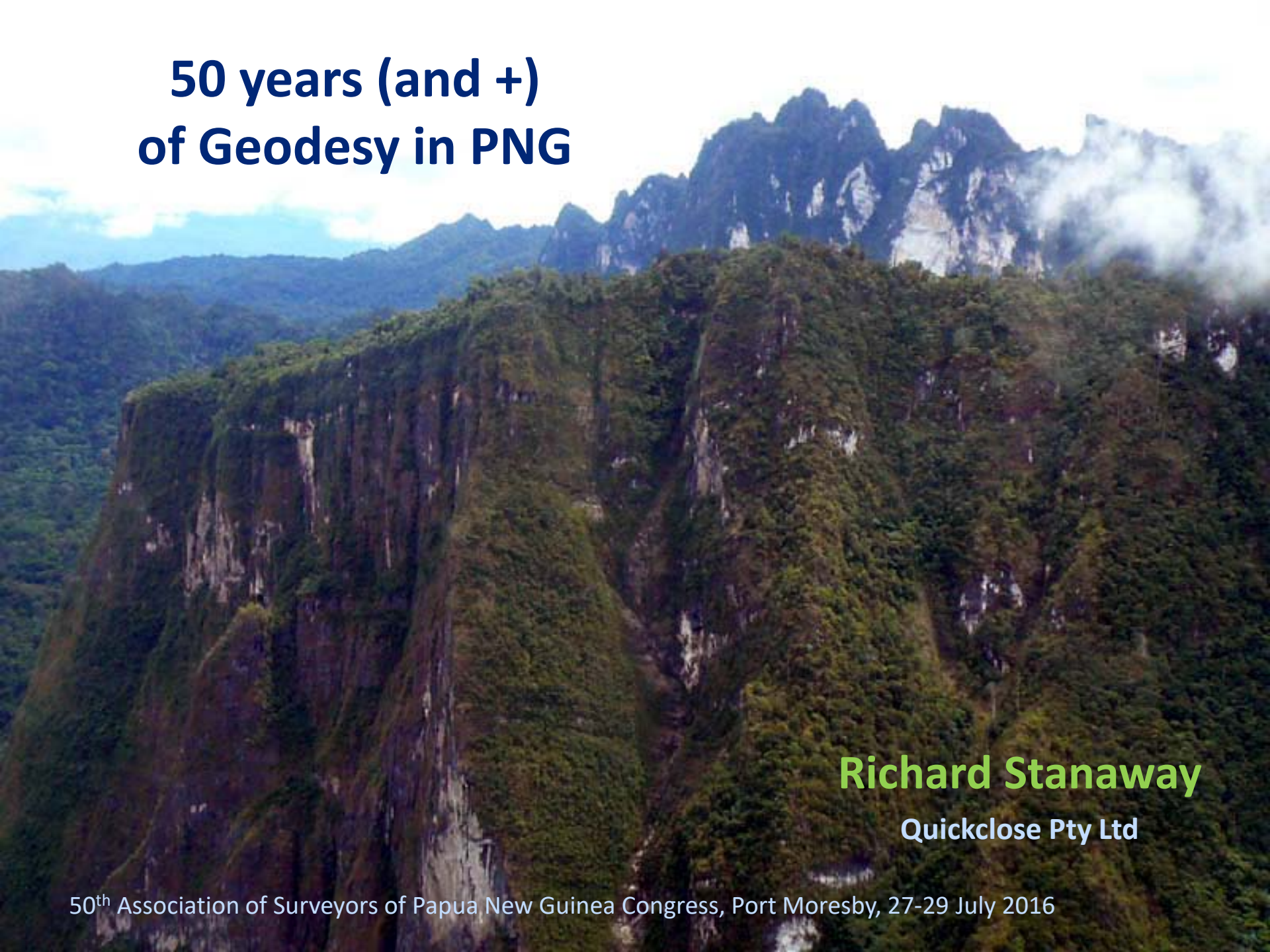
50 years (and +) of Geodesy in PNG

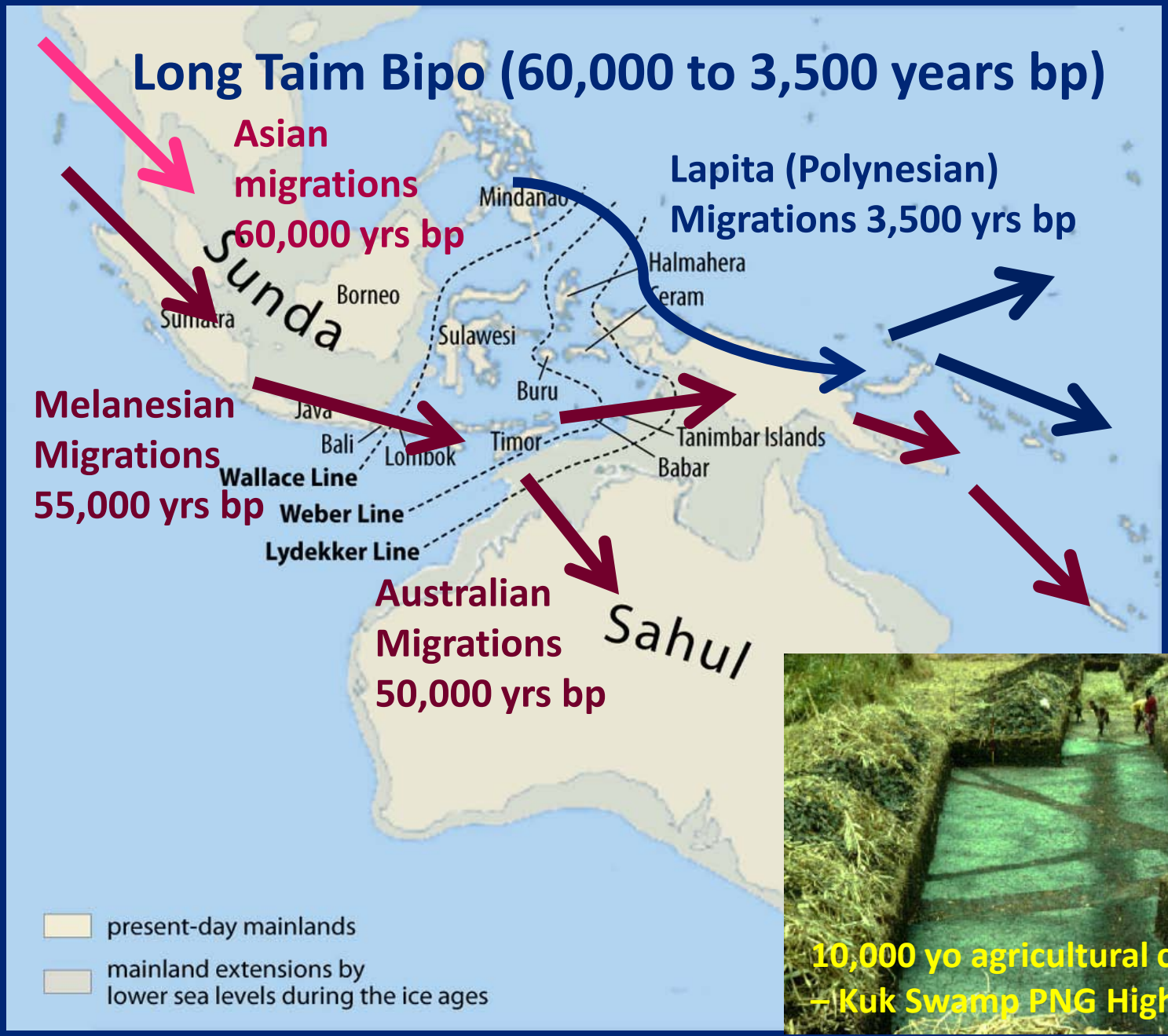


Richard Stanaway

Quickclose Pty Ltd

50th Association of Surveyors of Papua New Guinea Congress, Port Moresby, 27-29 July 2016

Long Taim Bipo (60,000 to 3,500 years bp)



Portuguese and Spanish exploration (by sea)

1512 Portuguese – Antonio d'Abreu

1526 Jorge de Menezes First use of "Papua" from Malay term for fuzzy hair.

1530 Spaniard – Alvaro de Saavedra N Coast of PNG – Isla del Oro

1545 Yñigo de Retez coined "Nueva Guinea"

1606 Luiz vaez de Torres claimed island for Spain

Maps likely destroyed in 1755 Lisbon earthquake

Arabic Astrolabe &

1602 copy of Pieter van de Keere map 1598.

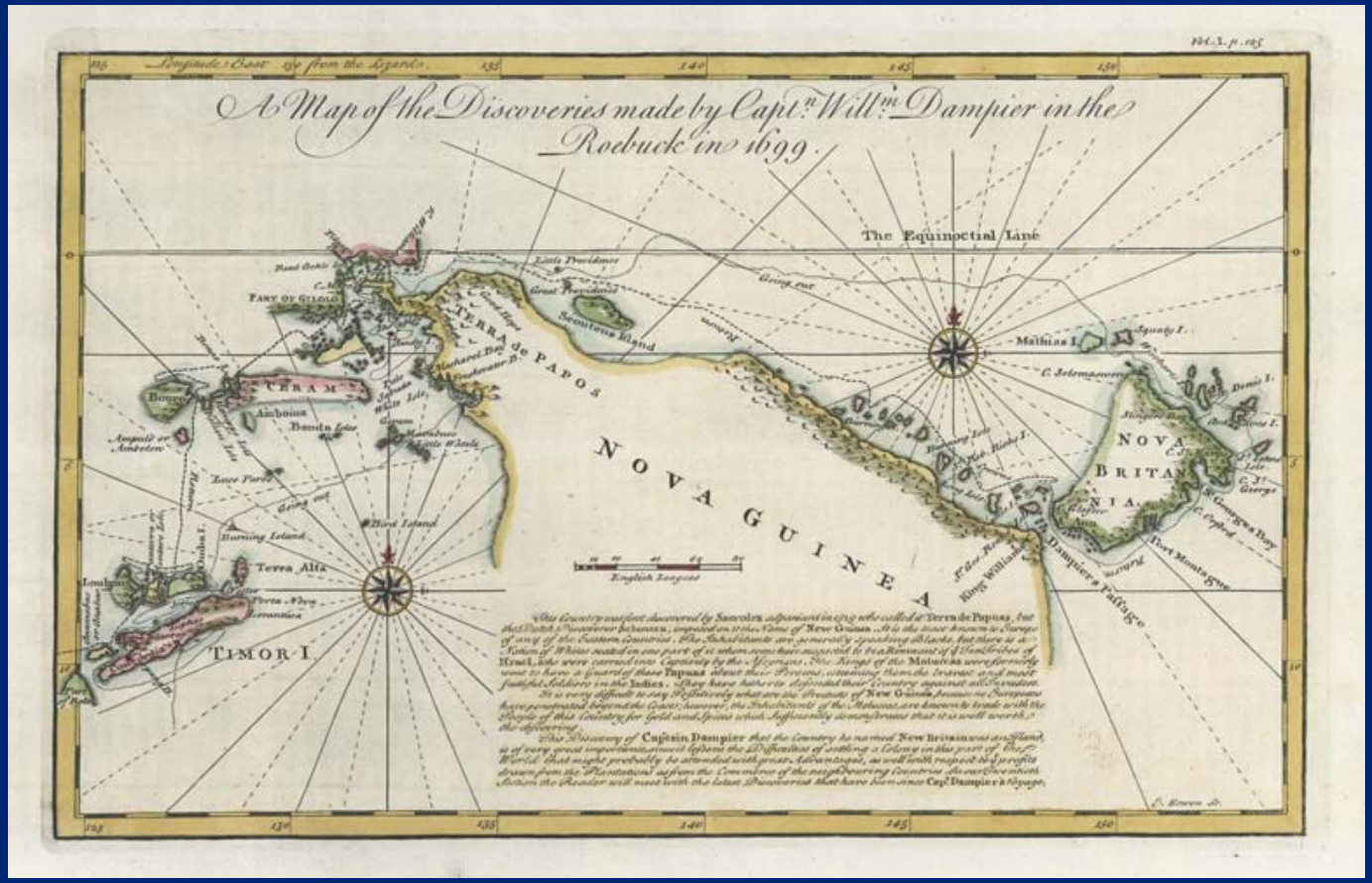
Dutch and British exploration

1607 –William Jansz (in Duyfken) E and S Coast

1617 – Jacob le Maire and Willem Schouten NE Coast – discovered Sepik

Cartensz and Abel Tasman

1699 – William Dampier In HMS Roebuck (NE Coast, New Ireland, S coast of New Britain)



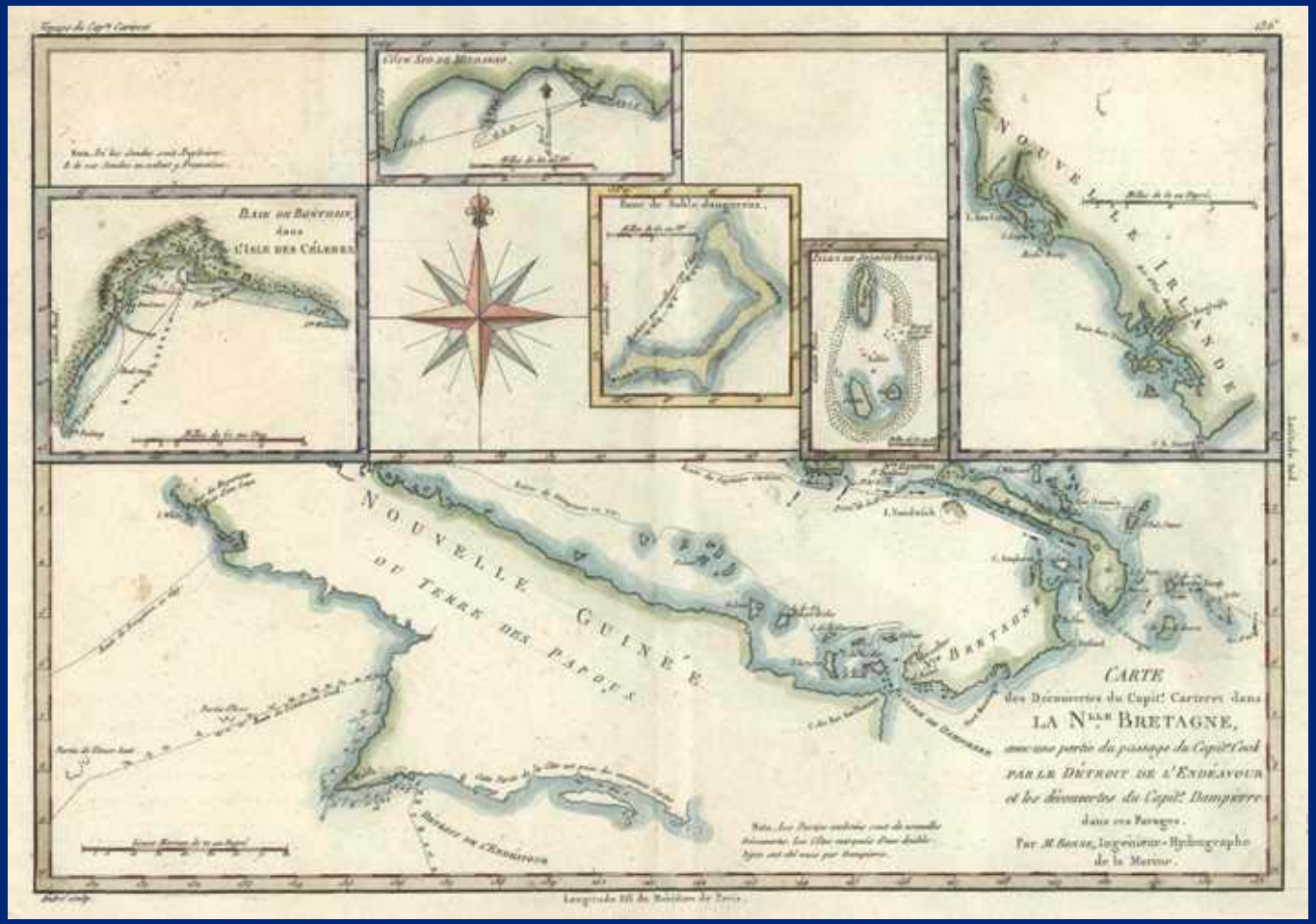
Dampier's 1699 Voyage (map by Emanuel Bowen c. 1746).

