JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

WATER RESOURCES BOARD (WRB)
MINISTRY OF IRRIGATION & WATER MANAGEMENT

THE STUDY
ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT FOR HAMBANTOTA AND MONARAGALA DISTRICTS IN THE DEMOCRATIC SOCIALIST REPUBLIC OF SRI LANKA

FINAL REPORT

SUPPORTING REPORT

FEBRUARY 2003

PACIFIC CONSULTANTS INTERNATIONAL

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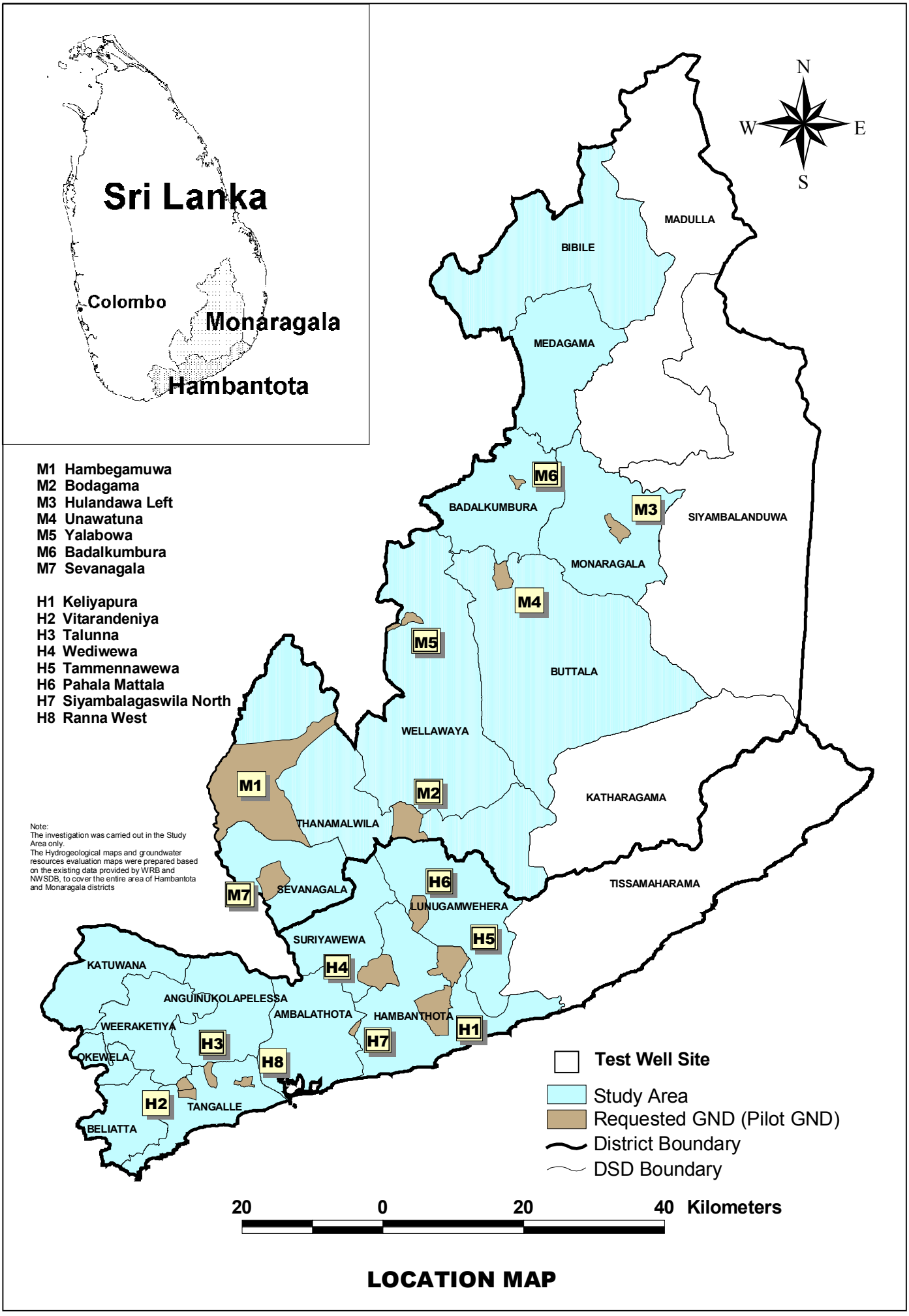

