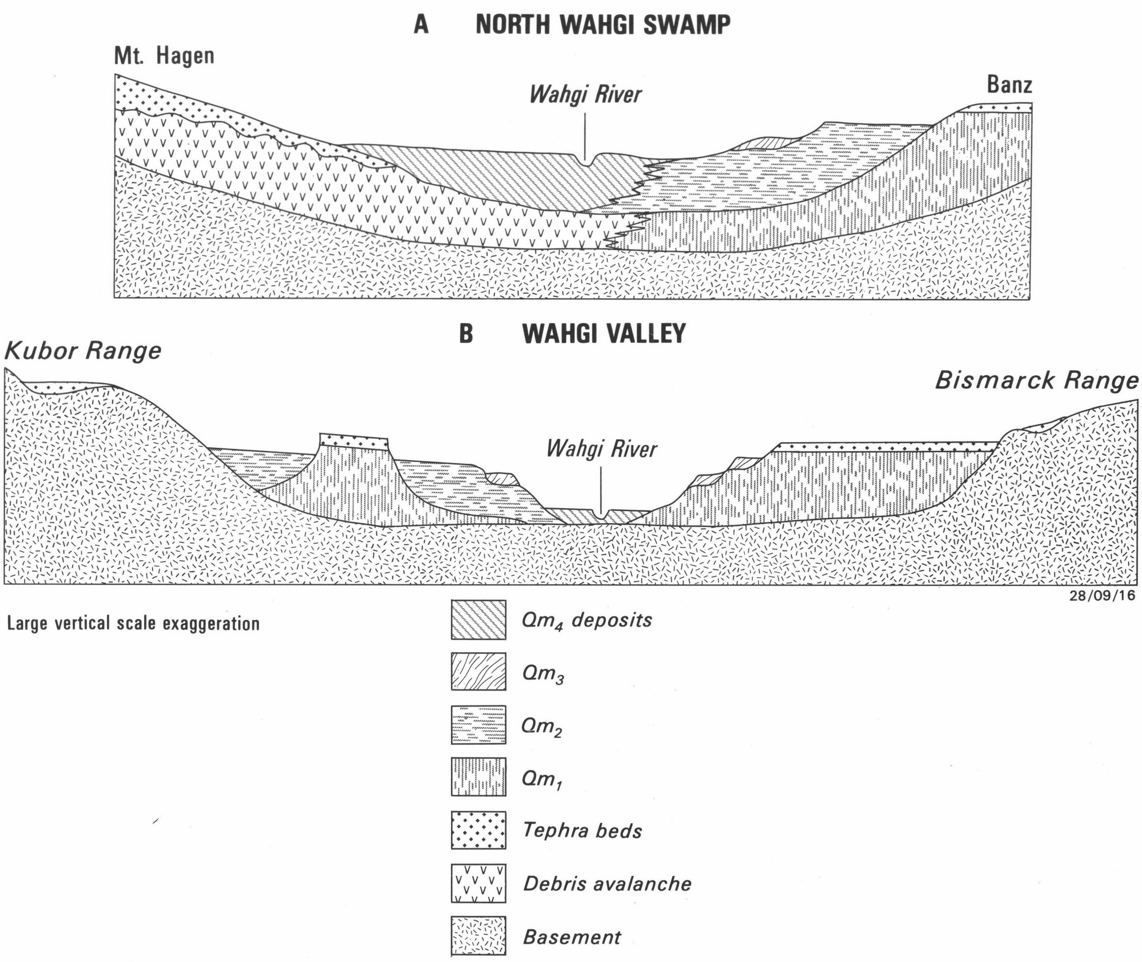

Figure 3. Schematic cross-sections across the Wahgi Valley, A—Western Wahgi Valley; B—Central Wahgi Valley.

