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S. WARREN CAREY: NEW GUINEA OIL EXPLORER (1934–1942)

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(with one text-figure, eight plates and one table)

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Samuel Warren Carey (1911–2002), Professor of Geology at the University of Tasmania from 1946 until 1976, was recognised internationally as a controversial extrovert in global tectonics. He joined Oil Search Ltd, and then the Australasian Petroleum Company working as a field geologist in New Guinea from 1934 until 1942. Carey and his colleagues carried out a heroic campaign of geology-based field exploration under the most difficult of conditions. Although their work did not find commercial hydrocarbons it paved the way for PNG's current hydrocarbon industry. While his post-World War Two work is well documented through his publications and the reminiscences of those who worked with and were taught by him, his pioneering work as an explorer in the inhospitable environment of New Guinea before he took up his post in Tasmania is less well known and the subject of this paper.
Key Words: S. Warren Carey, pre-WW2, geology, exploration, New Guinea, Oil Search Ltd, Australasian Petroleum Company.

INTRODUCTION

S. Warren Carey (1911–2002), Professor of Geology at the University of Tasmania from 1946 until his retirement in 1976, was internationally acknowledged as a controversial extrovert in global tectonics who vigorously expounded and defended his belief in Earth expansion (Quilty & Banks 2003).

An early believer of continental drift, many of his ideas were developed and matured as a result of fieldwork carried out in the (then) Territory of New Guinea and the Mandated Territory of Papua in the decade preceding World War Two (WW2). He was a geologist with Oil Search Ltd from 1934 to 1938 and subsequently a senior geologist with the Australian Petroleum Company (APC) from 1938 until the intervention of war in 1942. A photo of Carey, taken in New Guinea around 1936 is shown in plate 1.

While his post-WW2 work is well documented through his publications and the reminiscences of those who worked with and were taught by him, his pioneering work as an explorer in the inhospitable environment of New Guinea is less well known. The purpose of this paper is to detail Carey's New Guinea work to better understand both its influence on his own thinking and in the context of New Guinea geology.

Many of the pre-WW2 geographic names used by Carey and his colleagues are no longer in use and their modern names have been adopted in this paper. The Imperial system of measures is sometimes retained as it was the system in use at the times under discussion.

NEW GUINEA PERSPECTIVE

The geography of the large bird-shaped island of New Guinea (see fig. 1) is diverse and dominated by rugged mountains, rainforests and river systems. A spine of mountains, the New Guinea Highlands, runs the length of the island, rises to over 4000 m with glaciers present in the highest areas (Lorenz National Park in the Indonesian Province of West Papua). Since the seventeenth century, the western part of the island had been part of the Dutch East Indies while after World War One (WW1) the eastern part comprised the northern

PLATE 1 – S.W. Carey about 25 years of age; New Guinea, circa 1936. The photo, without attribution, is from Carey's 1936 thesis. The identification was confirmed by his daughter Robyn to the late Max Banks.

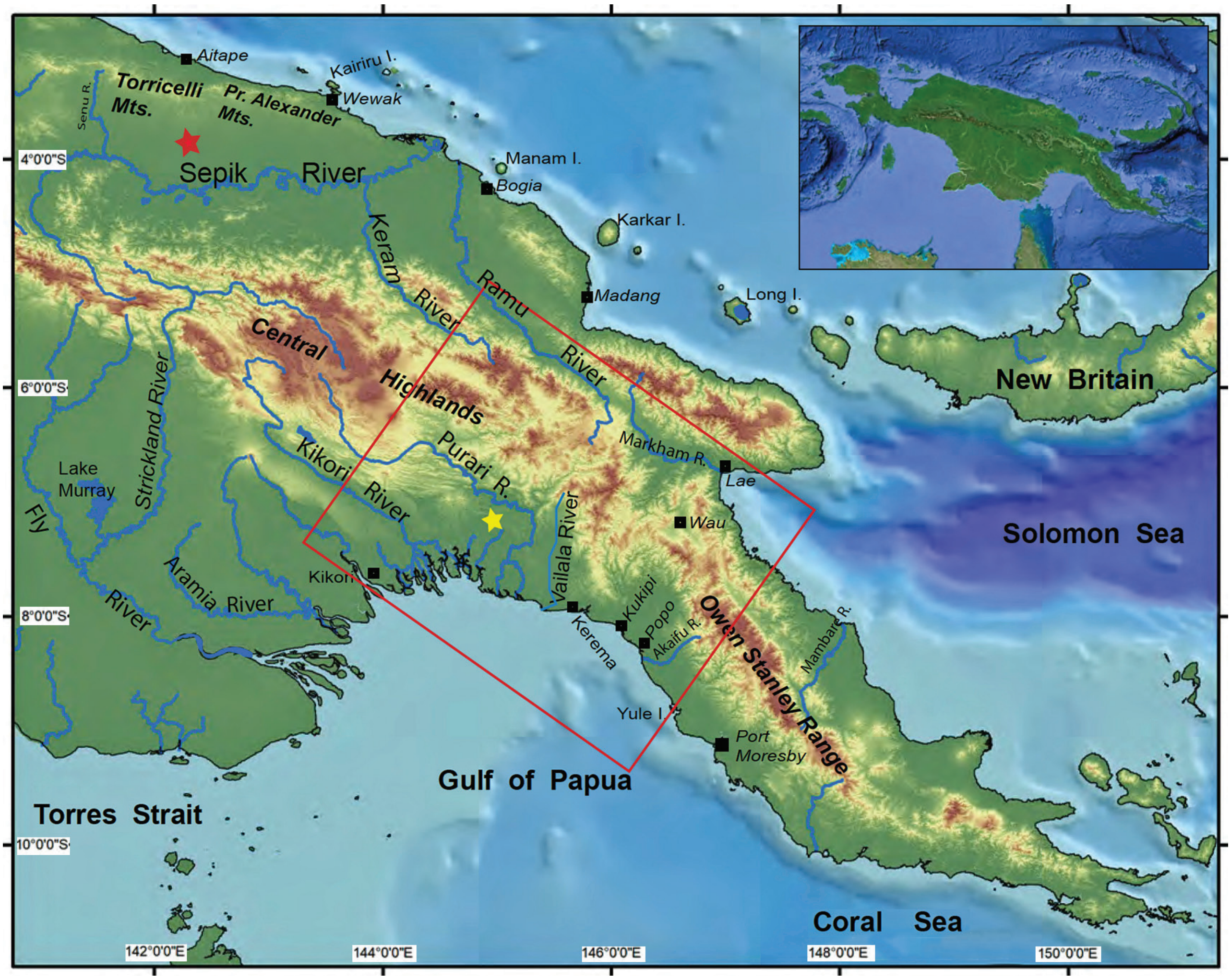

FIGURE 1 – Locality map of eastern New Guinea; red star near Sepik River approximate position of the Maimai Dome; yellow star south of Puari River approximate position of the Puri Anticline. Approximate position of Plate 7 indicated by red rectangle. Inset from Google Earth showing whole island of New Guinea.

Mandated Territory of New Guinea (prior to WW1 a German colony; mandated to the British Government, on behalf of Australia, by the League of Nations in 1920) and the Territory of Papua (ceded from the British to Australia in 1906 (plate 2). The territories were united in 1949 becoming self-governing in 1975 as the sovereign nation of Papua New Guinea (PNG).

Although all the climatic regions of New Guinea are basically tropical, climate is variable. In general, eastern New Guinea has a wet, warm-to-hot humid climate with two seasons governed by prevailing wind direction:

- a drier season from May to October with northwesterly winds
- a wet season from November to April when over five metres of rain might fall.