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ABBREVIATIONS

ASL, asl	: above sea level
AGL, agl	: above ground level
BGL, bgl	: below ground level
CBO	: Community Based Organization
CEA	: Central Environmental Authority
CSAMT	: Controlled Source Audio-frequency Magneto Telluric Method
DN	: Digital Number
DO	: Dissolved Oxygen
DSD	: Divisional Secretary's Division
EC	: Electric Conductivity
EIA	: Environmental Impact Assessment
GCP	: Ground Control Point
GDP	: Gross Domestic Product
GND	: Grama Niladhari Division
GPS	: Global Positioning System
GSMB	: Geological Survey and Mines Bureau
GVA	: Gross Value Added
IEE	: Initial Environment Examination
JICA	: Japan International Cooperation Agency
LAN	: Local Area Network
MIWRM	: Ministry of Irrigation and Water Resources Management (was reorganized as Ministry of Lands, Irrigation and Energy in September 2001)
MIWM	: Ministry of Irrigation and Water Management
MLIE	: Ministry of Lands, Irrigation and Energy (was reorganized to Ministry of Irrigation and Water Management in December 2001)
NORAD	: Norwegian Agency for Development
NWRA	: National Water Resources Authority
NWSDB	: National Water Supply and Drainage Board
P.W.L	: Pumping Water Level
PS	: Pradeshiya Sabha
RWS	: Rural Water Supply
S.W.L	: Static Water Level
T	: Temperature
TDS	: Total Dissolved Solids

TOC	: Top of Casing
USGS	: United States Geological Survey
WRB	: Water Resources Board
WRC	: Water Resources Council
WRT	: Water Resources Tribunal
T	: Transmissivity
k	: Permeability Coefficient
S	: Storativity
Q	: Yield
s	: Drawdown
Q/s	: Specific Capacity

SUPPORTING 1 TOPOGRAPHY AND GEOLOGY

1.1 INTERPRETATION OF LANDSAT IMAGERY

1.1.1 GENERAL

The Landsat imagery over the southeastern area of the Island of Sri Lanka was used for the examination of geological structure, which is one of the factors to control the groundwater occurrence in the Study area.

1.1.2 DATA USED

The latest data of LANDSAT/ETM+ with wide coverage area were used for the examination of imagery. Although some parts of the imagery are clouded over, it does not affect the target area. All of the data were satisfactory for the interpretation. The data list is shown below,

The data used for the interpretation of imagery

Sensor	Path-Row	Date	Spatial resolution	Projection
LANDSAT/ETM+	145-055	26/07/2000	30m (Band 1-7)*	UTM, zone 44
LANDSAT/ETM+	145-056	28/09/2000	30m (Band 1-7)*	UTM, zone 44
LANDSAT/ETM+	145-055	17/07/2000	30m (Band 1-7)*	UTM, zone 44
LANDSAT/ETM+	145-056	23/06/2000	30m (Band 1-7)*	UTM, zone 44

Note: *; Resolution of Band 6 is 90m

1.1.3 MOSAIC

The digital mosaic of the area was assembled in the following processes, using Band 1, 4 and 5, combination of which emphasizes the colour variation of rock and soil.

- Edge enhancement.
- DN value correction by using its statistic analysis in overlapping areas between images.
- Mosaicking.
- Geometric correction using GCP.
- Grey level stretching.
- Trimming and annotation

1.1.4 INTERPRETATION

Interpretation work consisted of the following items.

- Extracting of faults and lineaments
- Extracting of fold, bedding and intrusive rock
- Density map of lineaments
- Providing the digitalized files of the above results (ArcView data).

1.1.5 RESULT OF INTERPRETATION

The results of the interpretation are described in the *section of 1.3.3* Geological Structure in this chapter.

1.2 TOPOGRAPHY AND GEOMORPHOLOGY

1.2.1 TOPOGRAPHY

On the basis of the digital contour data of USGS, a topographic map of the study area was delineated as shown in *Figure 1.1*. The contour lines are at 20 m interval.

The topography in general reflects the geological structure in Sri Lanka. The area with the distribution of Highland Complex is mountainous and the area with the distribution of Vijayan Complex is a hilly or gentle slope area.

Most of the study area is a gentle slope area at the elevation of 200 m or less. Northern part of the study area is a little hilly at the elevation of 200 m or above and partially mountainous at the elevation of 400 m or above. The southern part slopes gently to the coastal area.

1.2.2 GEOMORPHOLOGIC CHARACTERISTIC

Geomorphologic characteristics in the southeastern part of Sri Lanka are shown in *Figure 1.2*.

The area can be divided into 11 distinct regions by geomorphologic units. The mountainous area at the elevation of 600 m or above consists of 1) Upper Highland Planation Surface, 2) Middle Highland Planation Surface and 3) Transitional Slopes between these planation surfaces. The eastern edge of the mountainous area overlaps generally with the western border of Monaragala district.

There are three planation surfaces in the area, namely 4) High Level Planation Surface, 5) Middle Level Planation Surface and 6) Low Level Planation Surface, 140 m, 300 m and 600 m above mean sea level, respectively. Low Level Planation Surface is distributed from the coastal area to the inland area in the western Hambantota.