French exploration

1767 Philip Carteret
1768 Comte de Bougainville

1790 d'Entrecasteaux searching for La Perouse - entered Huon Gulf

1827 Dumont d'Urville (in the Astrolabe) surveyed Finisterre range and SE Coast



Carteret's 1767 Voyage including Cook's and Dampier's discoveries (map by Rigobert Bonne c. 1788).

Dutch and British colonialism

1828 Dutch claimed New Guinea w. of 141 deg E

1843 Capt F P Blackwood in HMS Fly – surveyed Torres Strait and Gulf of Papua and Fly River

1846 Lt Yule in HMS Bramble took possession of E New Guinea at Cape Possession (NW of Port Moresby)

Capt Owen Stanley – HMS Rattlesnake – surveyed E Coast

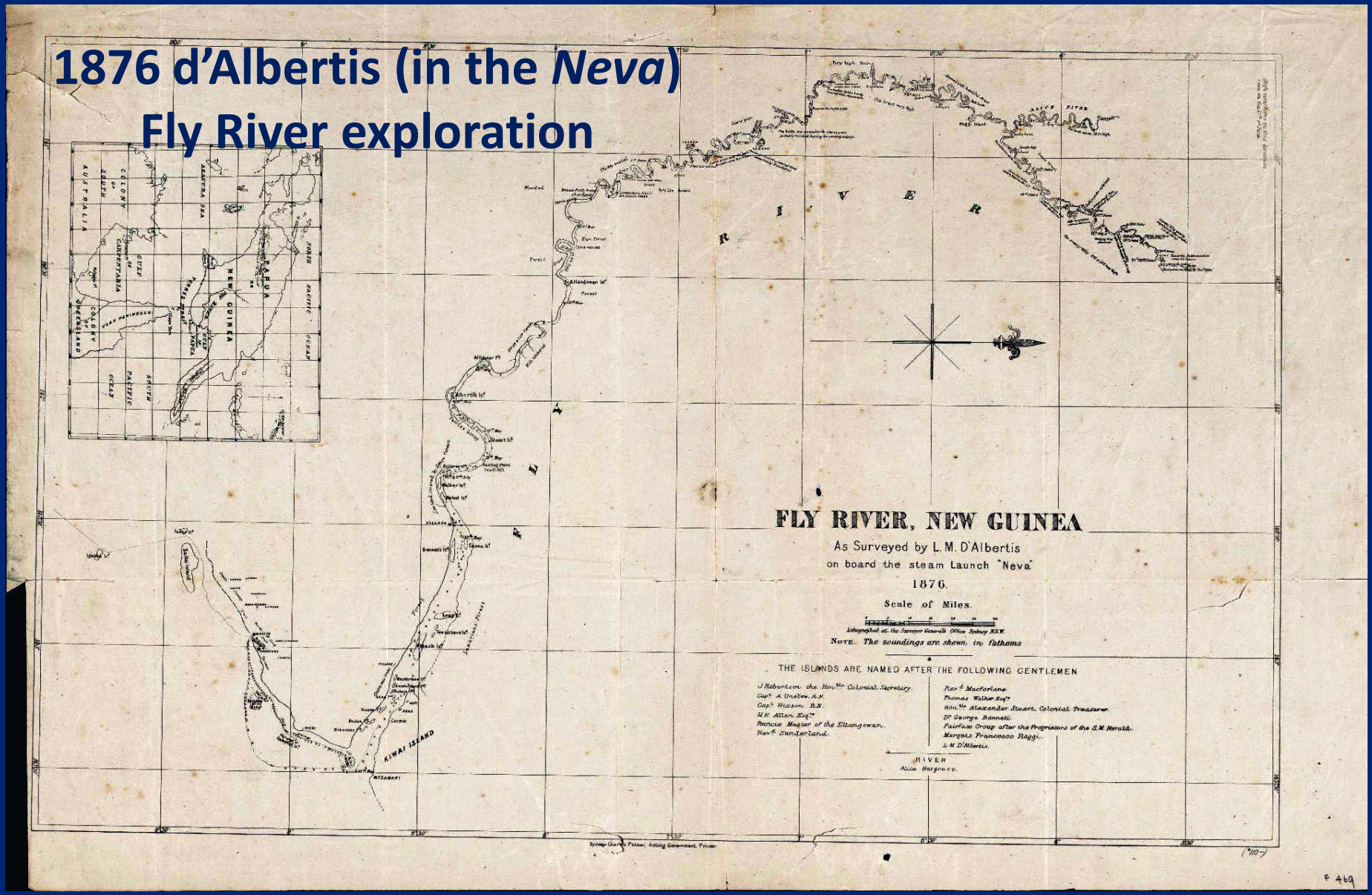
1872 Capt. Cortland Simpson – HMS Blanche – New Hanover, New Ireland, DoY Islands

1873 Capt. John Moresby – HMS Basilisk – named Fairfax Harbour after his father Admiral Sir Fairfax RN.

1874 – Moresby with Lt L Dawson – NE Coasts and named Markham River

(This was the last extensive survey of unchartered coastline in the habitable world)

1876 d'Albertis (in the *Neva*) Fly River exploration



British New Guinea 1884 - 1906

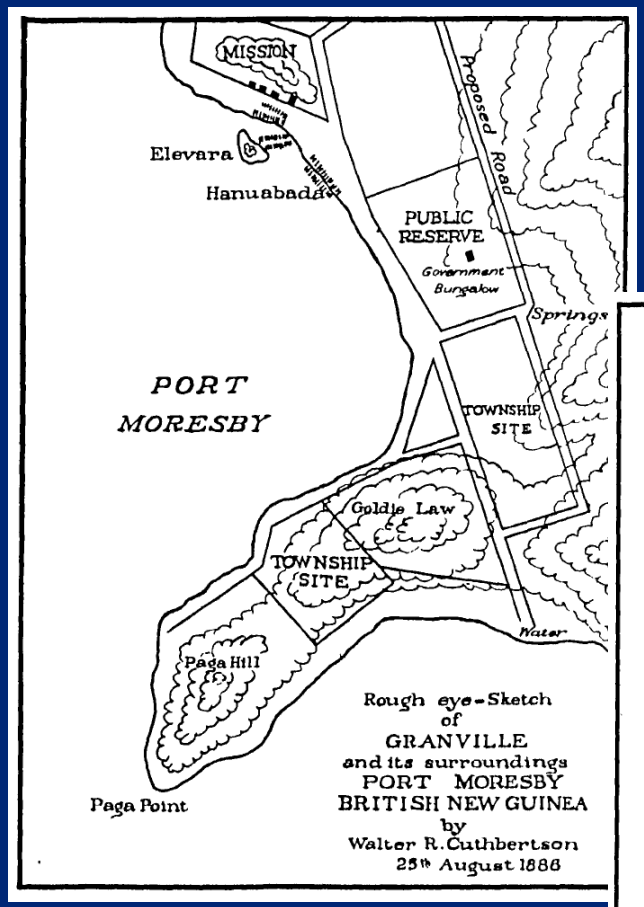
1880s Reverend James Chalmers – London Missionary Society established missions along Papuan coast

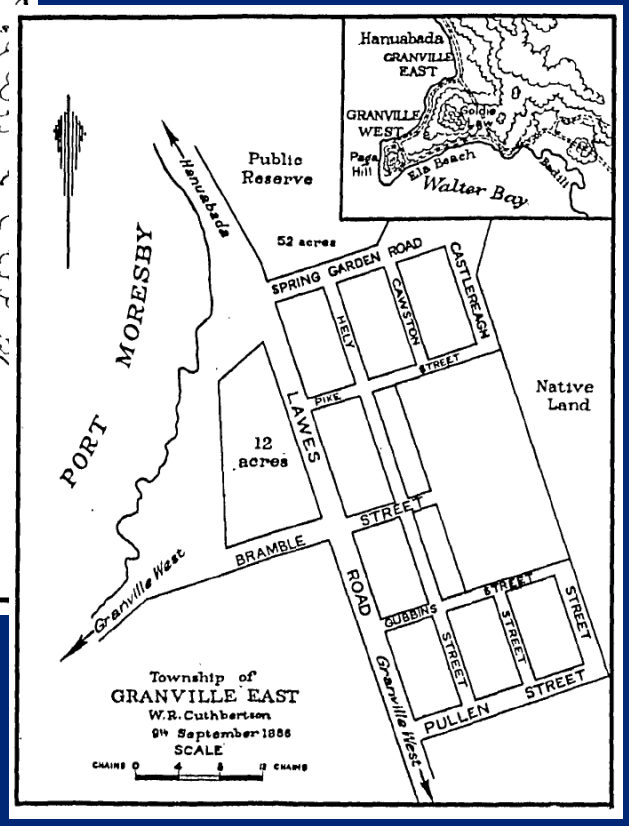
1883 Queensland took control of Papua

1884 British protectorate (British New Guinea) administered from Queensland

1886 Walter Cuthbertson survey of Port Moresby (first land survey)

1888 – William MacGregor administrator





British New Guinea – exploration and border surveys

1888 Extensive exploration by James Brewer Cameron and James Cobon

1898 – Cameron surveyed Fly Bulge for inclusion into British New Guinea with longitude compensation S of fly to Netherlands

Many surveys of Crown Land (later state land)

1899 Lands and Survey department established

Henry Hamilton Stuart-Russell as Govt. Surveyor

German New Guinea (Kaiser Wilhelms Land) 1884 - 1919

1884 Deutsche *Neu Guinea Kompanie* established several trading posts and plantations along the N New Guinea coast (and New Britain, New Ireland and Bougainville)

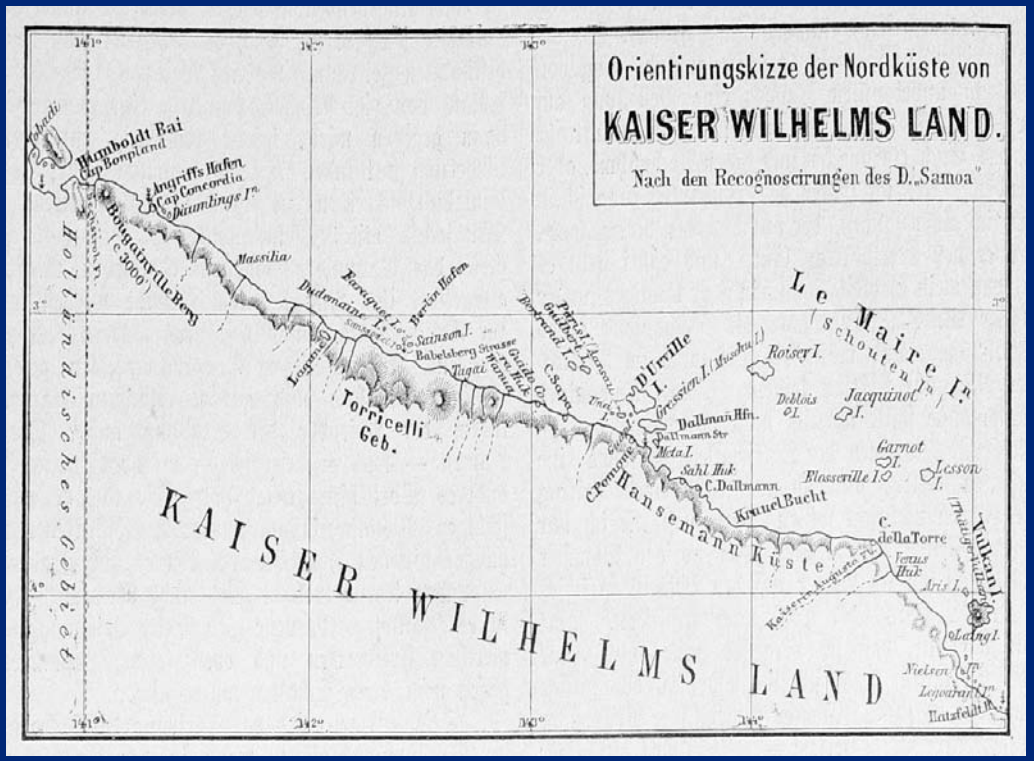
1886 – Plantation surveys by von Schleinitz

1899 – under direct German Government control

1907 Otto Frolich inland surveys

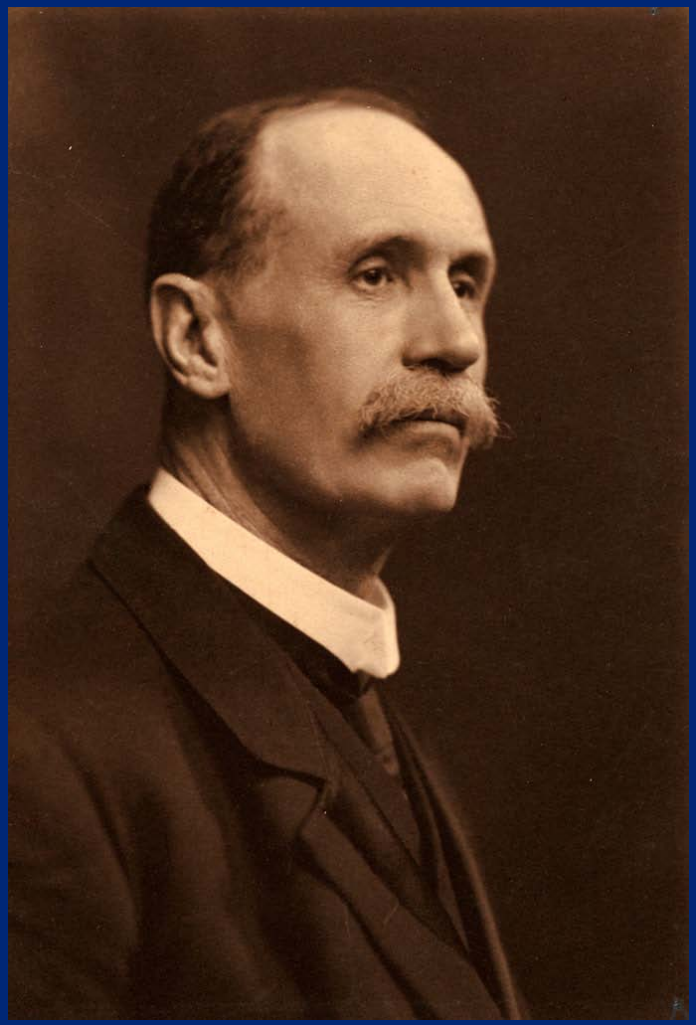
1913 – Aerial survey of German New Guinea using zepellins