All early exploration was hampered by the mountainous terrain, dense (often impenetrable) vegetation and rugged topography (broad valleys bounded by steep jungle-clad mountains characterise the Central, Western and some of the Southern Highlands). Early surveys were conducted in areas that were unexplored, unmapped and populated by people who had never been in contact with the outside world and were often at war with their neighbours (e.g., Wade 1927, Rickwood 1990, 1992). Survey parties faced problems caused by isolation, the prevalence of tropical diseases such as malaria, dysentery and scrub typhus (quinine was the only treatment for malaria and there was virtually no cure for dysentery or scrub typhus), the hostile climate with its annual periods of high rainfall (and consequent high flow in the rivers), thunderstorms and cyclones, and the discomforts due to a bewildering assortment of insects, leeches and other unpleasant creatures. Persons who undertook such work required exceptional physical and mental qualities.

EXPLORATION SUMMARY TO WW2

Little effort was made to understand the geology of New Guinea until the end of the nineteenth century – unsurprising given the logistical difficulties. Joseph Beete Jukes (after whom Mt Jukes in the West Coast Range of Tasmania is named), naturalist and geologist on the surveying expeditions to New Guinea of HMS *Fly* said:

> *I know of no part of the world, the exploration of which is so flattering to the imagination, so likely to be*

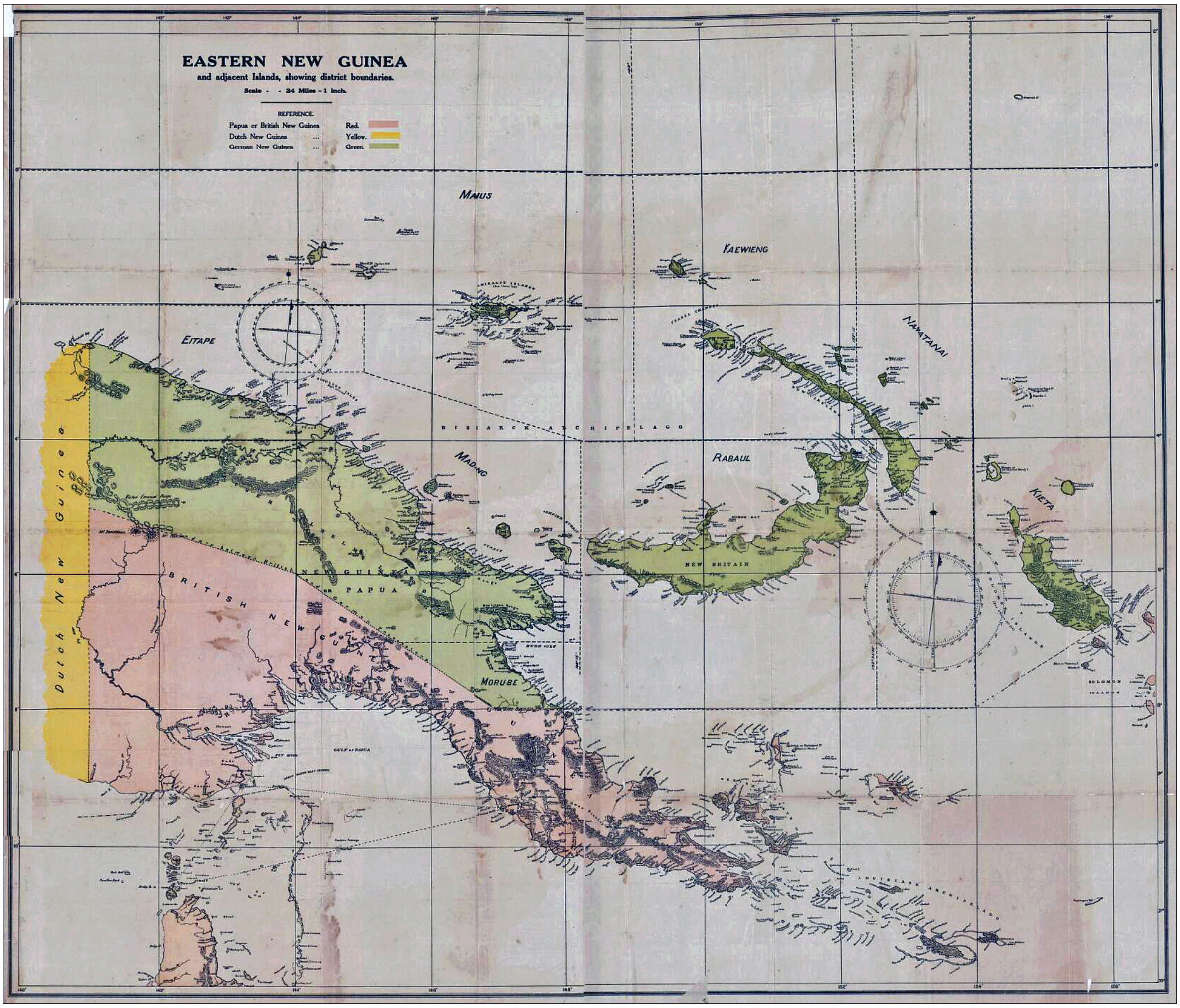

PLATE 2 – 1924 Map by E.R. Stanley of Eastern New Guinea showing post-WW1 district boundaries; Mandated Territory of New Guinea (green), Territory of Papua (pink), Dutch New Guinea (now Indonesia) (yellow); accessed from https://nla.gov.au/nla.obj-1992750272/view. Territories of New Guinea and Papua now the sovereign nation of Papua New Guinea (PNG).

> *fruitful in interesting results, whether to the naturalist, the ethnologist, or the geographer, and altogether so well calculated to gratify the enlightened curiosity of an adventurous explorer, as the interior of New Guinea.* (Jukes 1847, vol. 1 p. 291)

Limited geological and palaeontological work was carried out in German New Guinea prior to WW1. In Papua, the first recorded geological observations were made around Port Moresby by Sir William MacGregor in 1893 who ascended the Purari River (fig. 1) by launch, collected some Cretaceous belemnites and noted the occurrence of coal which subsequently became the target for limited exploration (Carey 1941).

Oil exploration commenced in 1911 when gold prospectors reported an oil seep ('kerosene on a small creek') in the Vailala River (fig. 1). Local inhabitants of the district had long known of the small mud volcanoes and bubbling pools, but since they regarded them as being due to the agencies of evil spirits, they not only avoided the localities but were loath to give any information concerning them (Wade 1927, Pratt 2000).

Evan R. Stanley was appointed the first Government Geologist for Papua in April 1912 and visited gas seepages near the Purari River (fig. 1) in May 1912. He commenced systematic surveys of the interior, examined many parts of the country east of the Purari River, produced a sketch map in 1913 at one inch to the mile (1:63,360) showing the location of many seeps he had visited, and published the first geological map of Papua in 1924 (Rickwood 1990, https://nla.gov.au/nla.obj-2057713415/view).

Exploration (including drilling and geological mapping) in Papua prior to WW1 was carried out by the Australian Commonwealth Government under the direction of Dr Arthur Wade. In 1918 a limited agreement was made with the British Government to share the expenses of further work, and the Anglo-Persian Company (which eventually became British Petroleum BP) was put in control of the combined effort, the results of which were published in 1928.