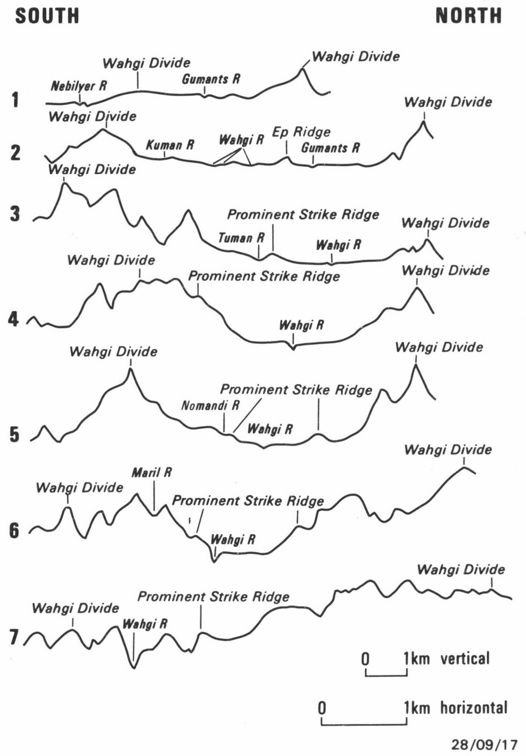

Figure 4. Cross-profiles of the Wahgi Valley, from the southern to northern divides.
See Figure 1 for cross-section locations.

The pre-tephra (Qm_1) fans are strongly dissected by closely spaced gullies and ravines. Original depositional surfaces, now covered with tephra beds, are preserved as long narrow interfluves, which coalesce towards the apices of the fans. These apices can be traced upstream into the ranges bordering the Wahgi Valley. A result of this dissection is that the original cover of tephra is preserved only on undissected parts of the fan surfaces, and is, therefore, often quite limited in extent. The oldest fans in the east are covered with Wanabuga Tephra, and, therefore, were formed before that unit was erupted (Table 1). Fans around Minj on the other hand are covered with 'basal' tephra, but not with Wanabuga Tephra, suggesting that they were formed somewhat later. This observation is supported by the degree of dissection, which increases towards the east.

The upper fan surfaces have elevations between 1560 and 1640 m, and slope gently towards the centre of the valley at angles between 1 and 3 degrees. The pre-tephra fans are the highest alluvial surfaces in the Wahgi Valley.

Post-tephra (Qm_2) fans occupy the central third of the Wahgi Valley Fig. 2). They have well-defined fan shapes, with apices high in the foothills and distal parts coalescing along the middle of the Wahgi Valley. In the west they pass beneath a thin veneer of flood-plain deposits in the meander trench. The upper surfaces of the post-tephra fans have elevations of 1520–1560 m, about 40 m lower than the surfaces of the pre-tephra fans. This difference is marked where the two sets of fans are juxtaposed, for example, west of Minj.

The absence of any tephra cover on these fans, despite the well-preserved nature of their upper surfaces, indicates that they were formed after the deposition of all the tephra units listed in Table 1. The presence of 6 tephra units and associated palaeosols emphasises the time interval between Qm_1 and Qm_2 deposits.

The Wahgi meander trench

The Wahgi Valley is incised into the toes of both pre-tephra and post-tephra fans from about 7 km downstream from the confluence of the Wahgi and Gumants Rivers (Figs 1, 2). From this point to Mingende, the trench increases in depth to 140 m. Within this incised trench, which is about 1.5 km wide, the Wahgi River flows on a flood plain that is characterised by shifting meanders and a number of meander cutoffs. Terraces are developed along the edges of the Wahgi meander trench and the lower parts of the major tributaries that join it (Fig. 2). Löffler (1977) reported two terrace levels, but, while there are usually only two or three levels, the maximum number in one place is five. Along the Wahgi River the terrace remnants are elongate to equant in shape, while along tributaries they tend to be triangular, widening downstream (Fig. 2). All terraces along the Wahgi River slope to the east, and they all postdate tephra deposition.

In some places small fans debouch from the higher fan remnants onto the floor of the meander trench, and in one place, near the eastern end of the valley, two fans constrict the Wahgi River so that there is no flood plain at all.

Swamps and undissected valley floors

The western end of the Wahgi Valley is dominated by swamps and undissected valley fills. In the southwest, the Komun and Kuna River valleys have more-or-less level valley floors, with only minor relief features resulting from flood-plain formation and shifts in the locations of the rivers that flow through them. These infilled valleys may be a result of the damming of their rivers by deposits associated with the Mount Hagen debris avalanche. The northwestern part of the Wahgi Valley consists of two major swamp basins, Kuk Swamp and North Wahgi Swamp (Fig. 2). The Gumants River drains the North Wahgi Swamp and the western part of Kuk Swamp. Undissected valley fill occupies the valleys that drain into the basins. A major bedrock ridge (Ep Ridge) forms an island between the two swamps. Deposition is continuing in the swamps and on the lower valley floors.