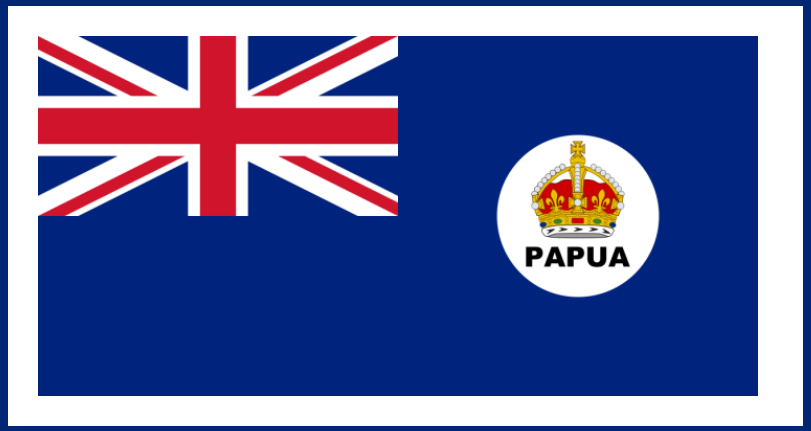
(abandoned in 1914 of course with WW 1)



German New Guinea

Australian Control – Territory of Papua 1906 - 1949





Transition from British administration to Australian control between 1902 and 1906

1907-1940 John Hubert Murray

(Lt Governor of Papua)

German – Australian Papuan border survey

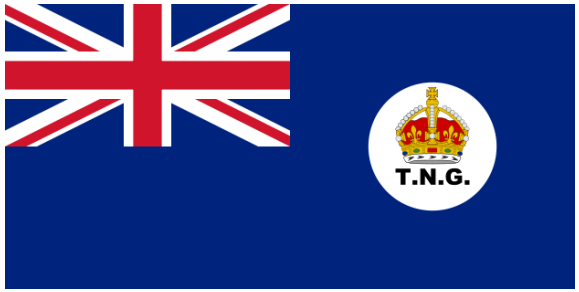
1909

Gustavus Sabine

Straight sections of the boundary

(e.g. 8 deg S)

Mandated Territory of New Guinea 1919 - 1949



1919 German New Guinea surrendered to League of Nations (precursor to the UN) administration by Australia as Mandated Territory of New Guinea.

1920s and 1930s characterised by Oil and Mining (Gold) surveys –

Harry Eve – Oil Search Ltd surveyor 1929-1939 then Jackson Fryer

1930 Leahy expedition

Astonishing discovery of Highland valleys with 1.5 million people.

1933 Ken Spinks – surveys in Highlands

1939 Ivan Champion Bill Adamson – surveys of S Highlands

1939 Paga Grid Datum established

World War II

Realisation of the absence of good maps (high loss of aircraft due to erroneous heights)

1942 – Royal Australian Survey Corps (RASC or RASvy)

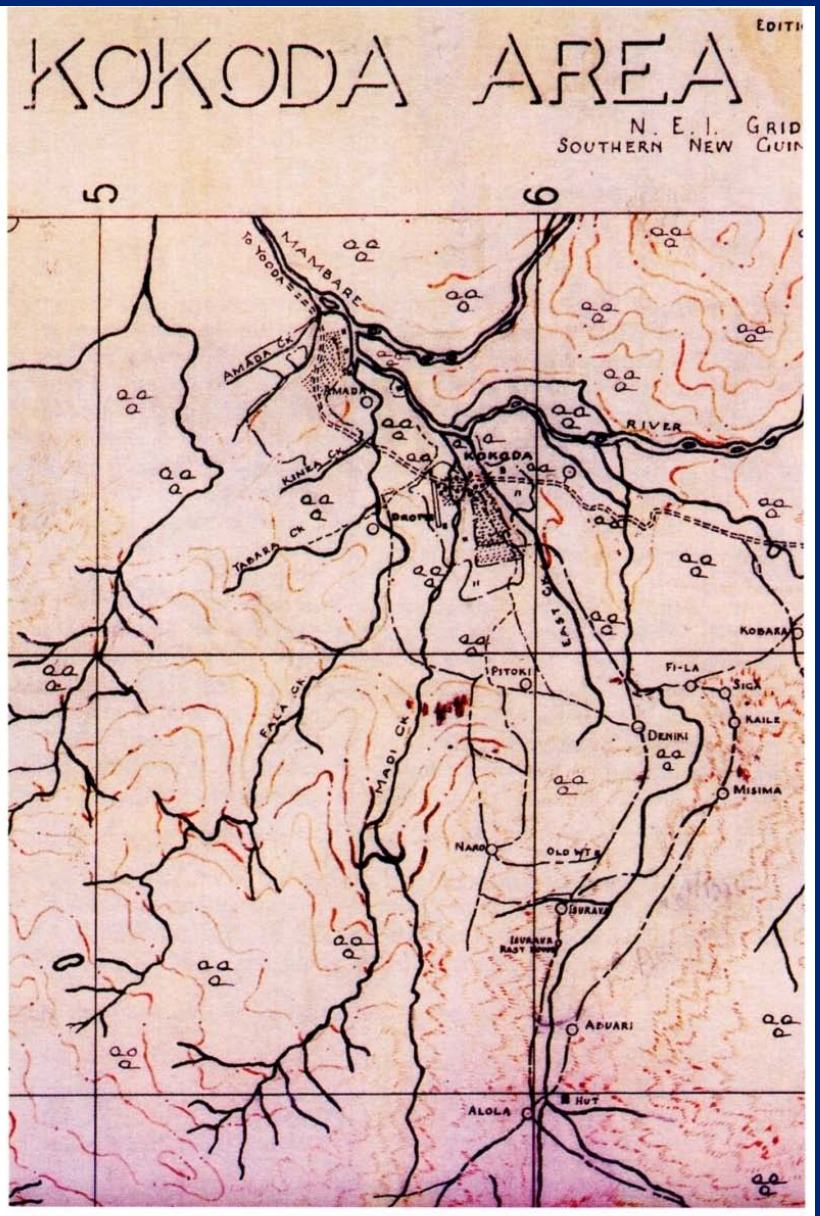
Aerial mapping to support field operations

(Lt Jerry Owers – Kokoda)

Support from US 8th Photographic Reconnaissance Squadron – use of the trimetrogon camera.

Bulldog Road – Survey

(feat of surveying and engineering at time)



Segment of two miles to one inch map of the Kokoda area, produced by 2 Field Survey Section, 1942.

Post-war era – TPNG, Ship-to-shore triangulation

1954-1955

US Army Corps of Engineers and RASC

Project XYLON

New Britain

Members of the base line party set up camp during Project Xylon. As the picture shows, American 'C' rations comprised the main element of the party's food. (AEM)

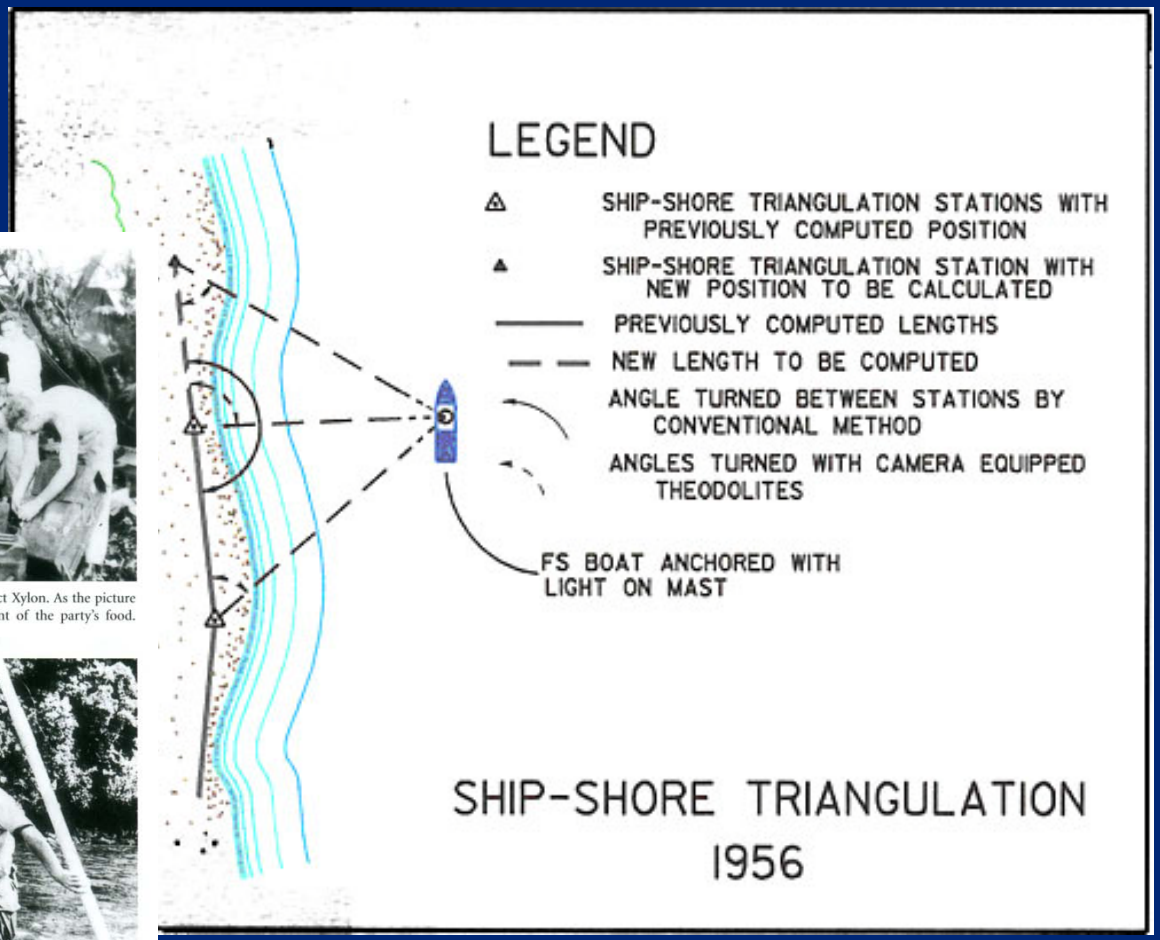
1956-1957

RASC and US Army

Project CUTLASS

New Ireland

'Blue' Crane (left) and Corporal J. Campbell observe to a ship during Operation Cutlass, 1956. Parties sometimes spent three or four hours in conditions like these. (AEM)

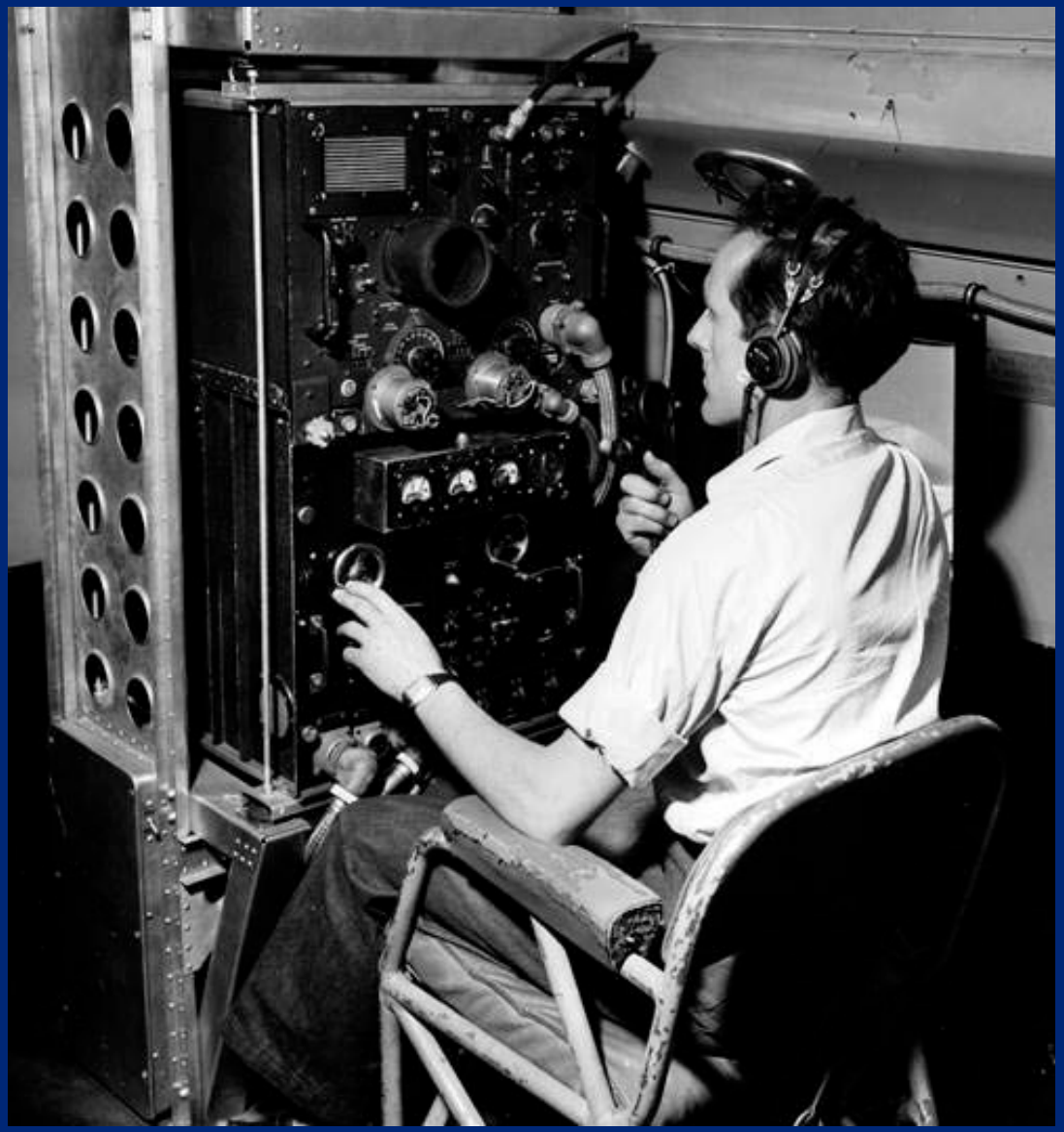


Memoirs of a geodetic surveyor, 1953-56, POB Online 2004

Shoran (SHOrt RAnge Navigation) – Surveys

Developed by RCA in 1940s (primitive radar measurement 500 km range – precision 3 m)

Air-to-ground trilateration



First serious geodetic surveys in PNG – 1960 to 1965

1958 Graham Matheson
Chief of Division of Surveys
(In 1965 titled Surveyor-General)

1960 Lambert (Director of National Mapping) instigated geodetic survey of PNG

PNG Government
Geodetic Section formed

Use of Geodimeter (Sweden)
Tellurometer (South Africa)
Revolutionised geodetic survey
Usage pioneered in PNG
Helicopters used for first time