Exploration was undertaken by private companies from July 1923 onwards with limited geological and geophysical reconnaissance surveys by several groups. In a report in the *Sydney Morning Herald* 25 April 1931 (p. 10), pre-eminent Australian geologist Professor Sir T.W. Edgeworth David (Professor Carey had a large photo of his former teacher and mentor Edgeworth David in his office at the University of Tasmania) noted the difficulties and high cost of exploration in New Guinea and thought that geophysical methods would be required together with 'careful' geological survey over a period of 'some years' to find payable oil fields. Largely because of the reports by Anglo-Persian, Oil Search Limited was incorporated in Port Moresby on 17 January 1929 having previously carried out exploration in Queensland. Shortly after its incorporation, the company acquired Oriomo Oil Company, which had drilled 16 shallow wells in Papua between 1927 and 1928 (Rickwood 1990, www.oilsearch.com). The company showed tremendous resilience, faith and patience – it received its first production revenues in 1992, 63 years after its incorporation (https://www.oilsearch.com/who-we-are/history).

The company acquired additional permit areas (Papua Permits 5 and 7) and expanded its geological staff through the 1930s. It continued to do extensive fieldwork, with Carey arriving in 1934; other Oil Search Ltd team members included E. Edwards, H.A.J. Fryer, J. McKinnon, J.N. Montgomery, J.C. Pratt and G.A.V. Stanley (McCarthy 1963, Rickwood 1992). McCarthy (1963, p.150) said of Montgomery:

> *The field manager and leader of all the field parties was a distinguished, hard-working geologist named Montgomery, one of the most vigorous men, physically and mentally, that I have met despite his size of no more than five feet. He was a first-class oil man and demanded that his staff should be of equal calibre.*

In 1936 the conditions under which prospecting for petroleum could be done in Papua and New Guinea were made more liberal and as a result, exploration activities greatly increased (Nye & Fisher 1954). In 1938 further ordinances were passed promulgating a modern petroleum code similar to those of Great Britain and New Zealand (Rickwood 1990). Permits held by Oil Search, Stanvac (Standard Vacuum New Jersey, a joint venture of Standard of New Jersey and Socony-Vacuum in the Far East, now ExxonMobil) and the Anglo-Persian Oil Company (now BP) were pooled in 1938 and operated by the Australasian Petroleum Company (APC); Oil Search Ltd staff were seconded to APC (Rickwood 1990, Pratt 2000).

In 1938 the first major aerial photographic survey was carried out, primarily to elucidate the broad geologic features. In this area of high rainfall and low cloud there was an average of only 18 minutes of effective flying time per day (Rickwood 1992). Topographic maps at scales of 1:40,000, 1:100,000 and 1:250,000 were produced over an area of 28,000 square miles (72,000 km^2). The new maps had a dramatic effect on the progress of mapping in the field, and subsequent surveys carried out, including those by Carey of the Purari and Vailala area of Papua, are classic references and facilitated progress in geological understanding (Rickwood 1992). In 1939 a palaeontological laboratory was set up in Port Moresby under the direction of Dr Martin F. Glaessner, who had come from Anglo-Persian. Glaessner's work made possible the zonation of the Cenozoic and correlation of Papuan stratigraphy with the Dutch East Indies (Rickwood 1992).

As a result of its investigations the Australasian Petroleum Company selected its first site for a deep test at Kariava on the Vailala River (fig. 1): an anticline had been identified from air photographs and confirmed by field geology (Rickwood 1990). Drilling operations were suspended on 10 January 1942, because of the Japanese offensive in New Guinea, when the well had reached a depth of 5117 feet. Drilling was resumed in March 1946, and the well was finally abandoned in April 1948 at a depth of 12,621 feet (3847 m). Some small gas shows were recorded, but the results were generally disappointing (Nye & Fisher 1954).

Due to the Japanese offensive, exploration largely ceased in January 1942 and remaining APC staff were evacuated to Australia.

FIELDWORK METHODS AND OBSERVATIONS

Transport by water was essential in New Guinea where there were no roads and before air transport became readily available. Coastal steamers provided initial transport around the coast and then smaller vessels were used in rivers until such time as walking became the only means by which the work could be carried out.

Oil Search Ltd developed a methodology based on systematic surveying and field geology rather than early drilling. The work involved:

- reconnaissance and follow-up more detailed mapping as required
- palaeontological studies to control the stratigraphy; local and regional correlation of stratigraphic sections; structural geology to define potentially prospective structures and regional tectonics
- petroleum indicators with search carried out in the field and previous reports.

Field parties usually comprised one or two geologists and a surveyor with support from local people, and was carried out largely by plane-table traversing with telescopic alidades and stadia rods of river and stream sections. In smaller creeks, navigation by prismatic compass might be utilised and sometimes stakes were set at 100-foot intervals.

Carey himself provided some wonderful insights into his *modus operandi* in reminisences published half a century later (Carey 1990) and illustrated by the following quotes:

> *No base maps.*
> *Mapping by chain and (prismatic) compass and plane table traversing with telescopic alidade distances being measured by stadia.*
> *To go to a place a hundred kilometres away, I walked.*
> *Leaving base camp, I would not expect to see another white man for several weeks, only neolithic natives* [sic]*, many of whom had not seen a white man before.*
> *The only fresh meat was that which I shot.*
> *I kept a working yeast bottle to leaven my bread.*

Mail reached base camp every six weeks.
(Away from base camp) no radio communication or news broadcasts.
Hydrocarbon occurrences noted: oil and gas seeps, rocks with 'kerosene' smell.
Crocodiles – I fired my Webley forty-five at it, but it did not even budge…Montgomery fired his Winchester... that night they had a great feast of fresh crocodile.

The author recalls Professor Carey (on more than one occasion) regaling all with tales of using the filament from a spider's web as crosshairs in his theodolite.

River access

Most traverses were on rivers transverse to major structures: a collage of photographs taken by Carey around 1936, illustrating aspects of this work, is shown as plate 3. The larger rivers were accessible for some distance by small coastal vessels. The Oil Search Ltd parties often made use of the *Orion*, an auxiliary yawl of 19 tons. The other main form of river transport was motor canoes – simple dugouts made on the spot and usually less than 50 feet long. The canoes were generally utilised in pairs, one with the alidade and plane table, the other as the surveyor's scale either carried vertically or painted horizontally on the vessel (plate 3B, E); sometimes one was used as a simple outrigger, at other times a deck was lashed between two canoes. Motor power was provided by outboard motors of 4 to 22 horsepower. Carey noted that: 'if travelling at night passengers can sleep comfortably on stretchers and a table can be set up for meals and a galley fire built on a clay pan' (Carey 1941, Appendix 1, p. 4). Beyond the limits where motor canoes could access, light paddle canoes were used (plate 3B).

Aerial reconnaissance

Observation flights were initiated by APC as a reconnaissance tool in 1937. Carey undertook aerial studies of the morphology of the Owen Stanley Range and the Yodda Valley in October 1937 and examined large areas of the Gulf of Papua in April 1938. In May 1938 he flew from Port Moresby to Salamua (then a small town situated on the northeastern coast, built on a minor isthmus between the coast with mountains on the inland side and a headland; the closest city is Lae) via Yodda and Chirima Valleys on the north side of the Owen Stanley Range and returned via Wau, Mt Lawson and Mt Yule on the south side of the Range. He also made a return flight along the length of New Britain.