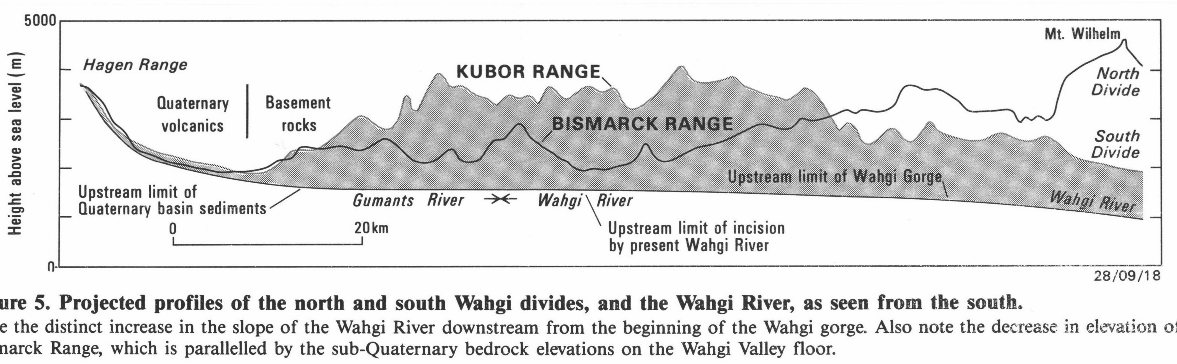

Figure 5. Projected profiles of the north and south Wahgi divides, and the Wahgi River, as seen from the south.
Note the distinct increase in the slope of the Wahgi River downstream from the beginning of the Wahgi gorge. Also note the decrease in elevation of the Bismarck Range, which is parallelled by the sub-Quaternary bedrock elevations on the Wahgi Valley floor.

Minor post-tephra fans (Qm_2, Qm_4) occupy re-entrants in the valley sides.

Geomorphic history of the Wahgi Valley

Earlier attempts to outline the history of the Wahgi Valley have centred on the theme of drainage reversal. We also concentrate on the development of drainage in the area, and consider the other aspects of the geomorphic history of the area in this context.

Various arguments have been used to support the idea of drainage reversal in the Wahgi Valley. The following points come from either Haantjens (1970) or Löffler (1977), and cover those made by other authors:
1. Bedrock elevations below the Quaternary sediments in the valley generally decrease to the west.
2. Valley width increases westwards.
3. Degree and depth of entrenchment and incision decrease westwards.
4. There is a significant westwards decrease in the relative height of fans above the Wahgi River.
5. The deep gorge in Tertiary rocks through which the Wahgi River flows in the east contrasts with the west, where no such obstacle existed in pre-volcanic times.

Two features, the nature of the pre-volcanic landsurface and the Quaternary deposits filling the Wahgi Valley, and their relative ages, provide evidence relating to the theme of drainage reversal.

The pre-volcanic landsurface

A reconstruction of the distribution of land and sea at various times during the Tertiary, such as that carried out by Dow (1977), shows that the Kubor Range became land in the Eocene, and the area that is now the Wahgi Valley has been land since at least the early Oligocene (Fig. 6). Thus, the landscape and drainage system go back at least 35 Ma.

The Wahgi Valley had its origin in the uplift of the northern flank of the Kubor Anticline — for the most part it is a strike-aligned structural depression between the anticline and the Bismarck Fault Zone.

This structural trench is widest in the west, extending eastwards as far as Chuave (Fig. 1), where it becomes narrower. However, serial cross-sections (Fig. 7) show that the valley has been enlarged by erosional removal of northward-dipping sedimentary rocks on the northern flank of the Kubor Anticline. While Wahgi Group rocks crop out throughout (Fig. 8), Cretaceous upper Wahgi Group rocks, the most erodible rocks in the area (Blong & Pain, 1978), are confined to the eastern part of the catchment. In the west, for the most part, basement rocks are more resistant. Thus, river incision could be more easily achieved in the east than in the west (cf. point 5 above). Bedrock slopes (Fig. 5) and westward widening of the Wahgi Valley are suggestive, but not definitive, evidence of a pre-volcanic, westerly flowing Wahgi River.