1960 ASPNG formed

Wild T3

MRA 2 Tellurometer

Southwest Pacific Geodetic Survey - HIRAN

Hi-Precision SHO**RAN** using aircraft

Air-to-ground trilateration

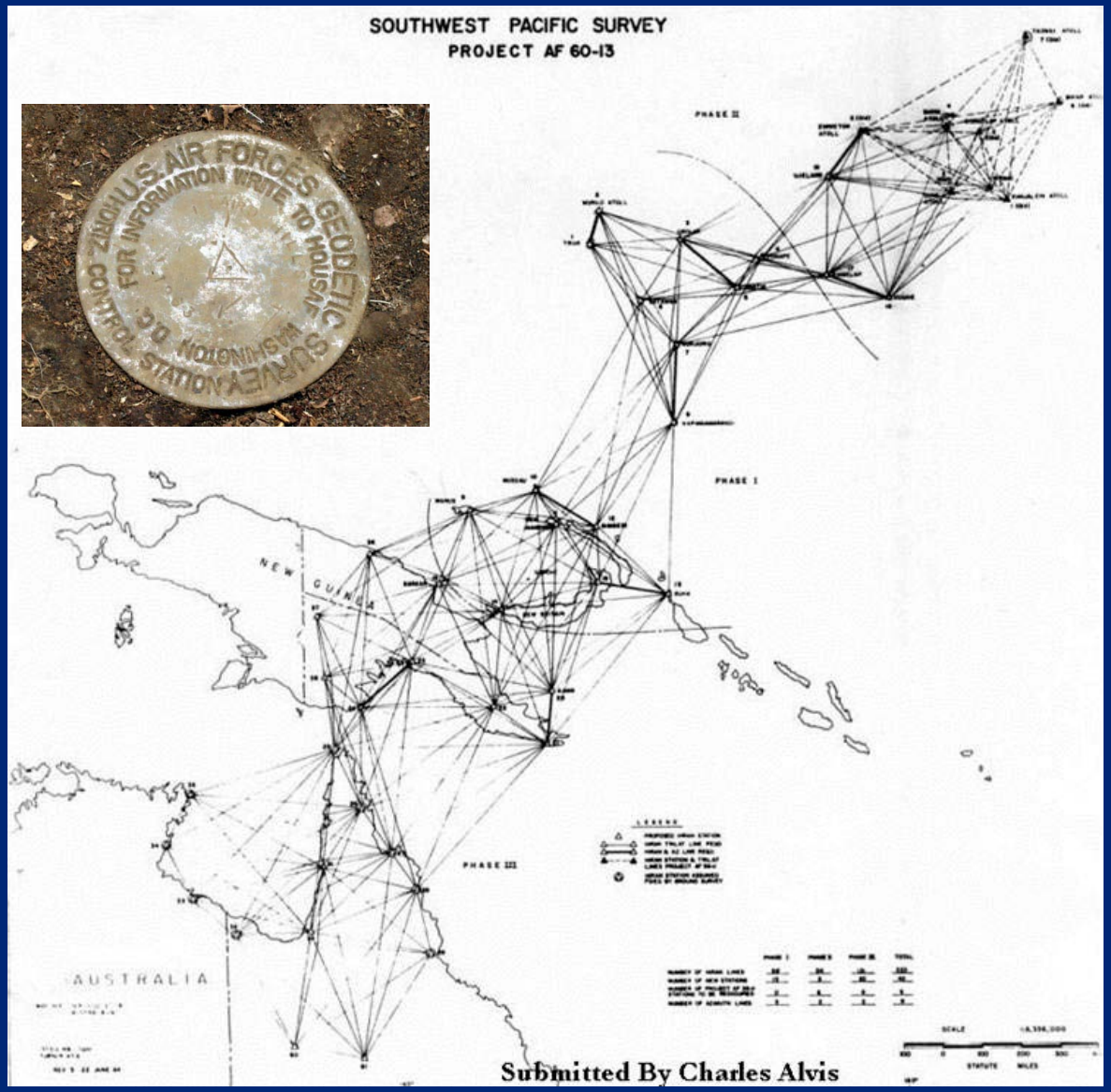
Longest line 870 km

1962-1964

16 stations including Aird Hills in 1963

Based on Mercury 165 Ellipsoid

Weak connection to Australia with ~10 m offset

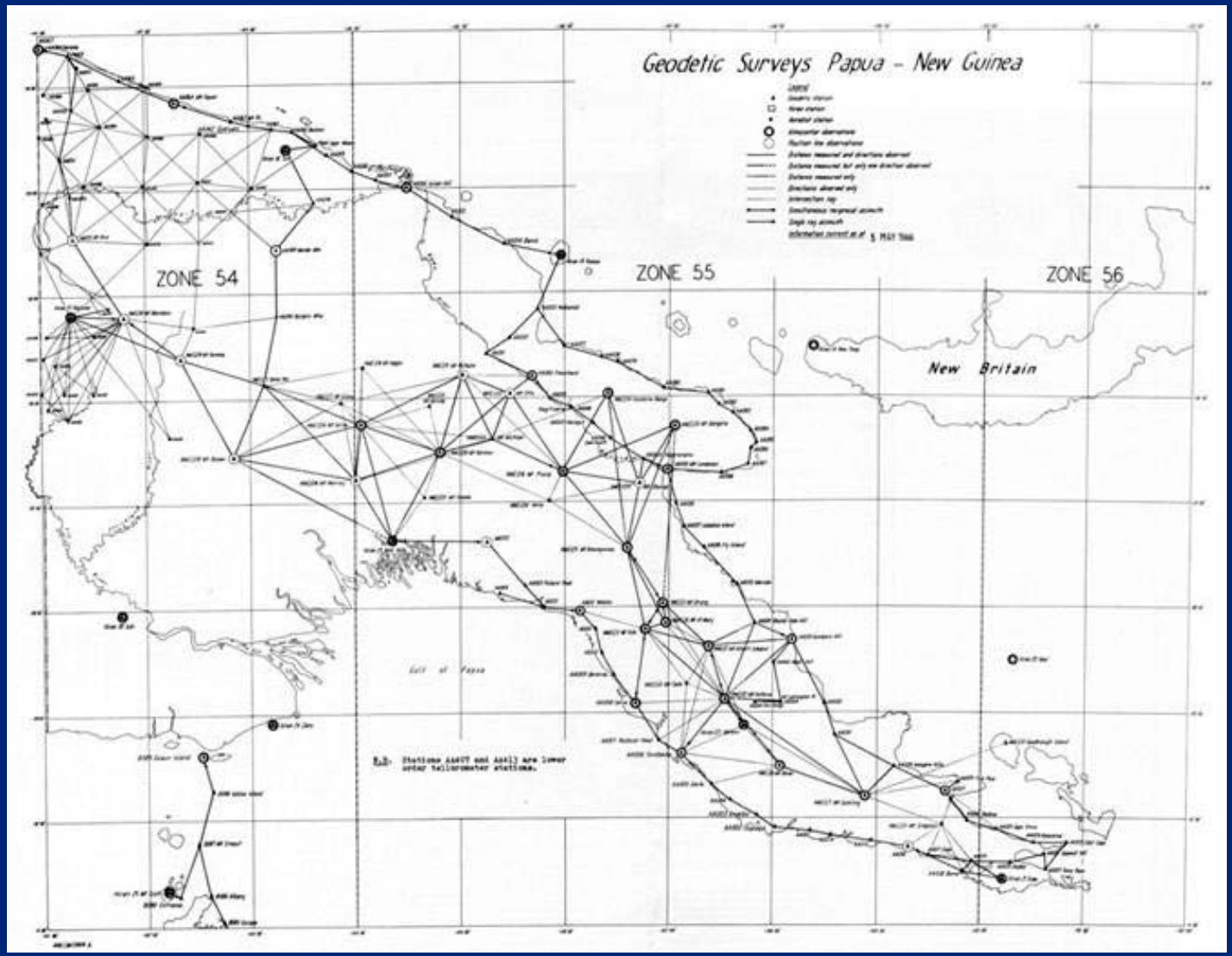


PNG Geodetic Surveys 1960s - AGD66

1963-1965 Geodetic Survey

Australian Army (AA) Royal Australian Army Survey Corps Coastal (AA stations)

and PNG NMD inland (NM/J stations)



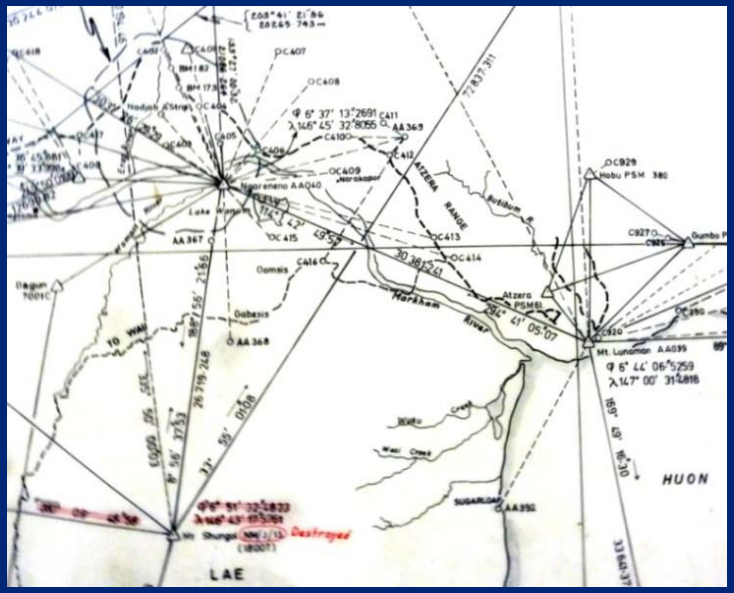
Aerodist and AGD66 difference with Australia

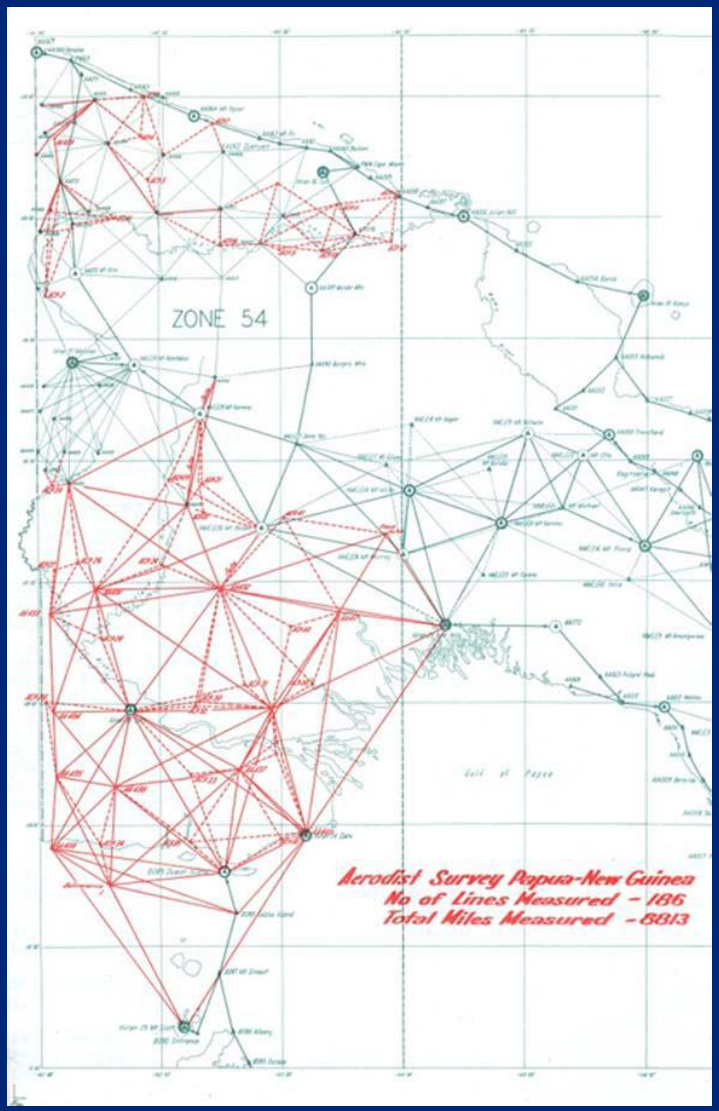
Air-to-ground trilateration

(Aircraft used as trig stations!)

Used in PNG in the low lying foreland areas devoid of notable mountain peaks for trig stations.

Larger imprecision resulting in AGD66 difference in PNG





1:100 000 Topographic Mapping – Skai Piksa

Commenced 1964

Maps published between 1969 and 1980

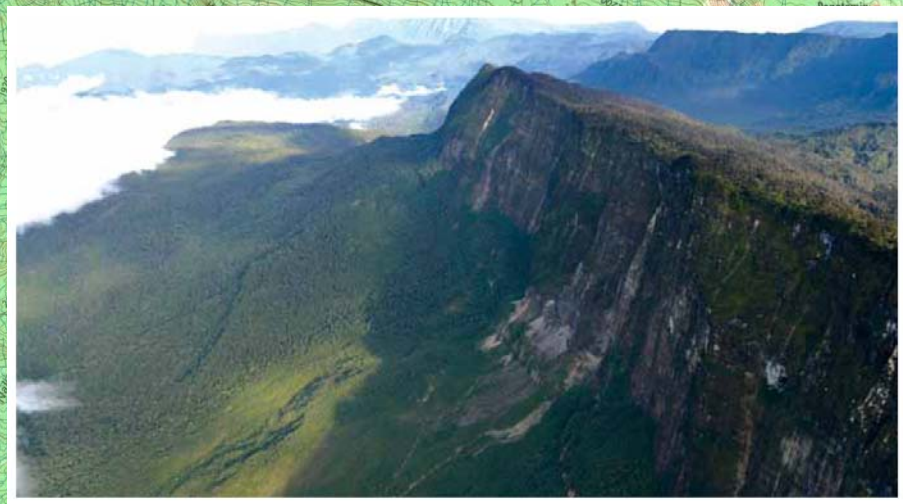
Skai Piksa – aerial photography 1973-1975 using Wild RC10 cameras mounted in Canberra Bombers

Support from AAM (Australian Aerial Mapping) Jim Tait and Keith Barrie – also QASCO and Mapmakers