Carey carried out aerial photographic mapping and reconnaissance of the Central Highlands from 14 February

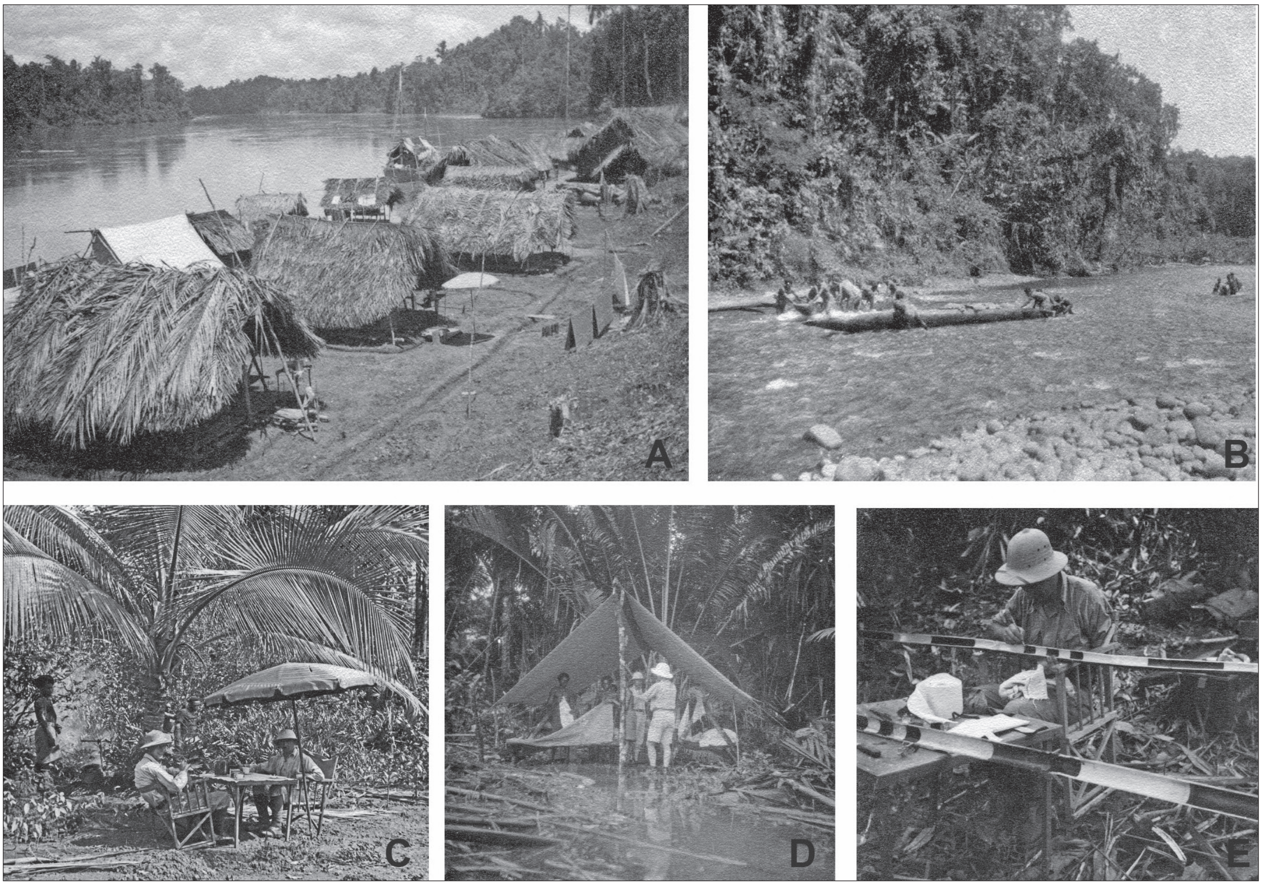

PLATE 3 – Life in the field, New Guinea circa 1936. The photos are scanned and enhanced from Carey's thesis. **A.** Geologist's camp on the lower Purari River; Orion moored next to camp. **B.** Hauling geological survey transport canoes in the Averi River, Gulf of Papua. **C.** Lunch stop, delta country, Gulf of Papua; K. McKinnon on the left, Carey on the right. **D.** Fly camp, delta country, Gulf of Papua (J.N. Montgomery nearest to camera). **E.** K. McKinnon improvising stadia rods from bamboo.

to 9 March 1939. The work was undertaken while travelling as a passenger in a Ford Trimotor on its flights across the mountains between Wau (fig. 1) and its survey assignment in Papua. K. Washington Gray (*in litt*., 17 October 1939) noted increasing interest in the Central Highlands at that time and that Carey's tasks included having to "trace the extension of the great sequence of Mesozoic sediments then discovered" and "obtain a preliminary conception [*sic*] of the geology of the central highlands". An example photograph is included as plate 4.

The practical difficulties of aerial observation and recording over hostile terrain in various weather conditions (in poor weather the geologist took the co-pilot's seat and became navigator and observer for a reconnaissance flight) can hardly be comprehended to the modern geologist, but Carey undertook the task with his customary zeal and meticulous planning. In an appendix to his report (Carey 1939) he provides an account of the methodology and details the necessary equipment:

- suitable clothing for working at altitude
- amber glasses for eliminating haze
- binoculars
- camera (preferably operated by another person)
- prepared map (including all known topographical information, radial course lines, magnetic bearings, approximate flying times)
- scribbling map at same scale
- spring bows set to 5 minutes flying on base map;
- protractor scale
- prepared notebook (ruled with longitudinal medial line marked off in minutes on the scale of one inch to the minute of flying time).

CAREY IN NEW GUINEA

Carey's work in New Guinea is conveniently divided into two phases, separated by a period of six months' leave he took in the second half of 1938 to return to Sydney to write the thesis for which he was awarded a Doctor of Science from the University of Sydney.

PLATE 4 – Example photograph of Carey's aerial reconnaissance undertaken for APC. The original caption reads "Bulolo Valley at Bulolo, looking southeast. Bulolo Gold Dredging Company's main camp (A) middle right; Wau-Bulwa road (B) in centre; Bulolo aerodrome (C) flanking road; dredge tailings (D) flanking the Bulolo River. The valley becomes constricted in the distance (E) owing to a cross upwarp of hard porphyry and phyllite, but beyond the constriction widens again to Wau near (F). The low grassy hills (G) belong to the Otibanda Series; the wooded hills are Kaindi Series, with intrusions of granites and porphyries. (APC Photo)."

Phase 1: 1934–1938

Carey commenced work in the Mandated Territory of New Guinea in 1934, arriving in Boram (5 km from modern-day Wewak; fig. 1) via Port Moresby and Rabaul (at the eastern end of New Britain) and subsequently worked over much of both New Guinea and Papua. His work included geological mapping, report writing and review, and administrative duties. In the field, he also prepared material for micro-fossil identification and assisted in identification and classification. He also made thin sections for petrographic studies.

He then spent several months examining the stratigraphy and structure of the Neogene succession of the Sepik Valley (fig. 1). It was at this time that the widespread occurrence of faulting was recognised in the Neogene folds. In June and July 1935, he worked in the Prince Alexander Mountains (fig. 1) on the northern coast of New Guinea and made a south-to-north section. In September 1936 he undertook a scout reconnaissance section across the Torricelli Mountains and recognised that most of the structures were related to shearing stresses. He then spent several months mapping in the Sepik Valley region where he first demonstrated the existence of an unconformity between the Oligocene to Lower Miocene Aitape Series and the Neogene Finsch Coast Series. Carey subsequently recognised three main biostratigraphic groups, separated by unconformities, in the Tertiary succession of New Guinea (table 1).

TABLE 1 – Carey's identification of the main biostratigraphic groups, separated by unconformities, in the Tertiary succession of New Guinea (letters refer to the Indonesian Tertiary Letter-classification).