At least part of the area now covered by the Hagen Volcanics was a topographic high in pre-volcanic times (cf. point 5 above). Inliers of the Cretaceous upper Wahgi Group occur within the area of volcanics; one of these is located high on the Hagen Range, at an altitude of 2700 m (Fig. 1). Hagen Volcanics overlie Upper Jurassic Maril Shale in the Baiyer River gorge above the Baiyer River basin at about 1600 m altitude. The Nebilyer River, to the south, flows on Hagen Volcanics all the way to its confluence with the Kaugel River at 1000 m (Fig. 1). Due west of Mount Hagen town the bed level of the Nebilyer is about 1640 m.

These observations indicate that deep pre-volcanic valleys were connected to both the Baiyer and Nebilyer Rivers, but they do not demonstrate that the Wahgi Valley drained into either.

North of a line joining Ep Ridge and the strike ridge north-east of the Tuman River (Fig. 1) the plan shape of the Wahgi River and its tributaries (and the angles at which they join) is consistent with an easterly flowing drainage network. South of this line, the tributary rivers, including the Tuman, all flow westwards before turning to join the Wahgi, and are thus more consistent with a westerly flowing drainage system. As these differences seem to be unrelated to structural or lithological controls, they perhaps suggest an early drainage divide, as indicated on Figure 8.

Quaternary deposits and landforms

The pre-tephra fans originated from both sides of the valley and coalesced across it. Despite Löffler's (1977) observation that their relative height decreases to the west (point 4 above), the fans do not provide evidence for direction of river flow. The problem here is twofold. First, since the fans slope towards the river, where should elevations be measured?

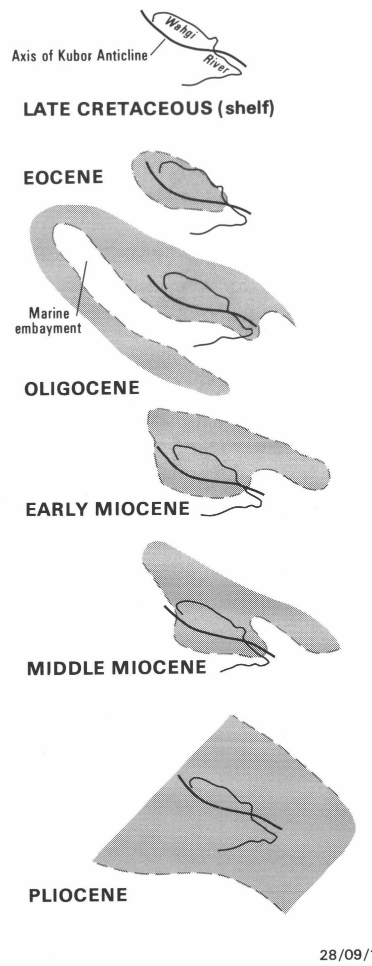

Figure 6. Reconstructions of the distribution of land and sea during the Tertiary in the Kubor Anticline/Wahgi Valley area (after Dow, 1977).
Note that the Kubor Anticline was emergent in the Eocene, and that by the Oligocene the Wahgi Valley area was also land.

Second, active fan deposition is controlled at the apex, not the toe, and therefore is not related to the altitude of the river (cf. point 4 above). If the fan toes did not reach the river, the river would have been unaffected. If the fan toes did reach the river, they would have blocked it, causing lakes to form, perhaps temporarily.

The relative ages of the Quaternary volcanic and sedimentary landforms provide some information about the sequence of events that occurred in the Wahgi Valley in the late Cainozoic. The volcanic footslopes and lahar surfaces range considerably in age. Lavas lying below lahar deposits at Togoba have a K/Ar age of about 200 000 years (Löffler & others, 1980). On the other hand, a shallow trench near the modern course of the Kim River (Fig. 1) contains lahar deposits that are directly overlain by Tomba Tephra, and are thus much younger. However, palaeosol on the main debris avalanche deposit is covered with at least some of the 'western' tephras, which indicates that the avalanche was emplaced at least as early as the early part of the tephra deposition (Table 1). Blong (1986) argues that the absence of an evident source area on Mount Hagen for the avalanche deposit, which has a minimum volume of 3.2 km^3, suggests that the avalanche occurred before the late cone-building phase. This indicates an age of at least 210 000 years and, possibly, as much as 400 000 years. The avalanche and lahar deposits would, by virtue of their volume and location, have been capable of blocking and reversing drainage directions in the western Wahgi Valley. However, there is no direct evidence that drainage ever flowed westwards.