Datum AGD66 (Mainland and New Britain) WGS72 remote islands

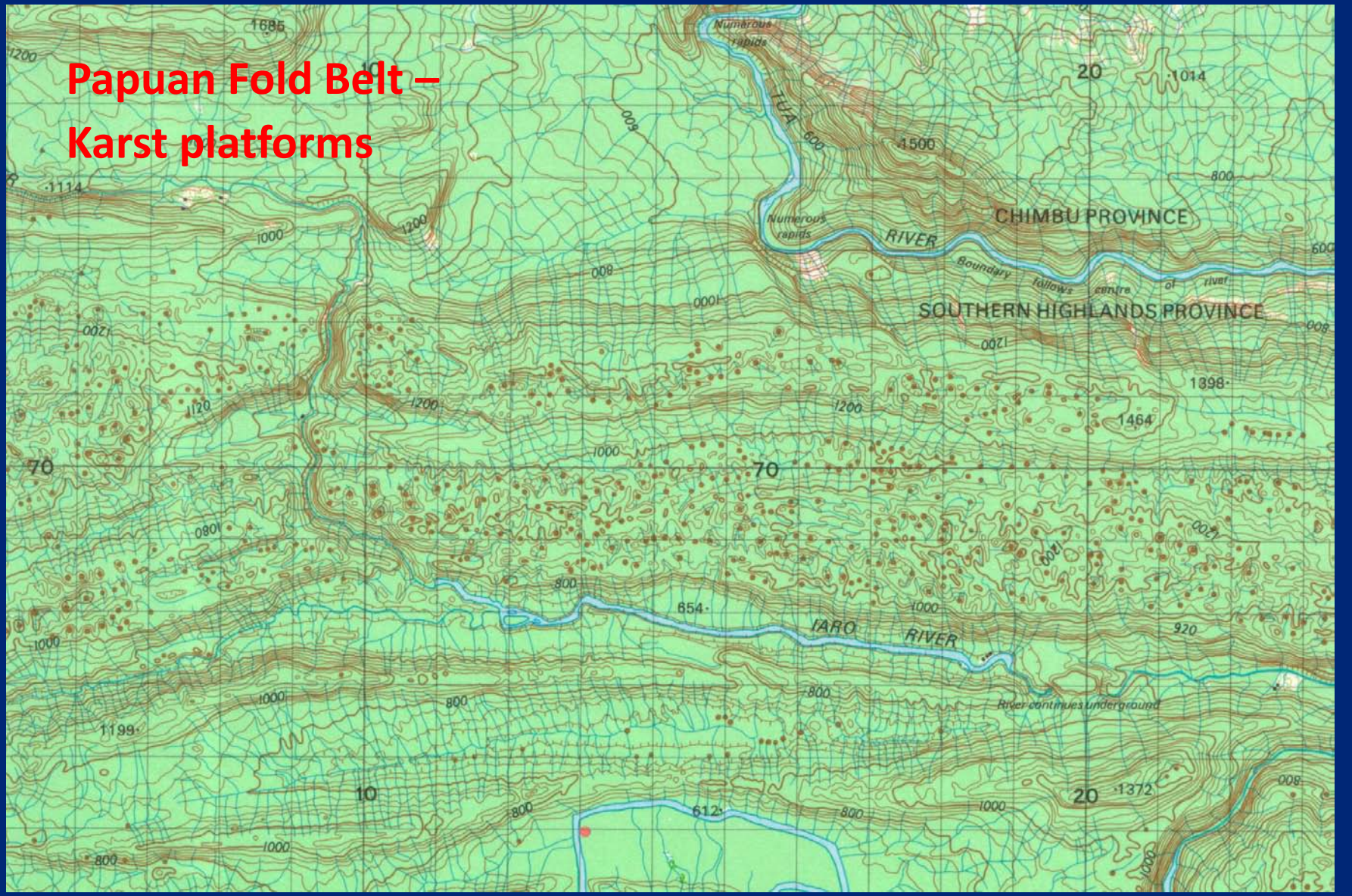
1:250000 JOG maps derived from 1:100000

Hindenburg Wall

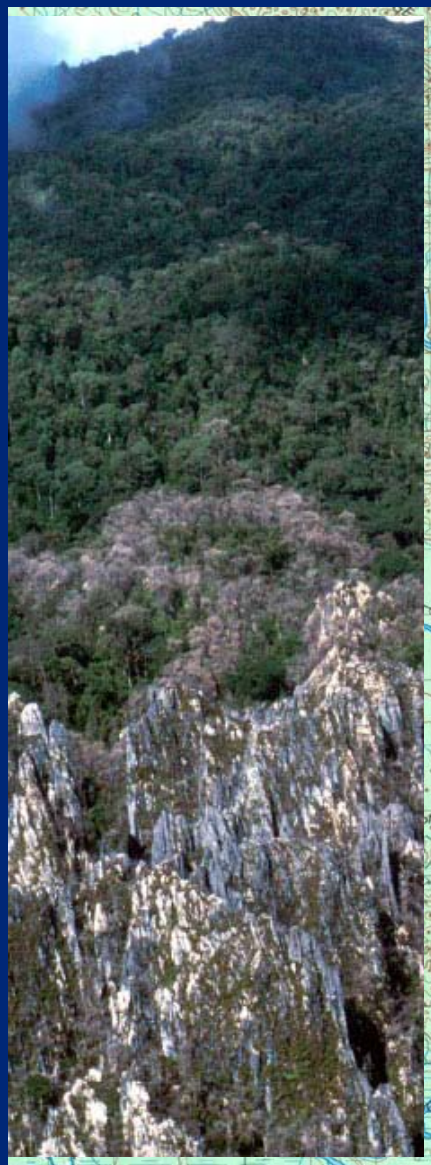


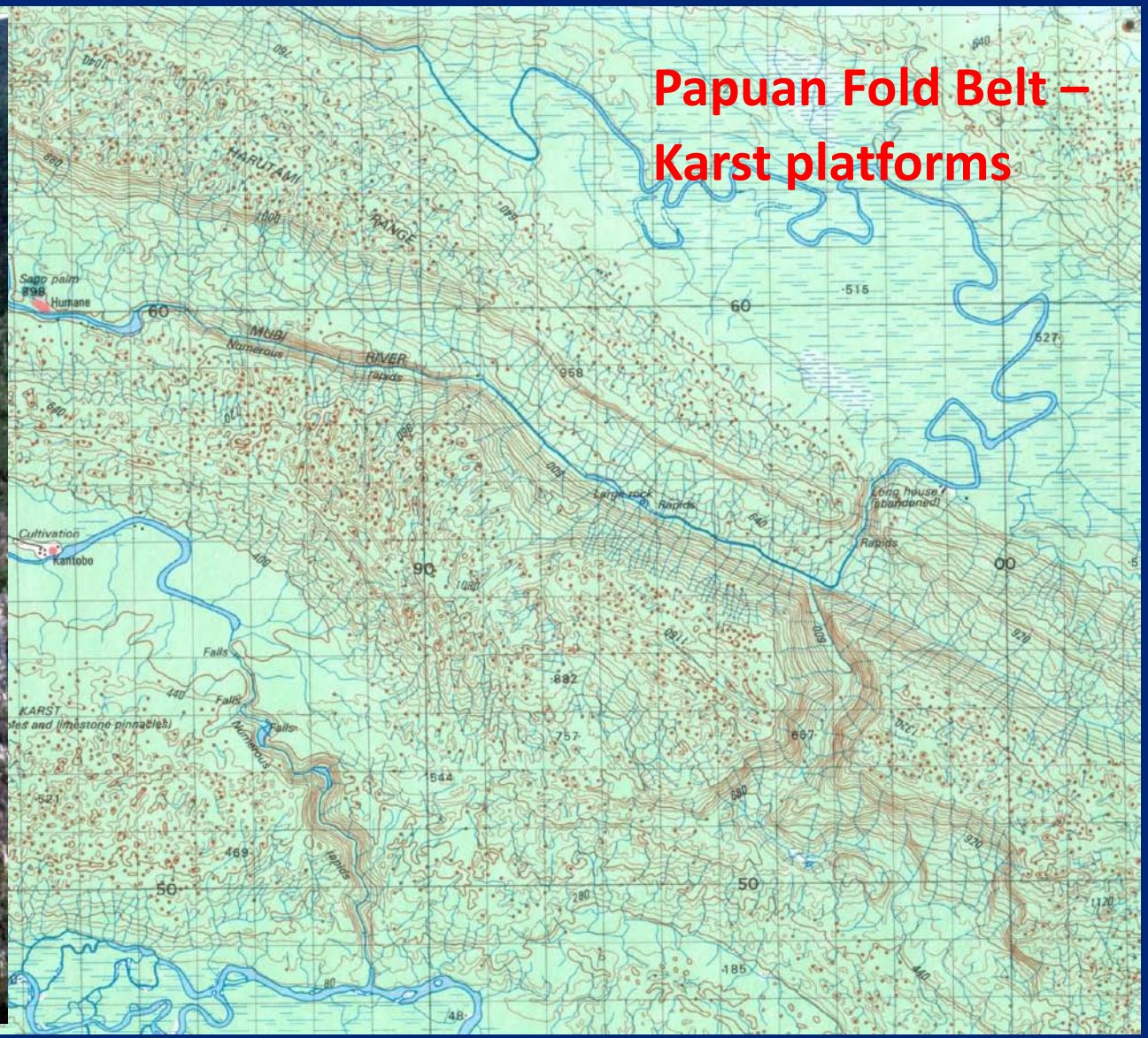
Extreme topography

Extreme topography



Extreme topography





Enter the space age for geodesy – Transit Doppler 1974-1988

1974-1979

RASvy 8 FD SVY SQN -

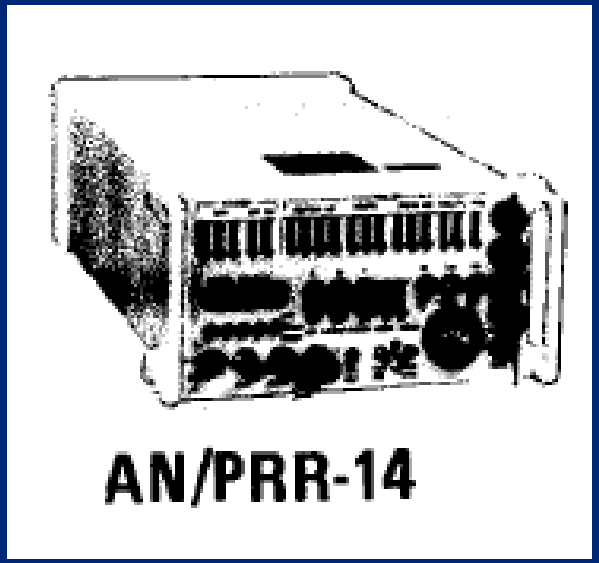
202 Doppler Fixes using AN/PRR 14 Geoceivers

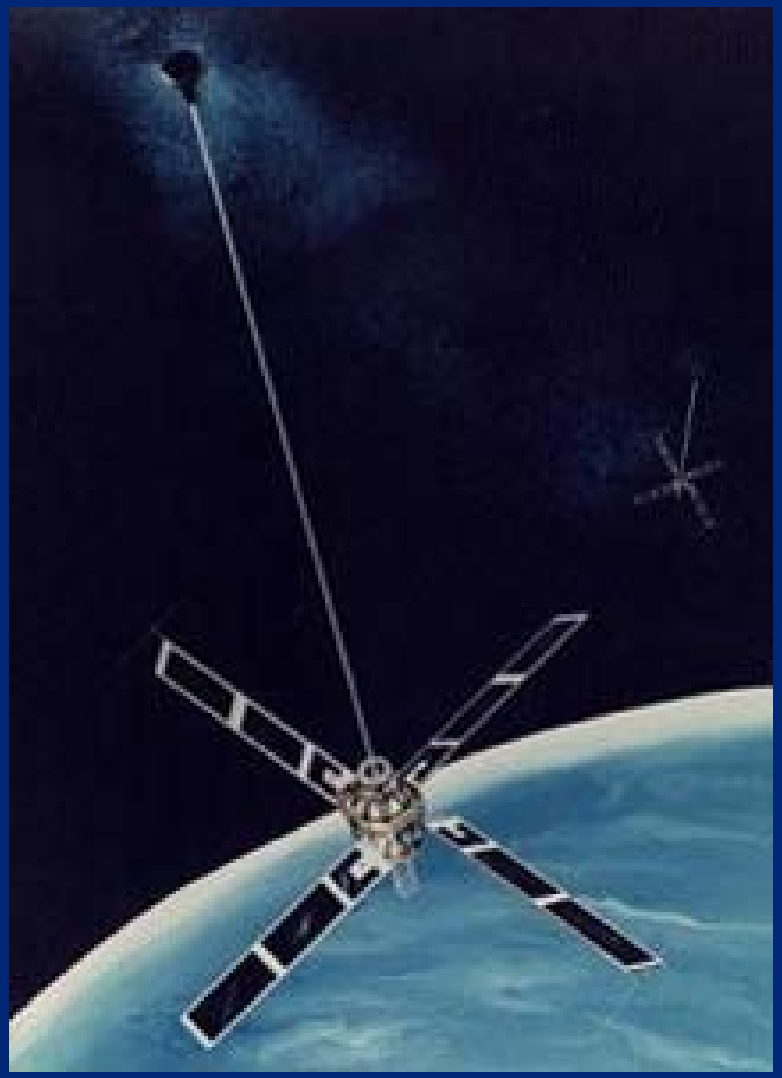
US Navsat system

NWL 9D ellipsoid – later transformed to WGS72.

Accuracy 1-4 metres

But with 24-25 m E-W offset from WGS84.





First measurements of tectonic deformation

1975

Barry Sloane and Jim Steed (DNM)

Construction of trilateration pillars across Markham valley

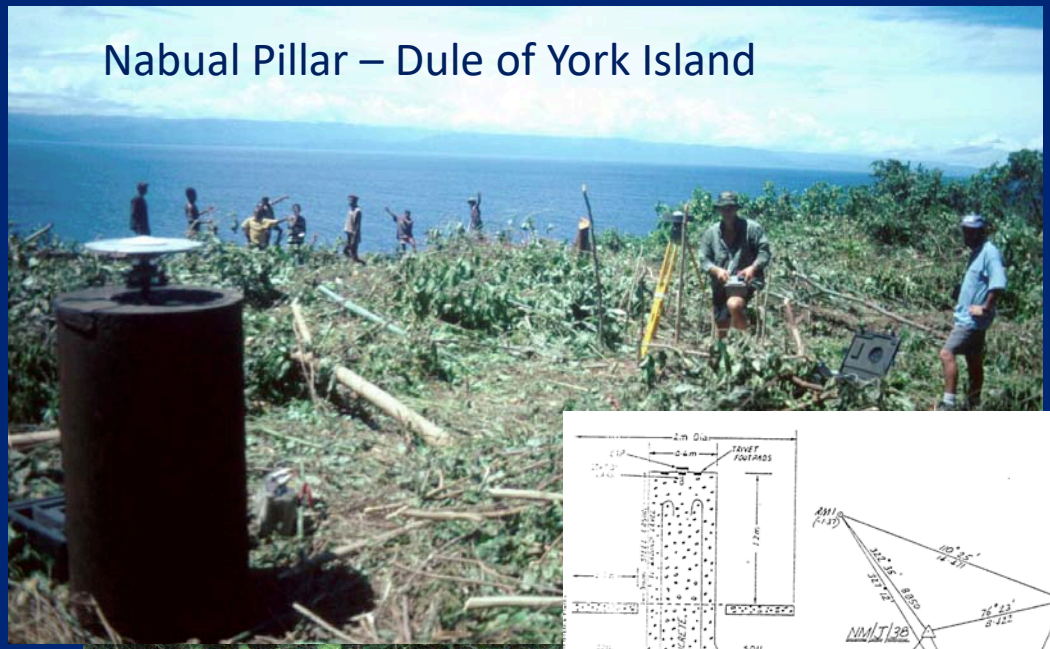
-Repeat measurements to directly measure tectonic deformation

-Similar network established across St Georges channel

-Results inconclusive due to poor siting (away from active faults) & construction