Age	Unit	Key Foraminifera	Indonesian Stage
Latest Pliocene – Miocene	Finsch Coast Series		g
Oligocene – Early Late Miocene	Aitape Series	*Lepidocyclina*	d-e-f
Paleogene	Port Moresby Series	*Nummulites-Discocyclina*	a-b

Shortly before noon on 20 September 1935, Carey was working in the Wapi district in the Senu River, south of the Torricelli Mountains (fig. 1), when his party was struck by one of the largest recorded earthquakes in New Guinea's history (magnitude 7.9). Carey (1935, p. 8) vividly described how his terrified workers:

> *… were first thrown to the ground, and picked themselves up, only to be thrown again and again. I fell on my knees and supported myself against a stout bamboo thicket and concentrated my attention on hanging on and watching the falling timber. I was shaken so violently that it was not easy to tell which trees were falling. Waves developed on the river and broke on the shore like surf. The traverse station I had just vacated was buried under a crumbling cliff.*

A second earthquake followed about 30 minutes later, severe, but less intense than the first. Aftershocks continued for the next full day and continued with lesser intensity for the next two months (Carey 1990).

Understandably, Carey's workers were terrified by the earthquake and its aftershocks. They packed his gear into boxes and prepared to move out. He:

> *… chided them soundly for their cowardice, and set all hands to work putting the camp in order … I explained to them, as clearly as pidgin-English would allow, just what an earthquake was—pointing out its wide extent and showing them the futility of trying to run away from it.* (Carey 1935, p. 9)

The earthquake was also experienced by a party led by Montgomery conducting an exploratory reconnaissance on the lower Sepik River (fig. 1). Montgomery and his surveyor H.D. Eve described 'a sudden hush, followed by a loud rushing sound and almost instantly the ground was rocking with an undulatory motion of such rapidity and intensity that it was impossible to remain upright without support'. Some days later:

> *… as the party proceeded towards the Torricelli Mountains, fallen houses, ruptured ridges, and landslides became increasingly frequent … the southern slopes of the main portion of the Torricelli Mountains, which previously had been densely forested, showed great stretches bared to bedrock and steep slopes replaced by cliffs.* (Carey 1935, p. 13)

At various times during 1935–1936, Carey worked with Montgomery, Edwards and Fryer to map the Maimai Dome (Montgomery & Carey 1936, fig. 1), which was seen as a potential hydrocarbon-bearing structure – a postulated Aitape Series buried hill beneath an anticline 5.5 x 1 miles in areal extent with a vertical closure of 1400 feet. The structure is about 64 km from the nearest coastal harbour at Aitape and access was difficult, the best being 56 km northwards from the Sepik River over swamp, forested plains and hilly country. It was noted that villages were comparatively small, and the area was situated between Mikili and Maimai, two mutually hostile clans.

The work was carried out in several phases:

- reconnaissance by Montgomery in October 1935 detected the structure
- reconnaissance mapping by Carey, Edwards and Fryer
- mapping by Edwards and Fryer at three inches to the mile ('the former standard')
- further work requiring mapping by Carey and Edwards
- follow-up ('"to gather up loose ends and cover some blanks") by Edwards and Fryer in May 1936.

The absence of seeps over the structure was seen as a negative and boring was recommended to determine if the structure contained petroleum in commercial quantities; further regional reconnaissance surveying and geological studies to determine the presence of hydrocarbons was also recommended (Montgomery & Carey 1936). The author has found no evidence that the structure was ever drilled.

In 1936, Edwards and Carey (1936) described the lithotypes present in the Aitape and Finsch Coast Series throughout the Sepik Basin ('Geosyncline'). The Aitape

Series comprised limestone, sand silt and mudstone with conglomerate and volcanics; a key fossil for recognition was *Lepidocyclina*. The authors noted the presence of great thicknesses of silty rhythmite, which they regarded as the result of the annual monsoon cycle. The Finsch Coast Series comprised limestone, mudstone, sandstone and siltstone and had a characteristic physiographic expression; six stages were recognised, with *Globigerina* the key fossil. During this period, Carey also made quick visits to islands off the north coast of New Guinea. Each has a volcanic origin, with Manam (fig. 1) being very active (Carey 1938b).

Carey took leave in Sydney during July and August 1936 and returned to New Guinea, commencing work in the Gulf of Papua (Territory of Papua) continuing structural mapping and resulting in the subdivision of the Neogene. In May 1937, he traced the edge of the Australian foreland (N–NW major monocline downthrown to the east, with significant Neogene thickening to the east) north and northwest from Kikori (fig. 1). From July 1937 to January 1938 the regional survey was extended from the Purari River to the Akaifu River (north of the Owen Stanley Range), including a reconnaissance expedition along the border of Papua and the Mandated Territory between the Vailala and Tauri rivers in November and December 1937 and down the Tauri River to the coast. Carey described this as 'uninhabited country (or) no-mans-land between mutually hostile clans' and noted that 'we knew we were being watched, all armed with bows and arrows'. In crossing the Pururi, Carey found a potentially large structure and a series of thick-bedded limestone.

During 1937 and 1938 Carey worked in the eastern Gulf region. In October 1937 he searched for gas seeps in the vicinity of the present town of Kerema (fig. 1), where seeps had previously been reported by Woolnough (1934). In early 1938 he carried out reconnaissance mapping down the western Tauri Valley from the border of the Mandated Territory to the coast at Kukipi (fig. 1); he also carried out mapping in the Murumie and Matupu rivers. He subsequently undertook a coastal traverse from Kukii to Yule Island and in May 1938 reviewed Gulf Coast structures between Popo and Yule Island (fig. 1).

Before the Oil Search Ltd Papua permits were transferred to the Australasian Petroleum Company, Carey compiled a major report on permits 5 and 7 (Carey 1938a). The report comprised detailed sections on physiography, stratigraphy (subdivided into Upper Neogene, Lower Neogene and Paleogene Series), analysis of the Tertiary succession in the Gulf of Papua, a review of Tertiary micro-faunas in the Gulf of Papua, structural correlation of the Tertiary of New Guinea, structural conditions in the Gulf of Papua and a section on petroleum which included an inventory of all known petroleum indications.

Arthur Wade said of the report (*in litt.* 11 Aug 1939, unpublished): 'In spite of Mr Carey's tendency to be a little dogmatic at times, his report is a valuable contribution to the knowledge of the Geology of New Guinea.'

A break from fieldwork: doctoral thesis 1938

Carey took six months' leave from June to December 1938, during which time he returned to Sydney and completed and submitted a thesis (Carey 1938b) entitled 'Tectonic Evolution of New Guinea and Melanesia' for which he was awarded a Doctor of Science degree from the University of Sydney in 1939. In the thesis, Carey noted that it was the 'reading and reflection' stimulated by his early fieldwork for Oil Search Ltd in which many of his tectonic ideas were developed. The thesis is in two parts: the first dealt with the morphology, stratigraphy and structure of New Guinea; the second with the nature, origin and evolution of the 'island fringe of Australia'.

In dealing with structure, Carey noted that almost every anticline bears the stamp of rotational stress either in the configuration of its axis, its relation to its neighbours, or its association of compression and cognate tension. Almost every thrust tells the same story, either by its place in the fault pattern, by its attitude, by the trend of the slickensides, or its association with a complementary thrust tend. The mountain orogens bear similar testimony, both in their internal architecture and their external trend.

He recognised:

- master faults running for hundreds of miles though the country, terminating all other structures;
- strata on either of the faults appear to have been folded and faulted independently
- structures between the master shears are always oblique.

Carey postulated that the regional folding and rotation resulted from 'great master shears' and that the whole New Guinea region bears the stamp of a 'colossal shear system', which he termed the Melanesian Shear System; furthermore, the stresses responsible were continental in scale: 'New Guinea has been sheared westwards under a colossal shear system, on a scale grander than has yet been demonstrated anywhere else on the globe' *(*Carey 1938b, p. 62*)*.