The above consideration of the ages of avalanche and lahar deposits from Mount Hagen shows clearly that any blockage of the western end of the Wahgi Valley must have occurred before (perhaps considerably before) the pre-tephra fans finished forming in the eastern part of the valley (Table 1).

Quaternary lake deposits occur in several parts of the Wahgi Valley. In the west, lake and swamp sediments lie at various levels below the North Wahgi Swamp (Blong, 1972), but the presence of a large continuous lake cannot be demonstrated. However, boreholes have been drilled to a maximum depth of only 35 m; the total thickness of sediments in the basin is unknown, but is probably the order of several hundred metres.

Qm_1 lake beds are exposed in road cuttings at the eastern end of the valley up to 40 m above the present Wahgi River, whereas fan sediments occur at least 160 m higher. The sequence indicates a history of fan deposition into a lake followed by further fan building after the lake was completely filled. The presence of peats in the sequence suggests that swamps may have occupied low-lying areas at some time. Thus, the eastern end of the Wahgi Valley has a modern analog in the western end, where lake, swamp, and fan sediments are interbedded and the area is still occupied by extensive swamps.

The systematic decrease in fan dissection and age towards the west suggests that the Wahgi River began trenching the fans from the east, beginning in pre-Wanabuga Tephra times. As the toe of each fan was trenched, deposition on the fan surface ceased, and fan dissection began, Thus, while trenching and dissection were taking place in the east, fan building was continuing in the middle part of the valley, leading to the formation of the pre-'basal' tephra fans, which were then in turn trenched by the Wahgi River. Major fan building in the west did not cease until after the Tomba Tephra was deposited. The trenching represents the retreat of a knickpoint from the upper end of the Wahgi gorge to the upstream limit of the meander trench during this time.

Unfortunately, there are no direct dates on the tephras or the fan deposits. Löffler (1977) considered that the fans are considerably older than the age of the youngest Hagen lavas, dated about 200 000 years. However, it can now be demonstrated that the tephras are younger than this, because they overlie both volcanic breccias and lahar deposits, which in turn overlie the dated lavas. Wanabuga Tephra, the oldest tephra found on Qm_1 fan surfaces, could be quite a lot younger than 200 000 years, because it lies in about the middle of the sequence of tephras that overlies the dated lavas. As already pointed out, Tomba Tephra is older than 50 000 years. Given these ages, it is clear that the Qm_1 fans in the middle and eastern Wahgi Valley fall in the age range 200 000–50 000 years, while the Qm_4 fans are younger than 50 000 years. Qm_2 fans are still being formed, mainly in the western part of the valley.

Drainage reorganisation

The evidence for drainage reorganisation in the Wahgi Valley is equivocal on several points, and provides support for at least two hypotheses. The two hypotheses differ mainly in the location of the drainage divide before reversal of flow took place.

The generally accepted view has been that the gorge through the strike ridge southwest of Mingende is the location of river capture from the east, and that the previous divide would have been between the Chimbu and Maril Rivers, and the Wahgi River (Figs 1, 8). The Wahgi Valley was dammed in the west by Hagen volcanics, causing a lake to flood the entire