& short time span

of repeat measurement



Tinbal – Crustal Motion Pillar – New Ireland, PNG

Tectonic deformation surveys – Doppler - UNSW

1981

15 station doppler network

Peter Angus-Leppan and Peter Morgan

Using JMR1A and JMR1 Doppler receivers

Network not reobserved by Doppler but with GPS

Doppler data reprocessed to 30 cm precison by Simon McClusky at UNSW

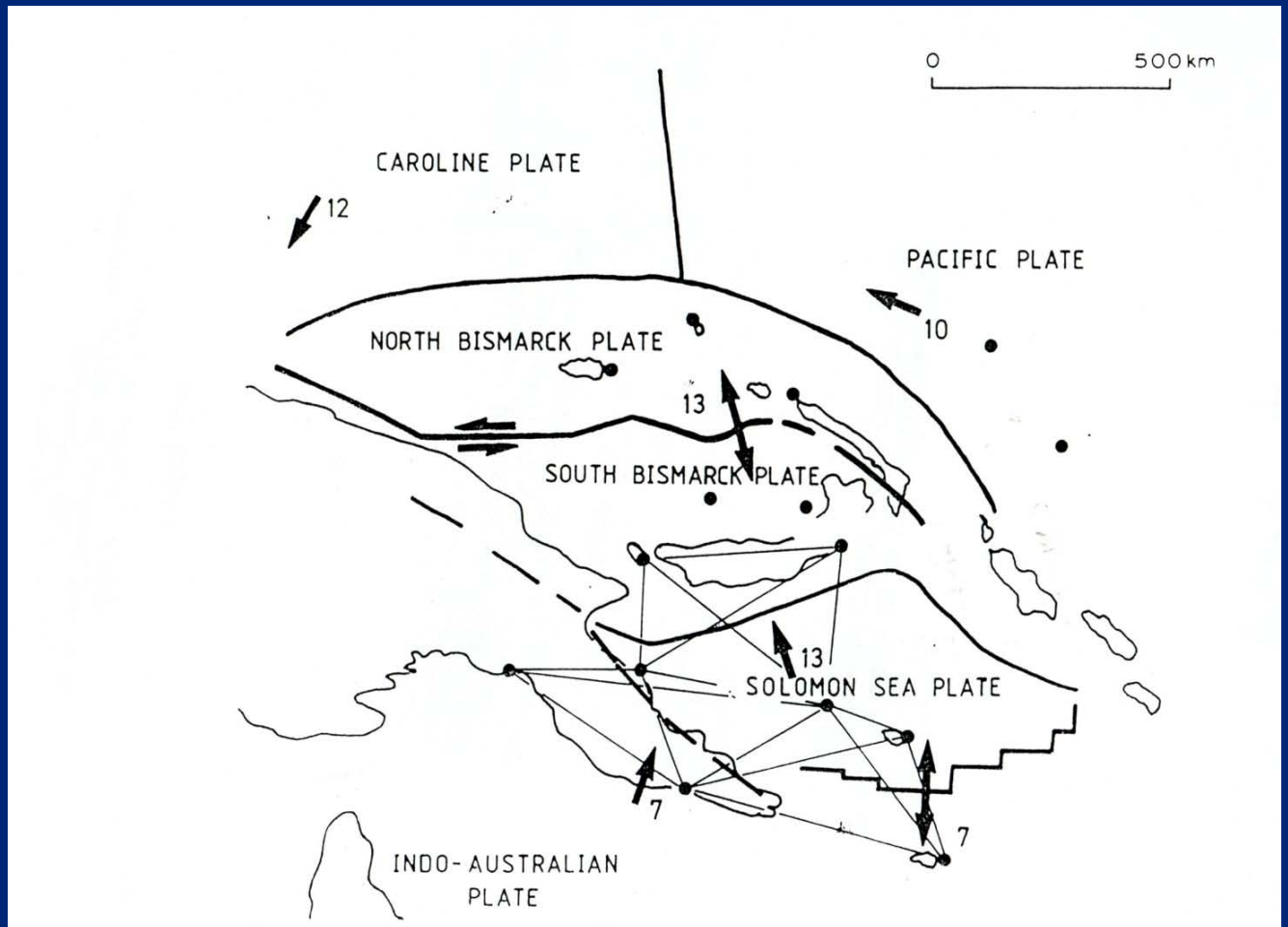


Fig. 2. Proposed crustal motion network to be surveyed in 1990 with GPS. Stations of the 1981 Doppler crustal plate survey are shown by solid circles.

First GPS Survey – Bevan Rapids and Purari

1988

SE Oil and Gas with RMIT

(Talbot and Carman)

Used Trimble 4000SX receivers + gravity measurements

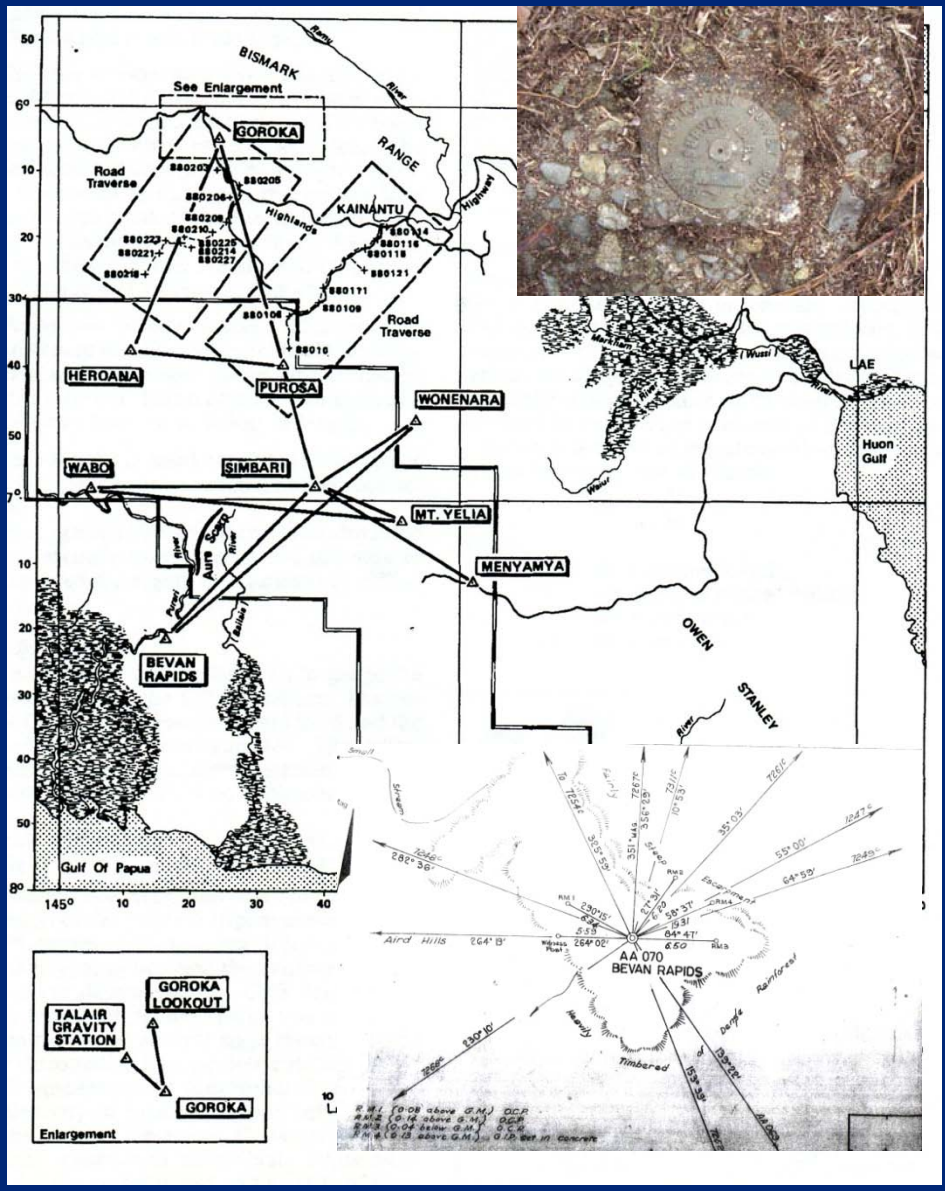
Occupied NMB Control from 1970s.

AA070 Bevan Rapids

Processed using TRIMVEC software

Heralded extensive use of GPS for Oil and Gas Exploration

(seismic surveys and well head locations)



Operation Kumul – PNG / Indonesian Border Mapping 1989 - 1994

1989-1994

Operation Kumul

RASvy 2 FD Svy Sqn and 4 Fd Survey Sqn

1:50000 border mapping

Using GPS control with TI 4100 GPS receivers

(Texas Instruments)

Some antennae elevated above jungle canopy using inflatable balloons

Tectonic motion GPS Surveys 1990 to 1992

1990, 1991 and 1992

GPS Observation Campaigns

UNSW funded by ANU RSES

Combined effort with NMB geodetic section and GPSCO

11 stations of 1981 Doppler network + new stations observed for multiple days.

Trimble 4000 SST and 4000 STD receivers

Data processed using Bernese Software

FIGURE 6 Some of the field party for the 1992 GPS crustal motion survey. Front row: Vic Macolino, Wahun Nohu, Loina Madanga, Piten Nama, Art Stolz. Back row: Roger Harvey, John Oa, Simon McClusky, Simon McElroy, Wesley Loratung, John Gilliland (left to right).

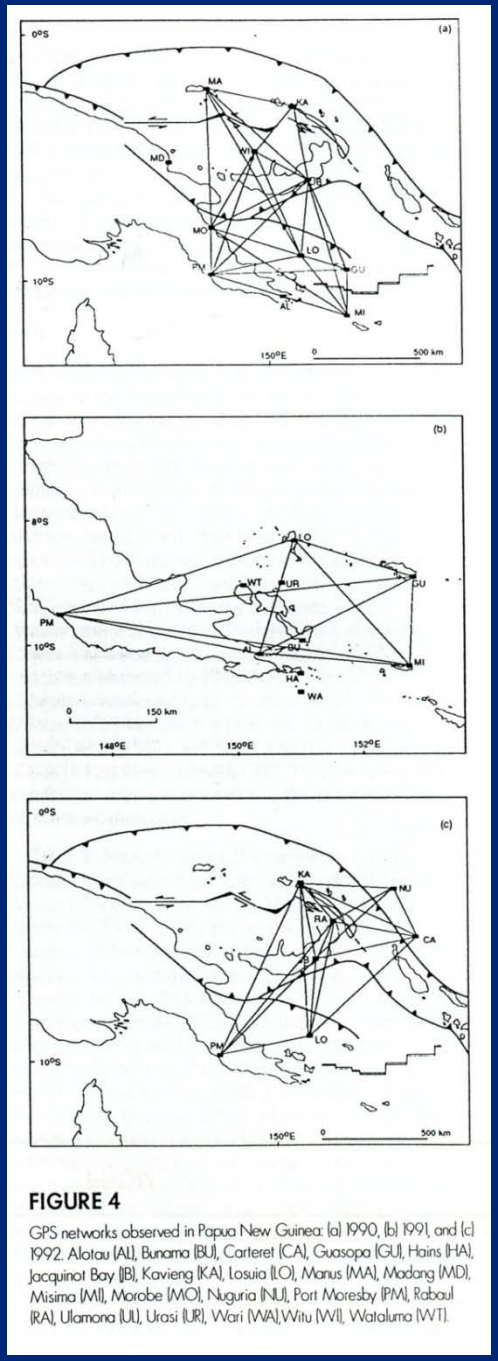


FIGURE 4

GPS networks observed in Papua New Guinea: (a) 1990, (b) 1991, and (c) 1992. Alotau (AL), Bunama (BU), Carteret (CA), Guasopa (GU), Hains (HA), Jacquinot Bay (JB), Kavieng (KA), Losuia (LO), Manus (MA), Madang (MD), Misima (MI), Morobe (MO), Nuguria (NU), Port Moresby (PM), Rabaul (RA), Ulamona (UL), Urasi (UR), Wari (WA), Witu (WI), Wataluma (WT).

PNG94 Geodetic Datum surveys 1993 and 1994

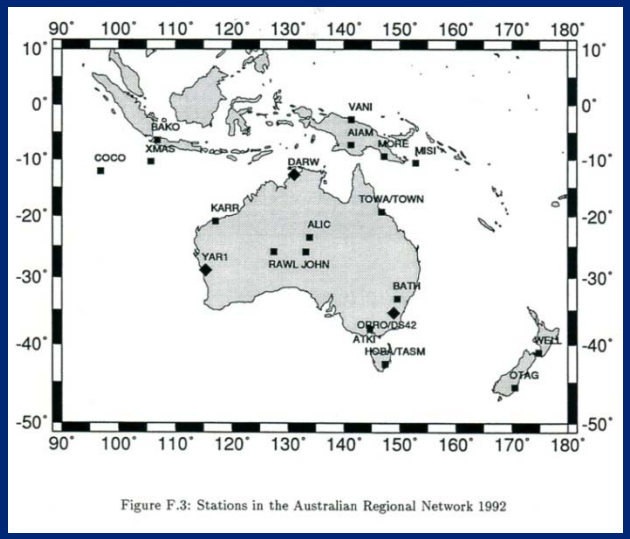


Figure F.3: Stations in the Australian Regional Network 1992

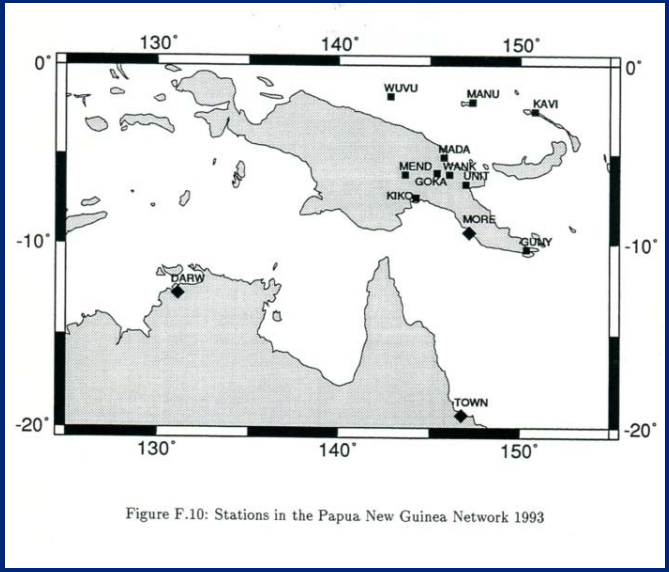


Figure F.10: Stations in the Papua New Guinea Network 1993

1993, 1994

AUSLIG and NMB GPS campaigns over Australia and PNG to develop new geocentric geodetic datum - Ashtech Z-12 receivers