In the second part of the thesis, he extended his hypothesis outside of his field area into the Indonesian Archipelago and beyond. At this time, Carey clearly believed in the large-scale horizontal movement of continents (Carey 1938b):

- He figured Du Toit's (1937) reconstruction of Gondwanaland (Carey 1938b, figs. 30, 31) and said of him: "developing the great new highway of thought blazed by Wegener, has prepared a masterly synthesis of the Gondwana continents for the Palaeozoic and Mesozoic eras" (Carey 1938b, p. 81).
- He quoted Professor Arthur Holmes (Holmes 1928) making 'an important contribution from the theoretical side and discussed sub-crustal convection movements arising from differential radio-active heating as a mechanism of orogenesis' and that Holmes' theory of sub-crustal convection movement satisfactorily accounts for the tectonic facts of Melanesia (Carey 1938b, p. 88).
- He also quoted Andrews (1938): 'Wegner by this imaginative excursion, was led to infer the impermanence of position of the major structures of the Earth, such as the continents and oceans' (Carey 1938b, p. 93).

To explain the palaeogeography of Melanesia, Carey postulated either large continental areas had foundered to oceanic depths or that continental material had moved great horizontal distances. He favoured horizontal displacement as there was no direct evidence of foundering and a growding body of evidence that island blocks had been displaced horizontally. He concluded that continents may be disrupted or torn apart, but they may not be foundered to a great depth.

Carey noted that his thesis commenced with seemingly routine parochial survey in New Guinea and finished with a philosophy of the Pacific: 'All real scientific progress, and all initiation of new trends in thought are based on bold, but intuitively guided imagination' (Carey 1938b, p. 100).

Phase II: 1939–1942

On his return to New Guinea, Carey commenced work in the Gulf of Papua studying the Neogene succession and undertaking structural mapping. For the first time, air photographs were available and brought an enormous advance, as it was now possible to extrapolate between creeks.

For the remainder of his time in New Guinea, Carey was involved in the Purari region of Papua (Carey 1941, 1942, fig. 1). Between 1939 and 1940 he led investigations of the Lower Purari and Vailala rivers (Carey 1941) – primary tasks were mapping (four inches to the mile, plate 5), the search for direct evidence of petroleum and study of the Neogene succession. Three main surveys were conducted:

- Middle Purari Survey, 10 April to 21 July 1939
- Trans Purari Survey, 13 September to 29 December 1939
- Hathos Gorge Excursion, 5 March to 3 April 1940.

Carey (1941, Appendix 2) noted potential problems with and between local clans in the Lower Purari area, no doubt reassured by 'three police officers, each with a Lee Enfield 303 rifle…two boys [sic] each with a shotgun [and] myself with rifle and revolver' (Carey 1990, p. 21).

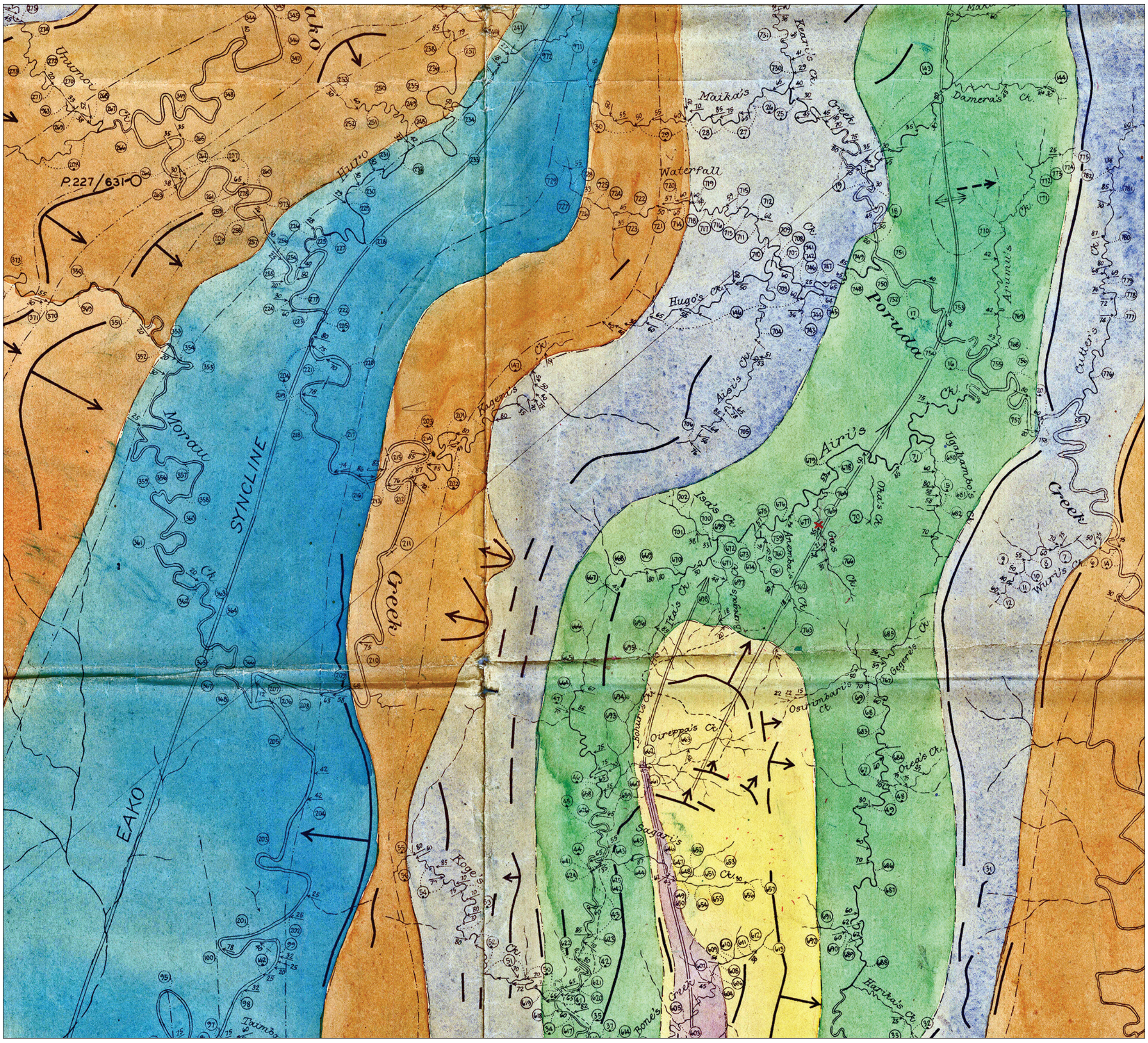

PLATE 5 – Detail of map of Vailala River area (Carey 1942; figure 12) illustrating detail of work undertaken. Information includes topographic information, stratigraphy, bedding dip and strike, sample points (numbers in circles), petroleum manifestations. Original map published at four inches to the mile.

The presence of 'most favourable' structural traps in the Purari region was recorded and Carey concluded that 'field evidence gives much more promise to lower part of the Upper Miocene'. He further noted that the Puri Limestone was a possible source rock succession, describing it as 'lithologically organic'. He also speculated on the presence of Paleogene source rocks.

In his report on the Puri Anticline (fig. 1; Carey 1940) it was noted that the structural feature was 22 x 4 miles in extent and within a belt of 'known manifestations of petroleum'. Five lithological subdivisions were recognised (Puri Limestone, Orbulina Marl, Toa Mudstone, Ena arenaceous group and Rapids Sandstone). He noted that a seismic (refraction) program was already underway. Carey's structural sections of the Puri Antlicline are shown as plate 6 – note the simple structure and lack of reverse faulting, although it can be inferred in Section CC. Plate 7 is the compilation map produced by Carey of the Oil Search Ltd work in the Gulf country through the Owen Stanley Range to the Markham River area on the north coast.