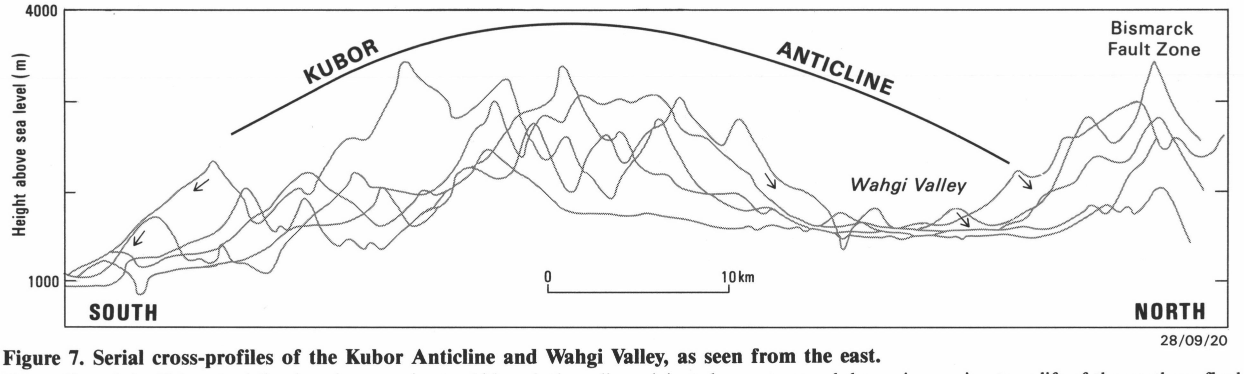

Figure 7. Serial cross-profiles of the Kubor Anticline and Wahgi Valley, as seen from the east.
The outline of the Kubor Anticline is only approximate. Although the valley originated as a structural depression, owing to uplift of the northern flank of the Kubor Anticline by the Bismarck Fault Zone, dip slopes (arrowed) on the north side of the valley show that the Wahgi Valley has been enlarged by erosion of the northern limb of the anticline.

valley and then overtop in the east, leading to river capture (Bain & others, 1975). Haantjens (1970) suggested that river capture may have taken place before blocking in the west, as a result of active knickpoint retreat related to the rejuvenation of the gorge downstream from the present-day Wahgi-Chimbu confluence. Whichever the case, the development of the fans and the deposition of lake and swamp beds must all have taken place either in a lake-filled valley or in a valley with an easterly flowing river.

An alternative, and in some ways simpler, hypothesis is that most of the Wahgi Valley always drained to the east. The previous divide in this case would have passed through Ep Ridge (Fig. 8). Inliers of basement north and east of Ep Ridge suggest that basement is not far below Quaternary sediments in this part of the valley. The debris avalanche from the Hagen volcano diverted the Kuna, Komun, Pin, and Tuman Rivers into the Wahgi River. The Kuna and Komun Rivers may have been completely blocked for some time before the present upper Wahgi River cut a channel between the deposit and basement rocks (Fig. 1). The plan form of these four rivers, structural trends, and the distribution of basement rocks west and south of Mount Hagen town are all consistent with former drainage into the Baiyer River rather than the Nebilyer River.

Following these events, fan formation began in the east, in the process damming the Wahgi River for sufficient periods to allow the the deposition of lake beds and swamp deposits. The location of this depositional activity appears to have shifted westward with time, but this may be an artefact of the trenching pattern, which has occurred from the east.

Extrapolating the slopes of the Koronigl and Nomandi fans to the centre of the valley at its eastern end (Fig. 1) suggests that they met at an altitude of about 1550 m. This altitude places an upper limit on the level of any lake, or lakes, that may have occupied the valley. Perhaps, coincidentally, this is about the level of the lower parts of the North Wahgi Swamp at the present time, and may explain the presence of the swamp. This contrasts with the first hypothesis, which implies a much higher lake level, perhaps shortlived, before overtopping occurred at the eastern end.

Largely for reasons of simplicity, then, the second hypothesis seems more likely. However, whichever hypothesis is preferred, a necessary implication is that much of the activity took place at a time when the valley was adjusted to a higher base level than at present. This is not to say that the area has been uplifted in the last 200 000 years. All that is required is that a knickpoint, or knickpoints, reached the area slightly earlier than the deposition of Wanabuga Tephra, thus initiating the