Data processed by Peter Morgan using GAMIT software

In PNG additional GPS measurements made

Processed using Ashtech PRISM and GPPS, John Allman NEWGAN adjustment software

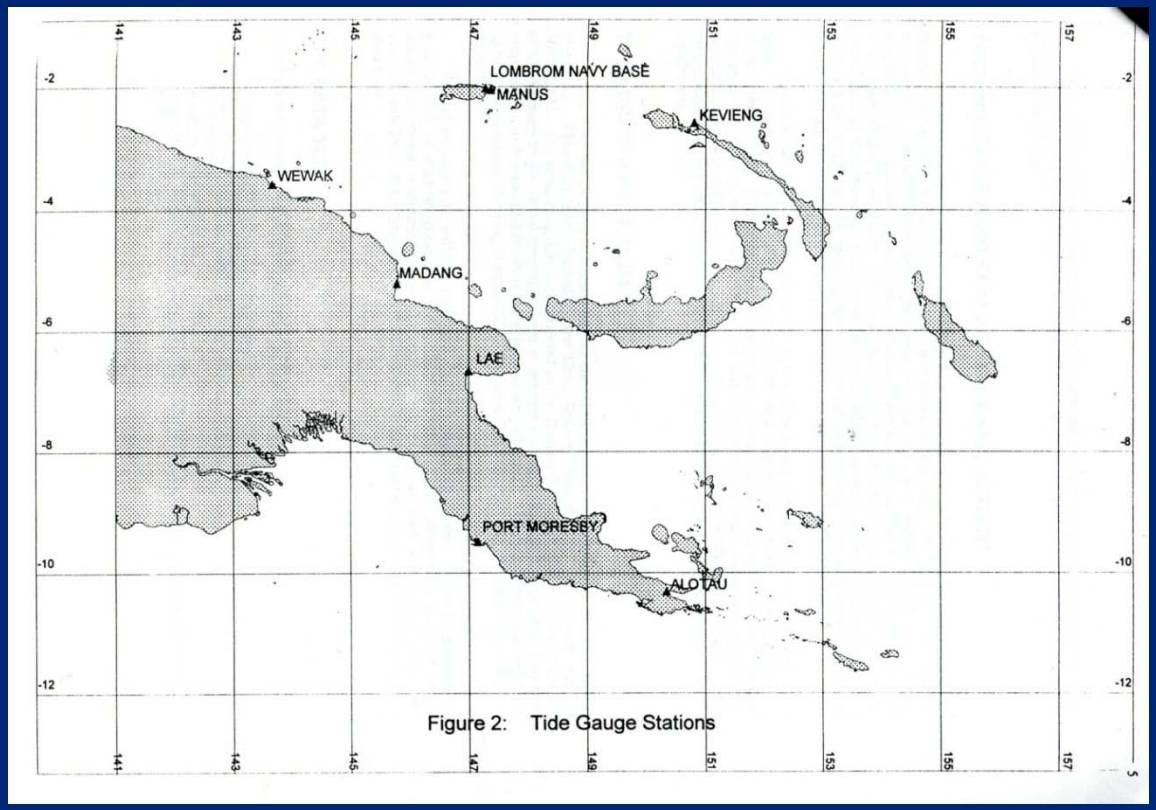
1999 adjustment:

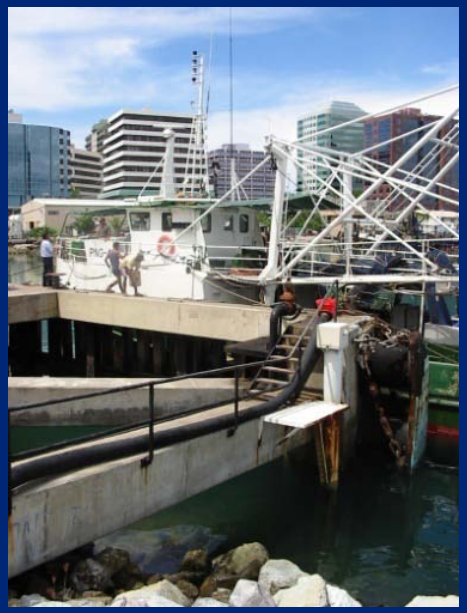
Prof. John Allman,

Jan van der Kevie

and Robert Rosa

Tide Gauge Connections, Gravity – PNG Geoid Model



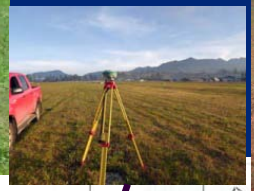


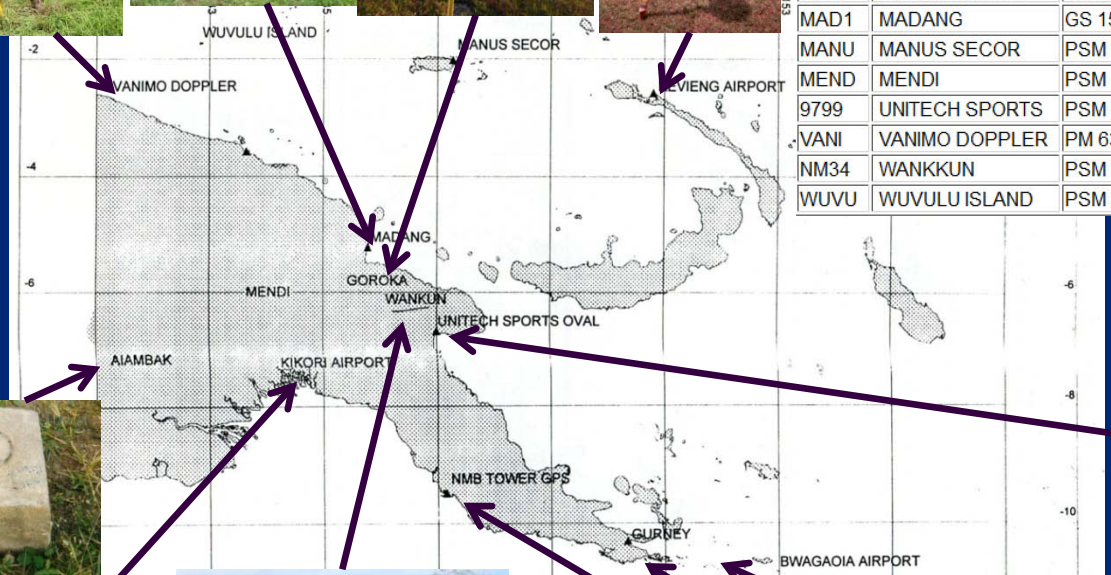
PNG Geoid model developed by Prof. Bill Kearsley UNSW and Z. Ahmad

PNG94 zero order network

Site ID	Site Name	Monument number	PNG94 Latitude	PNG94 Longitude	PNG94 Ellipsoidal Height
MORE	NMB TOWER GPS	PSM 15832	-9°26'02.76968"	147°11'12.20017"	116.610
AIAM	AIAMBAK	PSM 9550	-7°20'51.81934"	141°16'01.44646"	95.465
MIS1	BWAGAOIA AIR	PSM 9195	-10°41'19.90490"	152°49'58.93878"	87.456
GOKA	GOROKA	PSM 9833	-6°04'53.07151"	145°23'30.44618"	1664.580
ALT2	GURNEY	PSM 9538	-10°18'37.50877"	150°20'18.09080"	94.871
KAVI	KAVIENG AIR	PSM 9513	-2°34'53.06528"	150°48'22.53578"	78.828
KIKO	KIKORI AIRPORT	PSM 5583	-7°25'24.65305"	144°14'55.76611"	88.965
MAD1	MADANG	GS 15495	-5°12'41.28824"	145°46'56.19305"	73.293
MANU	MANUS SECOR	PSM 9522	-2°03'02.29337"	147°21'37.63577"	129.751
MEND	MENDI	PSM 3507	-6°08'36.73422"	143°39'22.16540"	1815.154
9799	UNITECH SPORTS	PSM 9799	-6°40'16.96985"	146°59'52.37457"	130.389
VANI	VANIMO DOPPLER	PM 63/1	-2°41'05.28039"	141°18'15.65564"	80.516
NM34	WANKKUN	PSM 15029	-6°08'52.07208"	146°04'52.44226"	510.015
WUVU	WUVULU ISLAND	PSM 15456	-1°44'07.59465"	142°50'10.07846"	79.056













GPS Surveys 1993 to 2008 – PNG Tectonics taking shape

1993-2001

UCSC – Huon Peninsula

Ramu Markham Fault

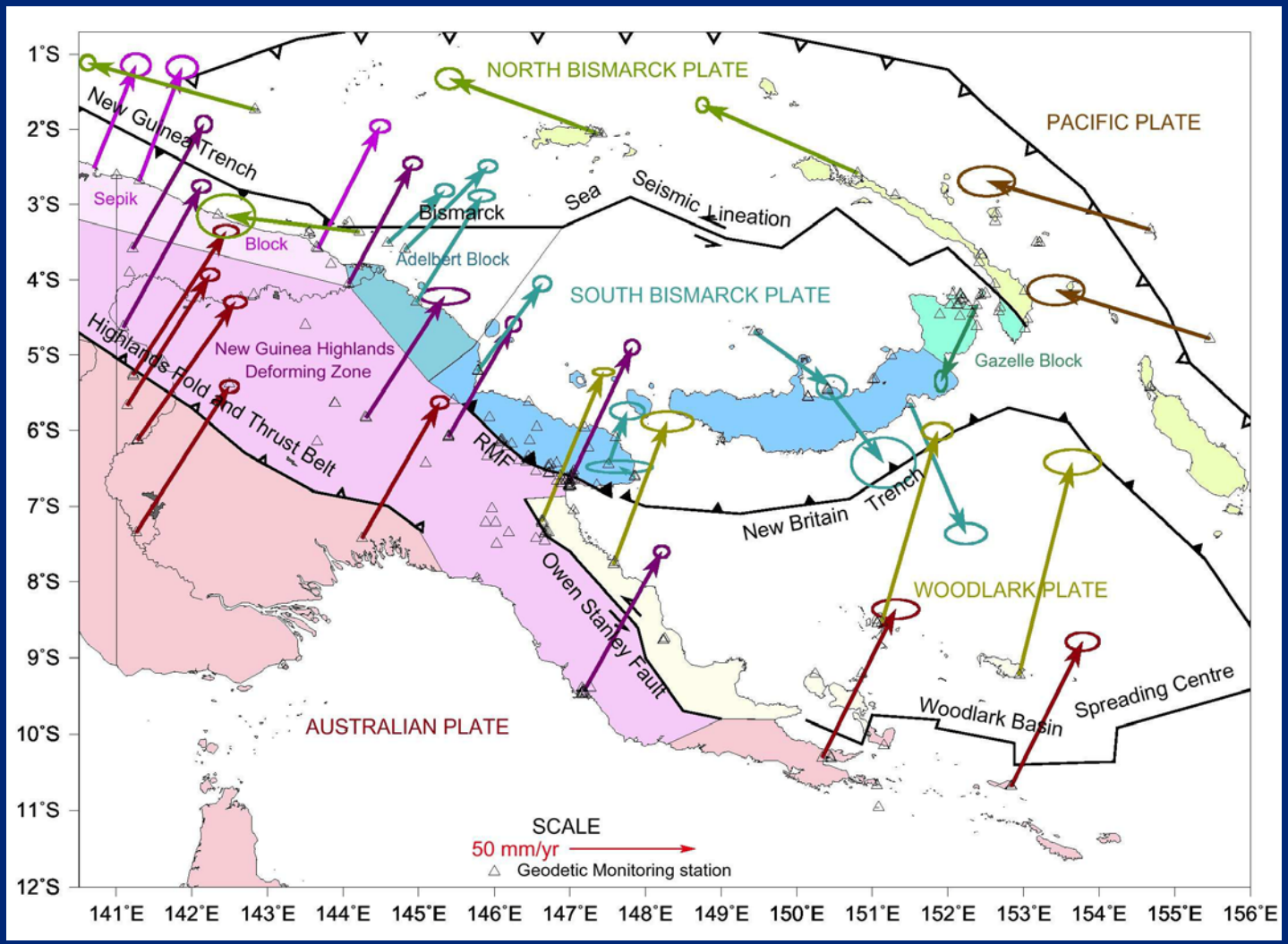
1996-2008

Australian National University

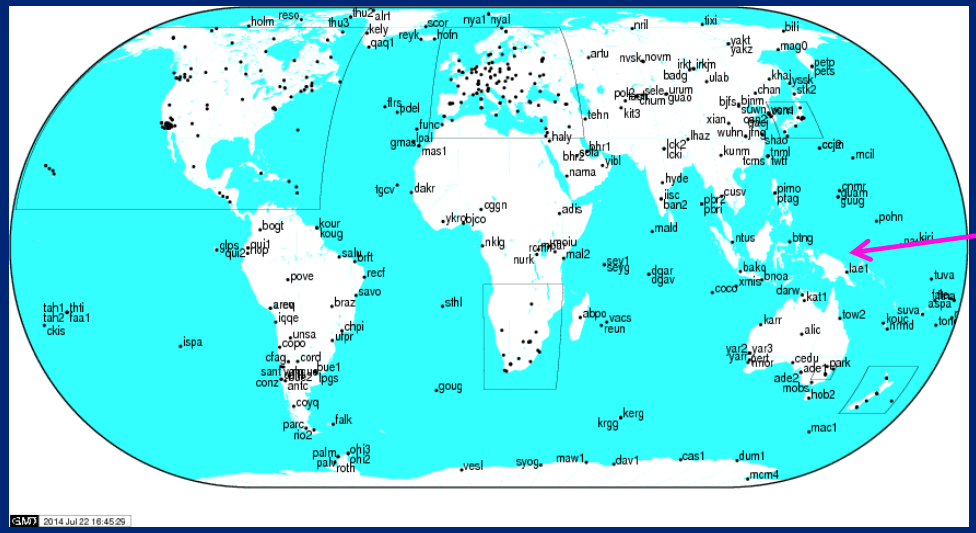
(Paul Tregoning, Richard Stanaway)

PNG wide

NMB Geodetic Section GPS surveys for DCDB and DCA



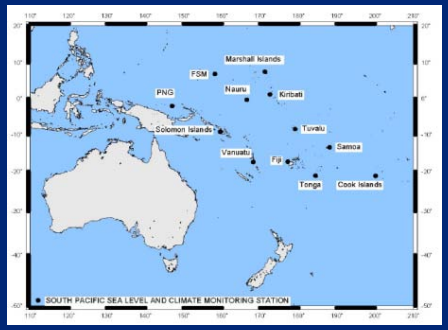
GNSS CORS and Global Contributions



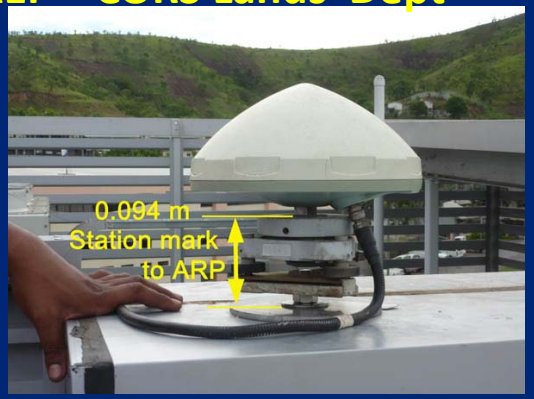
LAE1 – IGS Reference Frame Site

DORIS and GPS Base at NMB

PNGM CORS – Manus



APREF – CORS Lands Dept



2011 re-adjustment of PNG94

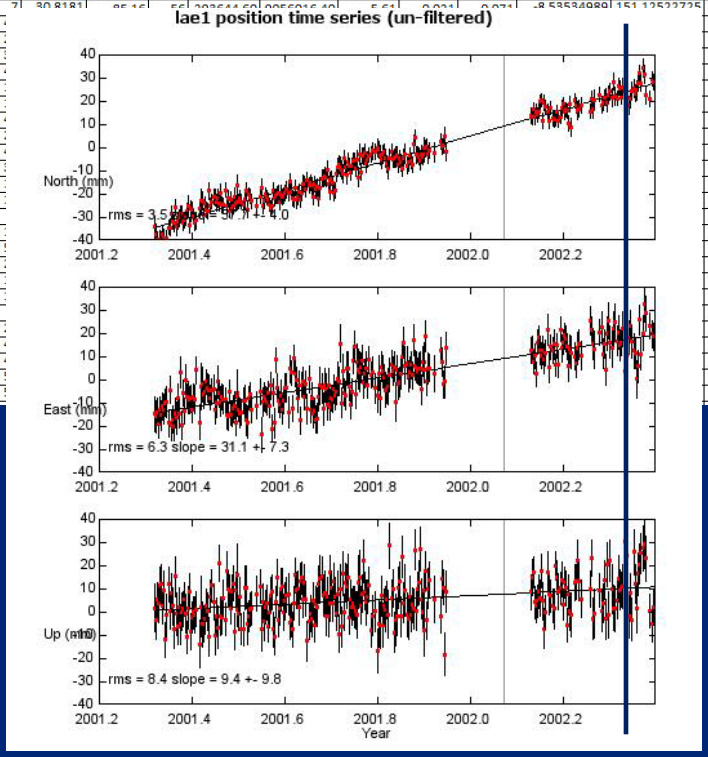
Quickclose in conjunction with PNG OSG geodetic section have re-computed and densified the PNG94 network to improve formal uncertainties