CAREY'S CONTRIBUTIONS

Carey and his colleagues carried out a heroic campaign of geology-based field exploration under the most difficult of conditions. Although their work did not find commercial hydrocarbons (drilling of the first well commenced in 1942, was suspended because of the Japanese invasion and was completed – as a dry well – after the war), it paved the way for PNG's current hydrocarbon industry.

The work became the classic reference for the areas and made enormous progress in geological understanding (Rickwood 1990). Rickwood also stated that 'the immediate advances in geological mapping and in geological thinking which followed the first photogeological work were probably the greatest single step ever made in understanding the geology of Papua New Guinea' (Rickwood, 1990, p. 6). It also paved the way for 1:250,000 scale mapping of all of PNG by the Australian Bureau of Mineral Resources 1950–1979 and this benefited both the petroleum and minerals sectors.

Largely driven by the presence of numerous oil and gas seeps which were first recorded as early as 1911, the Oil Search/APC exploration campaign was almost entirely directed towards Neogene rocks, with Paleogene and Mesozoic successions being regarded as non-prospective. Conventional thinking at the time was that the hydrocarbons in the seeps were sourced from carbonaceous rocks of Tertiary age (e.g., Woolnough 1934).

Carey (1936, p. 1) commented on a reported seep in the Ramu Valley some 35 miles southwest of Nubia (fig. 1). He met the gentleman who reported it and noted: 'I gathered what particulars I could without displaying much interest'. He also noted there were no maps and thought that an exploratory trip would take one to two weeks. Unfortunately, they were looking in the wrong place: it is now known that most of the hydrocarbons in the Papuan Basin (with the notable exception of the twenty-first-century giant Elk-Antelope discovery) are sourced from Late Jurassic mudstones, reservoired within Early Cretaceous (Berriasian) sandstones and sealed by Mesozoic age (Berriasian–Turonian) clastic successions (Davies *et al.* 1996, Hill & Hall 2003, Karwagle 2007).

Carey (and his co-workers) understood the difference between bio- and lithostratigraphy and time and time-rock units, and used fossil determinations to help subdivide the Neogene stratigraphic units (in this context, the work of Dr Martin Glaessner was critical). The work was published by the Australian Petroleum Company (1961) where five Papuan Stages were defined: the Kereruan (Late Oligocene to earliest Miocene) characterised by shallow-water 'larger' foraminifera known from the Indonesian Te Letter stage; the Taurian (mid Early to mid Middle Miocene) characterised by shallow-water 'larger' foraminifera known from the Tf1-2 Letter Stage; the Ivorian (late Middle to early Late Miocene) characterised by shallow water 'larger' foraminifera known from the Indonesian Tf3 Letter stage; the Kikorian equivalent to both the Taurian and the Ivorian; and the Muruan (Late Miocene) characterised by 'smaller' foraminifera including planktonic species of deep-water deposits. By 1961 the Australian Petroleum Company had discontinued use of these local stages in favour of applying European chronographic nomenclature to the Papuan successions and significant advances in global foraminiferal biostratigraphy and chronostratigraphy of the latter part of the twentieth century made the Papuan Stage names superfluous (Haig & Perembo 1990).

He recognised tectonic control over New Guinea geomorphology and named the Sepik Geosyncline (Basin) to encompass the conspicuous strike valleys north of the cordillera (pl. 8). This structural and physiographic feature traverses the length of New Guinea – from Huon Gulf responsible for the valleys of the Markham, Ramu and Sepik rivers, the Iddenberg, Wouffaer and Wapenga rivers in western New Guinea, and then emerging into Cenderawasih Bay (the prominent triangular-shaped bay east of the Birds Head at the western end of the island of New Guinea, see inset fig. 1; termed "Geelvink Bay" by Carey). He described the Central Highlands as a geanticlinal complex, between the Sepik-Ramu-Markham depression on the north and the Papuan Geosyncline to the south, modified by several powerful fault systems together with several distinct nuclei or uplift areas around which younger sediments have been faulted and folded (Carey 1939).

Carey, influenced by the pioneering work of Alfred Wegener, was an early believer in the concept of continental drift as evident in his thesis. He was aware of the massive tectonic movements responsible for the creation of New Guinea and noted that the cordillera system had raised Neogene marine beds to an altitude of 16 000 feet (4900 m) and 55 miles (88 km) from its front. Carey's inventive tectonic synthesis resulted not only in the Melanesian Shear but led to the globe encircling Tethyan Shear and Carey's "new global tectonics", arguably the basis of current plate tectonics.

The relevance of this heroic work was not long-lasting. Carey himself described the work as being carried out:

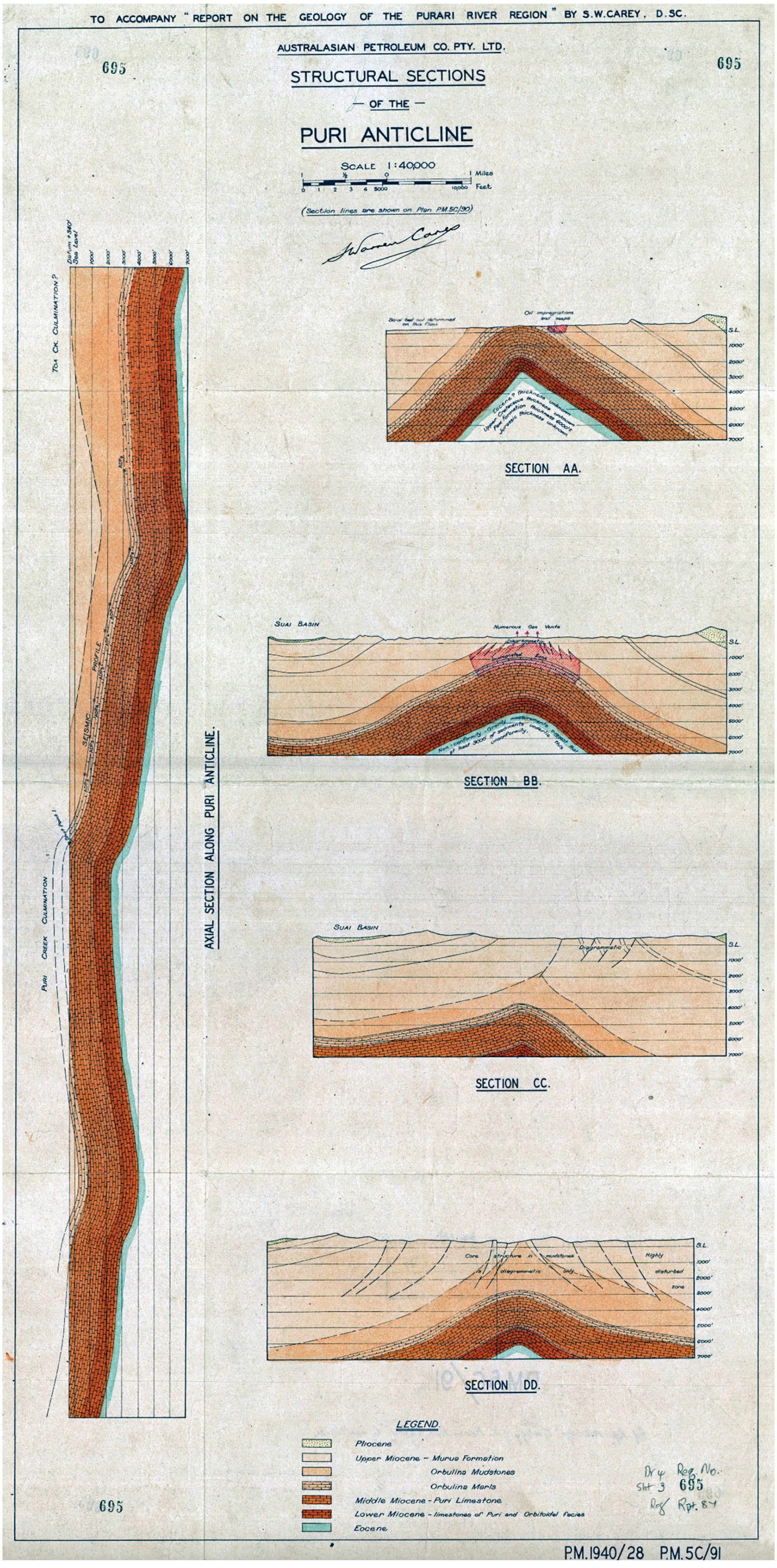

PLATE 6 – Interpreted structural sections, Puri Anticline (from Carey 1940).