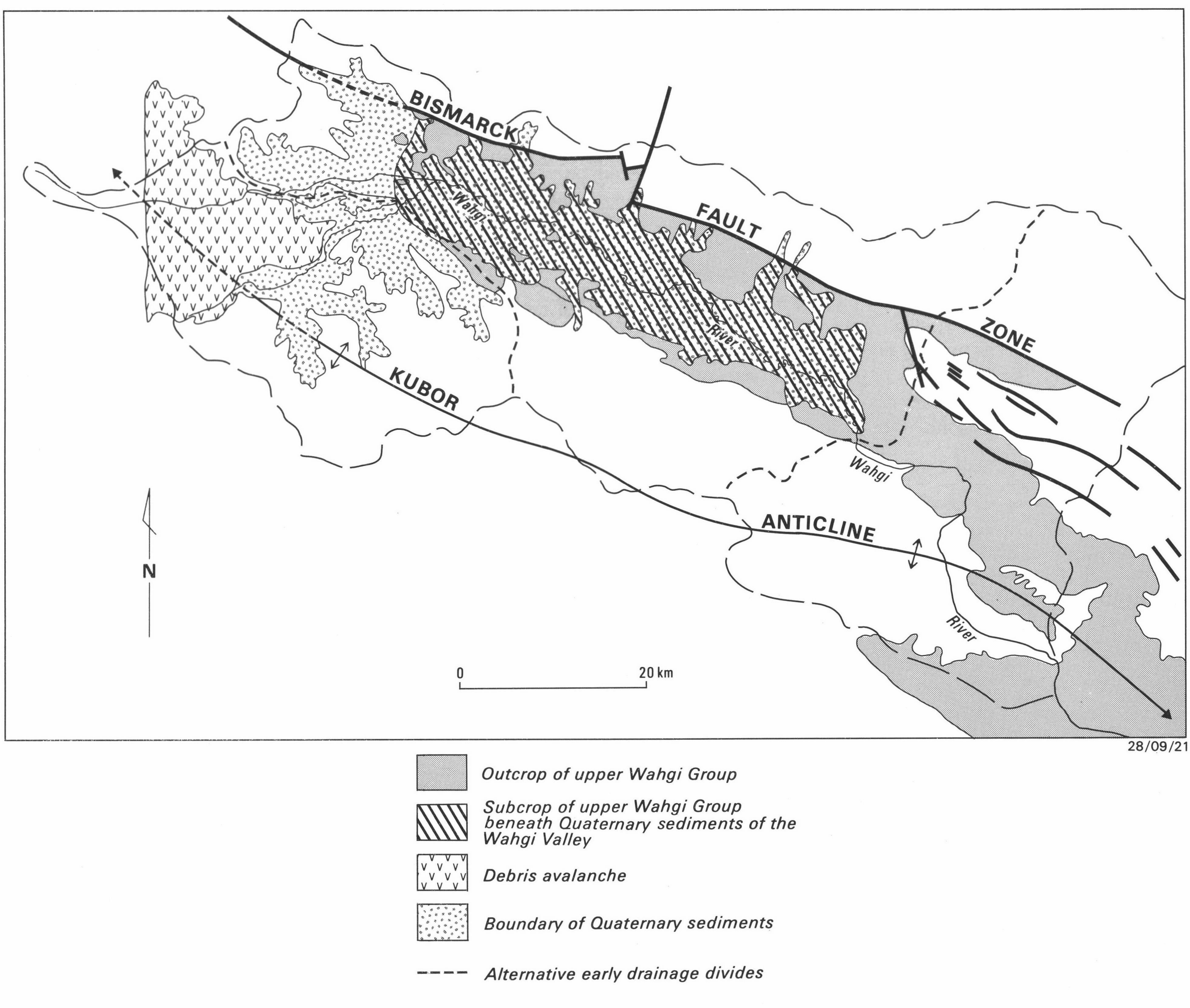

Figure 8. The Wahgi Valley, showing the area of outcrop of Cretaceous upper Wahgi Group rocks within the valley, and the two alternative divides between easterly and westerly flowing drainage before the western end of the valley was blocked by lahars and agglomerates from the Hagen volcanoes.

See the section on **Drainage reorganisation** for further explanation of the divides. The distribution of the upper Wahgi Group is taken from Bain & others (1975).

cutting of the Wahgi meander trench. Once this had happened, trenching led to the cessation of fan deposition from the east, as outlined above.

Summary

The relevant points about landform and drainage changes in the Wahgi Valley may be summarised as follows:

1. The Wahgi Valley has its origins as a tectonic depression between the Kubor Anticline and the Bismarck Fault Zone, and results from uplift of the northern limb of the anticline on the Bismarck Fault Zone. However, part of its present form is a result of erosion of sedimentary rocks dipping northward from the Kubor Anticline.

2. Drainage patterns and directions on basement rocks may have originated as long ago as 35 Ma.

3. The eruptions from the Mount Hagen volcano, and any associated blocking of the western end of the Wahgi Valley, took place well before the deposition of most of the Quaternary sediments in the valley. The massive debris avalanche that may have created the blockage occurred at least 80 000-100 000 years ago and, possibly, 400 000 years ago.

4. The formation of fans at the eastern end of the Wahgi Valley took place over a considerable time, during which any drainage of the valley must have been to the east.

5. Trenching of the fans took place from the east as the Wahgi River began to incise its bed. This probably happened as a result of up-valley migration of a knickpoint from outside the study area.