Implemented a semi-dynamic datum

(deformation model using estimated site velocities from microplate Euler pole, fault locking models and known coseismic offsets) to enable ITRF and WGS84 coordinates to be propagated to epoch 1994.0

PNG94 (ITRF92 at epoch 1994.0) - 1st order control - Adjustment 7th June 2008 - Updated 1st December 2011

Station location			PNG94 Ellipsoidal Coordinates							PNGMG94 Grid Coordinates			MSL RL	ITRF Site Velocity		PNG94	
Location	GPS ID	NMB Number	Latitude			Longitude			Ellipsoid Height	Zone	Easting	Northing	(PNG08)	E	N	Latitude	Longitude
														m/yr	m/yr	Decimal	Decimal
Aiambak	AIAM	PSM 9550	-7	20	51.8206	141	16	1.4470	95.52	54	529475.73	9187801.94	21.20	0.037	0.058	-7.34772794	141.26706861
Alotau - Gurney Airport	ALT2	PSM 9538	-10	18	37.5094	150	20	18.0912	94.87	56	208478.37	8859053.57	16.37	0.031	0.058	-10.31041928	150.33835867
Bulolo - Unitech Weather	BULO	PSM 32629	-7	12	25.0357	146	37	32.2264	802.11	55	458667.37	9203356.01	722.94	0.027	0.058	-7.20695436	146.62561844
Buka Airport	BUK1	PSM 4871	-5	25	34.3712	154	40	8.4373	73.25	56	684918.22	9399967.57	2.87	-0.059	0.031	-5.42621422	154.66901036
Daru - Airport	DARU	AA 440/A	-9	5	15.5229	143	12	27.1952	80.28	54	742639.83	8994719.42	5.28	0.035	0.055	-9.08764525	143.20755422
Finschhafen	FINS	PSM 19471	-6	36	55.4209	147	51	17.6868	74.24	55	594504.66	9268686.35	7.42	-0.006	0.004	-6.61539469	147.85491300
Gobe - Airport	GOBE	PSM 15262	-6	52	45.5700	143	43	21.3500	129.24	54	800901.00	9238734.50	50.98	0.034	0.054	-6.87932500	143.72259722
Goroka - Airport	GOKA	PSM 9833	-6	4	53.0717	145	23	30.4470	1664.47	55	322023.98	9327531.64	1584.83	0.023	0.046	-6.08140881	145.39179083
Hoskins - Airport	HOSK	PSM 9795	-5	28	0.4073	150	24	31.6614	101.35	56	212869.72	9395119.32	18.42	0.022	-0.027	-5.46677981	150.40879483
Kavieng - Airport	KAVI	PSM 9513	-2	34	53.0660	150	48	22.5361	78.81	56	256077.96	9714464.61	2.85	-0.067	0.027	-2.58140722	150.80626003
Kenabot - Lands Base	KENB	PSM 23342	-4	20	45.1168	152	16	7.9951	136.69	56	418875.65	9519602.79	63.12	-0.002	-0.041	-4.34586578	152.26888753
Kerema - Catholic Mission	KERE	PSM 31703	-7	57	28.0191	145	46	19.0726	97.57	55	364647.58	9120168.45	21.32	0.030	0.052	-7.95778308	145.77196461
Kikori - Airport	KIKO	PSM 5583	-7	25	24.6531	144	14	55.7677	88.93	55	196298.45	9178490.00	12.38	0.035	0.054	-7.42351475	144.24882436
Kiunga - Airport	KIU3	PSM 32685	-6	7	28.3824	141	17	12.2347	112.45	54	531725.31	9323018.83	37.48	0.038	0.056	-6.12455067	141.28673186
Kumul - Oil Export Platform	KU34	Kumul 34	-8	3	51.3916	144	33	38.3558	103.3	54	892563.96	9106883.55	28.22	0.035	0.054	-8.06427544	144.56065439
Lae - Unitech DSLS Base	LAE1	PSM 31107	-6	40	25.3661	146	59	35.4668	140.37	55	499246.79	9262320.80	67.45	0.026	0.052	-6.67371281	146.99318522
Lae - Unitech Sports	9799	PSM 9799	-6	40	16.9707	146	59	52.3754	130.31	55	499765.91	9262578.60	57.40	0.026	0.052	-6.67138075	146.99788206
Lake Kopiago - Airport	KOPI	PSM 17001	-5	23	9.0852	142	29	42.1907	1412.79	54	665650.98	9404480.51	1329.45	0.031	0.055	-5.38585700	142.49505297
Losuia	LOSU	AA 583	-8	32	7.2596	151	7	30.8181									
Madang - Airport	MAD1	GS 15495	-5	12	41.2891	145											
Manus - Lombrum Secor	MANU	PSM 9522	-2	3	2.2944	147											
Mendi - Airport	MEND	PSM 3507	-6	8	36.7344	143											
Misima - Airport	MIS1	PSM 9195	-10	41	19.9049	152											
Moro - Airport	MORA	PSM 17442	-6	21	44.9072	143											
Mount Hagen - Airport	HGEN	PSM 3419	-5	49	55.7591	144											
Nadzab - Airport	NADZ	ST 31024	-6	33	47.9879	146											
Namatanai - Airport	NAMA	GS 19461	-3	39	58.5422	152											
Nogoli Hides - Helipad	NOGO	PSM 30041	-5	56	2.4348	142											
Pomio	JACQ	PSM 9515	-5	38	42.9782	151											
Popondetta	POPN	PSM 9371	-8	46	9.6499	148											
Port Moresby - NMB Base	NMB2	PSM 31927	-9	26	2.7697	147											
Rabaul - RVO Base	RVO_	RVO	-4	11	27.1915	152											
Tabubil - Airport	TAB2	PSM 32695	-5	16	45.0122	141											
Tari - Airport	TARI	T630	-5	50	37.7496	142											
Tokua - Airport	TOKU	GS 9822	-4	20	27.7832	152											
Tufi - Hospital	TUFI	PSM 7518	-9	4	46.4549	149											
Vanimo - Doppler	VANI	PM 63/1	-2	41	5.2819	141											
Wankkun - Pillar	NM34	NM//34	-6	8	52.0739	146											
Wafi - Helipad	WAF1	PSM 32631	-6	51	54.6238	146											
Wau - Airport	WAUA	GS 9840	-7	20	48.5674	146											
Wewak - Airport	WEWK	PSM 15497	-3	35	2.5848	143											
Woodlark - Guasopa	GUA1	PSM 9519	-9	13	30.0049	152											
Wuvulu	WUVU	PSM 15456	-1	44	7.5951	142											



PNG08 Geoid Model

EGM2008 model

fitted to observed MSL at limited TG around PNG

2.5’ grid of N values

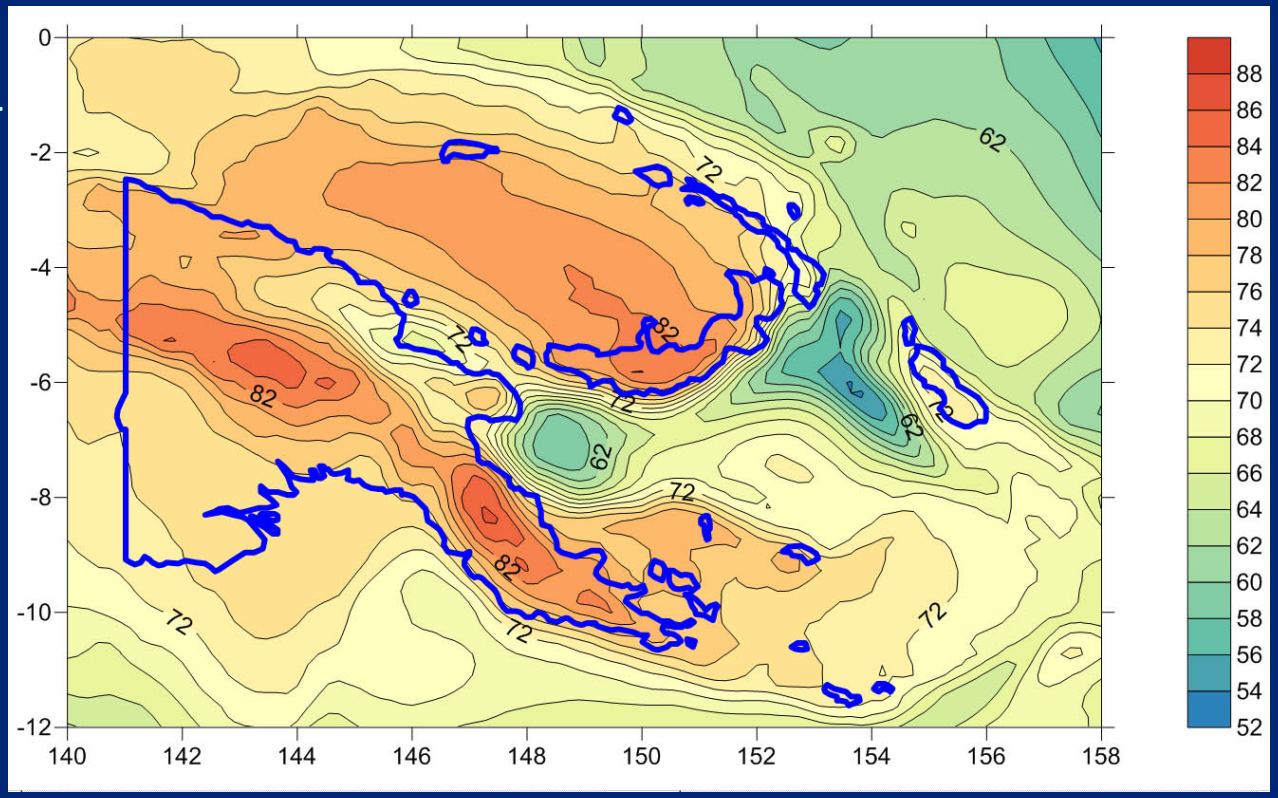
Precision 0.2 m 1σ

ASCII, Leica, Topcon and Trimble formats for use in GNSS and GIS

Future improvements:

Dynamic height model

MDT updates & denser TG



Transformation parameter estimation – EPSG

Transformation parameters between datums have been estimated using GPS observations on earlier datum monuments (e.g. AGD66 and WGS72)

Parameters published at EPSG and soon ISO TC 211

Usage in GIS and spatial databases

AGD66 to PNG94 transformation parameters

Area of Use	EPSG Code	Accuracy (m)	Tx (m)	Ty (m)	Tz (m)	Rx (sec)	Ry (sec)	Rz (sec)	Sc (ppm)
Medium accuracy - 7 parameter Position Vector convention									
PNG Mainland	6937	1.0	-0.41	-2.37	2.00	3.592	3.698	3.989	8.843
PFTB	6939	1.0	-131.876	-54.554	453.346	-5.2155	-8.2042	0.0900	5.02
North Fly	6941	0.5	45.928	-177.212	336.867	-4.6039	-3.0921	0.5729	36.796
Medium accuracy - 7 parameter Coordinate Frame rotation convention									
PNG Mainland	6937	1.0	-0.41	-2.37	2.00	-3.592	-3.698	-3.989	8.843
PFTB	6939	1.0	-131.876	-54.554	453.346	5.2155	8.2042	-0.0900	5.02
North Fly	6941	0.5	45.928	-177.212	336.867	4.6039	3.0921	-0.5729	36.796
Lower accuracy - 3 parameter									
PNG Mainland	6938	4.0	-129	-58	152				
PFTB	6940	2.0	-131.3	-55.3	151.8				
North Fly	6942	2.5	-137.4	-58.9	150.4				

Recent Surveys

2008 –

Oil and Gas and Mining GPS Survey control

2008 –

LiDar control surveys

2012-2014

PNGASL WGS-84 Survey

Arman Larmer Surveys

Asia Pacific Surveys

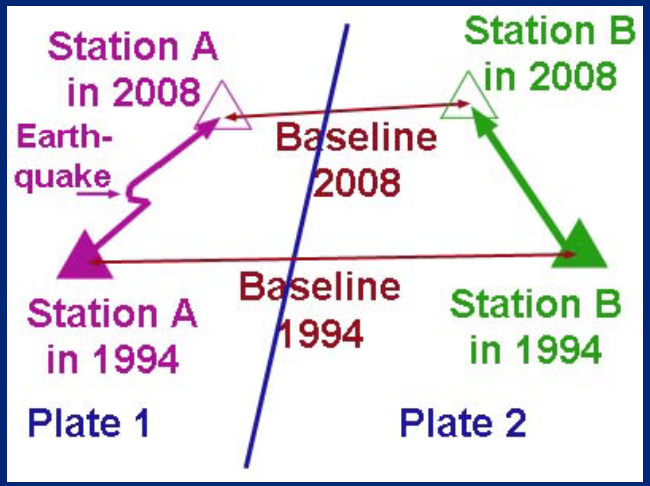
PNG Land Surveys

PNG94 issues – mostly earthquakes!

Originally realised as a static datum in a very complex tectonic environment – regular large earthquakes

(cannot measure baselines across plate boundaries)

Cannot transform current ITRF and WGS84 to PNG94 with any precision without a suitable velocity and deformation model (conformal transformations cannot be applied)



Planned improvements to datum

Need good GPS observations on PSMs at useful and secure locations

Repeat GNSS observations on all geodynamics stations to improve velocity model

Gridded velocity and seismic patch model for PNG, to enable PPP and Auspos solutions to be propagated to epoch 1994.0 or other epoch and to facilitate GNSS post-processing within ITRF

Construction of CORS at each major provincial capital to support local GNSS surveys and DCDB updates. This aspect could be run by the private sector as a subscription service to surveyors. RTK corrections by radio link or GSM.

Tide Gauge observations and connections to improve geoid model and develop offset models for Chart Datum, LAT and CDW height datums

PNG2020? and beyond

Existing PNG94 already 21+ years old now

(i.e. Possibly past its coming of age)

PNG2020? (ITRF2014 at epoch 2020.0) would remove any uncertainty arising from 26 years of earthquakes (coseismic and postseismic deformation).

Coordinates closer to current ITRF, but up to 2 m different to PNG94.

Requires gridded distortion model for PNG94 to PNG2020 transformations (e.g. legacy data such as DCDB, project datums, GIS data).

The future of positioning circa 2030

multi-GNSS
+ augmentation (e.g. SBAS)
+ indoor positioning (e.g. Locata)
+ miniature inertial sensors

real-time
precise broadcast
orbits

4D GIS in the cloud

real-time positions

mm

active transformation model

accurate

real-time information currency

centralised data
+ clone

authoritative

ubiquitous

5G/6G wireless
and satellite comms.
(e.g. Beidou, Galileo)

mm/cm accurate real-time personal positioning and navigation – everywhere - No need for "coordinates" *per se*!

10Q tru