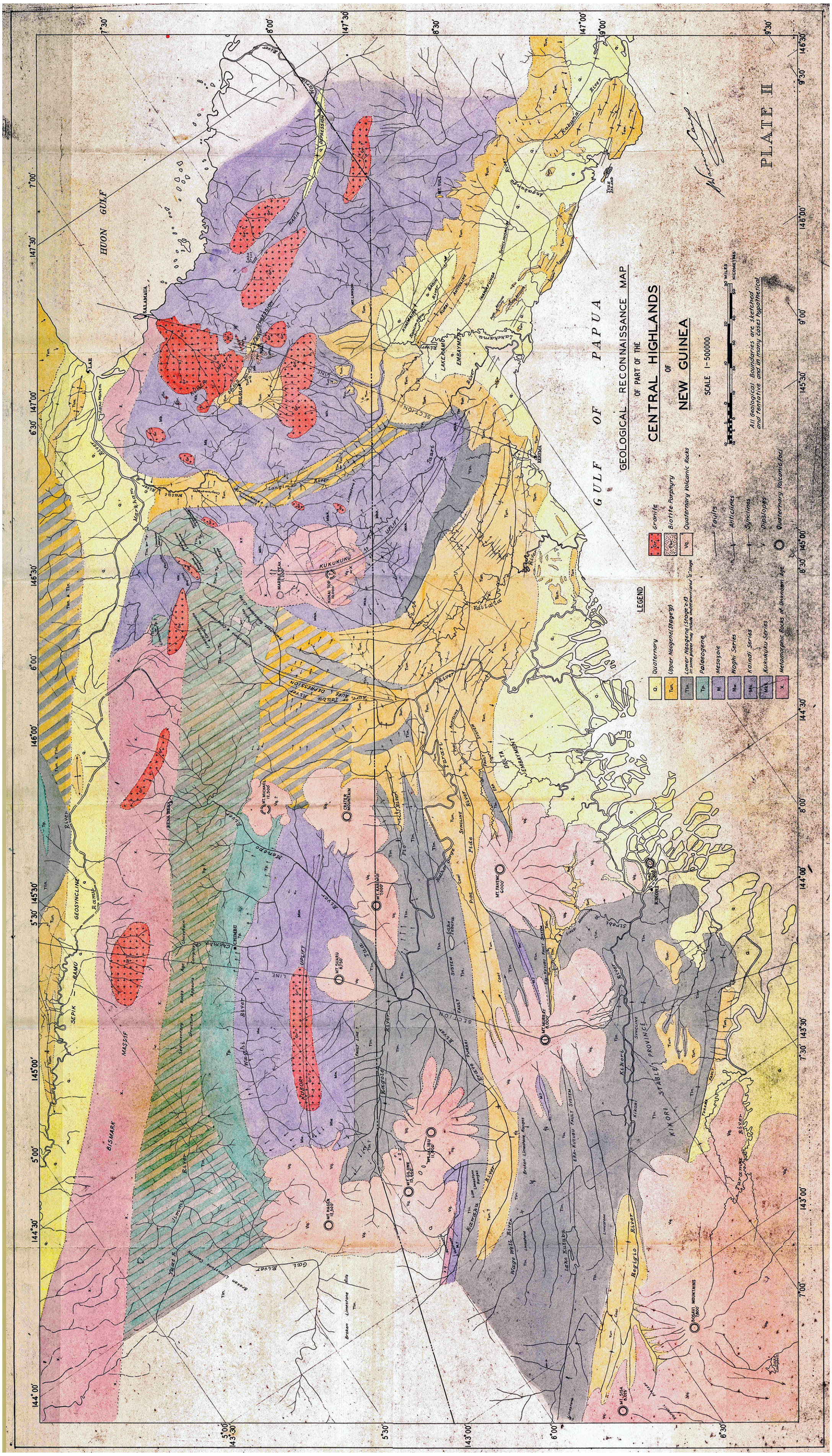

PLATE 7 – Compilation geological map (Plate II, Carey 1938a) of Gulf of Papua-Central Highlands-Markham River region; location indicated by red rectangle on fig. 1.

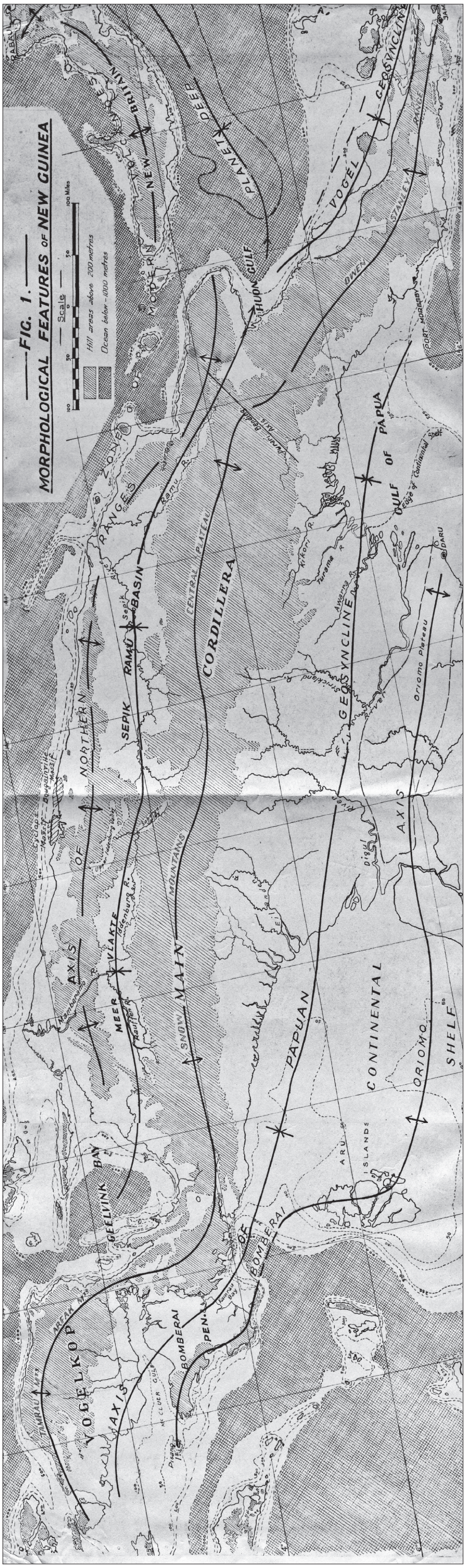

PLATE 8 – Interpreted morphological features of New Guinea (Carey 1938a and also included in his thesis as plate 1).

… at the end of the puttee and paddle period of field geology in New Guinea … at a time when the strand line was the boundary of the vast region of total ignorance … and being out of date within a very few years. (letter to Peter Purcell, 31 October 1969)

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