6. The location of the divide between easterly and westerly flowing rivers, before blocking took place in the west, is not clear from the available evidence. It may have been in the east, in which case the entire Wahgi River above Mingende has been reversed. Alternatively, Ep Ridge may mark the previous divide, and only the upper, or southwest, part of the Wahgi Valley has undergone a drainage reversal. This second alternative seems more likely.

Acknowledgements

Funding for fieldwork by CFP was provided initially by the Australian National University, and then the University of Papua New Guinea. Fieldwork by CJP and GOA was carried out while they were employed by the Geological Survey of Papua New Guinea. Fieldwork by RJB was supported by the Wahgi Project (Prof. J. Golson, Australian National University), The Myer Foundation, and Macquarie University. Borehole information has been kindly provided by Wilton & Bell, Dobbie & Partners, and Vallentine, Laurie & Davies, engineering consultants of Sydney. Figures were drafted by Kathy Ambrose.

References

Bain, J.H.C., Mackenzie, D.E. & Ryburn, R.J., 1975—Geology of the Kubor Anticline, central highlands of Papua New Guinea. *Bureau of Mineral Resources, Australia, Bulletin*, 155.

Bik, M.J.J., 1967—Structural geomorphology and morphoclimatic zonation in the central highlands, Australian New Guinea. *In* Jennings, J.N., & Mabbutt, J.A., (editors), Landform studies from Australia and New Guinea, *Australian National University Press, Canberra*, 26-47.

Blong, R.J., 1972—A report on the geomorphology and Quaternary history of the Gumants Basin and surrounding areas, Western Highlands District, Territory of Papua New Guinea. *Geological Survey of Papua New Guinea Data File* 20 DU.

Blong, R.J., 1986—Pleistocene volcanic debris avalanche from Mount Hagen, Papua New Guinea. *Australian Journal of Earth Sciences*, 33, 287-294.

Blong, R.J. & Pain, C.F., 1976—The nature of highlands valleys, central Papua New Guinea. *Erdkunde*, 30, 212-217.

Blong, R.J., & Pain, C.F., 1978—Slope stability and tephra mantles in the Papua New Guinea highlands. *Geotechnique*, 28(2), 206-210.

Dow, D.B., 1977—A geological synthesis of Papua New Guinea. *Bureau of Mineral Resources Australia, Bulletin*, 201.

Haantjens, H.A., 1970—Outline of the geologic and geomorphic history of the Goroka-Mount Hagen area. *In* Lands of the Goroka-Mount area, Territory of Papua New Guinea. *CSIRO Land Research Series*, 27, 19-23.

Leahy, M., 1936—The Central Highlands of New Guinea. *Geographical Journal* 87, 229-262.

Löffler, E., 1977—Geomorphology of Papua New Guinea. *Australian National University Press, Canberra.*

Löffler, E., Mackenzie, D.E. & Webb, A.W., 1980—Potassium-argon ages from some of the Papua New Guinea highlands volcanoes, and this relevance to Pleistocene geomorphic history. *Journal of the Geological Society of Australia*, 26, 387-397.

Mackenzie, D.E. & Johnson, R.W., 1984—Pleistocene volcanoes of the western Papua New Guinea highlands: morphology, geology, petrography, modal and chemical analyses. *Bureau of Mineral Resources, Australia, Report*, 246.

Pain, C.F. & Wood, A.W., 1976—Tephra beds and soils in the Nordugl-Chuave area, Western Highlands and Chimbu Provinces, Papua New Guinea. *Science in New Guinea*, 4, 153-164.

Pain, C.F., 1978—Landform inheritance in the central highlands of Papua New Guinea. *In* Davies, J.C., & Williams, M.A.J., (editor), Landform evolution in Australasia. *Australian National University Press, Canberra*. 48-69.

Pain, C.F. & Blong, R.J., 1976—Late Quaternary tephras around Mount Hagen and Mount Giluwe, Papua New Guinea. *In* Johnson, R.W.,(editor), Volcanism in Australasia. *Elsevier, Amsterdam*. 239-251.

Pigram, C.J. & Panggabean, H., 1984—Rifting of the northern margin of the Australian continent and the origin of some microcontinents in eastern Indonesia. *Tectonophysics*, 107, 331-353.

Rickwood, F.K., 1955—The geology of the western highlands of New Guinea. *Journal of the Geological Society of Australia*, 2, 64-82.