A hilly area where inselbergs are developed is distributed in the northern part of Monaragala. This hilly area, 7) Hills with Inselberg, is located from 140 to 600 m in elevation surrounding the mountainous area. 8) Transitional Slope is distributed in the western part of Hambantota in the elevation up to 140 m.

Most part of the study area is covered by 9) Micro Relief Planation Surface with an inclination of 0.4 degree or less up to the elevation of 140 m from the coastal area to the inland area.

10) Coastal Lowlands are distributed in the southern coastal area. The eastern coastal area is classified as 11) Beach Ridges, Bars and Spits.

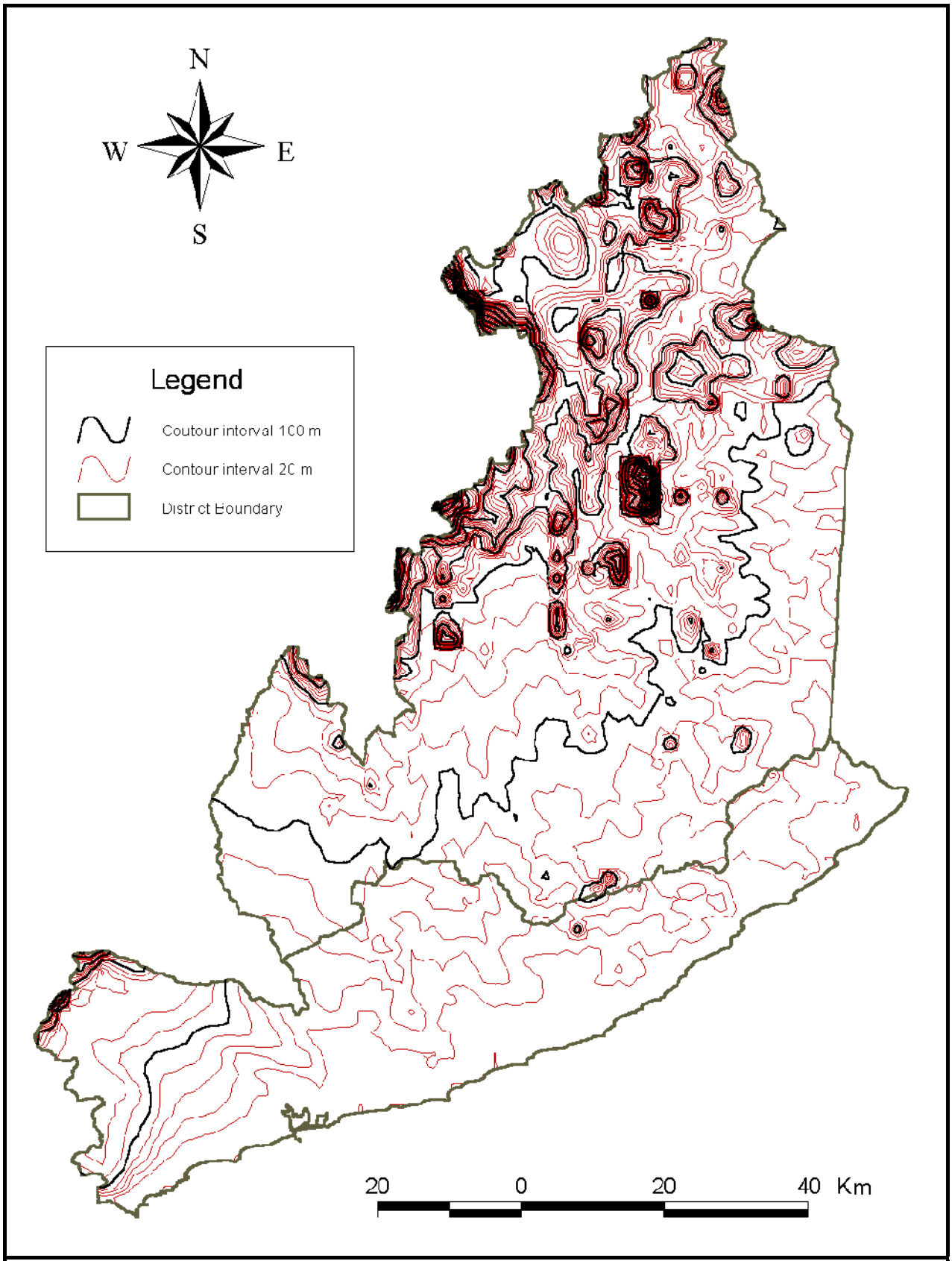

FIGURE 1.1 TOPOGRAPHIC MAP OF THE STUDY AREA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**

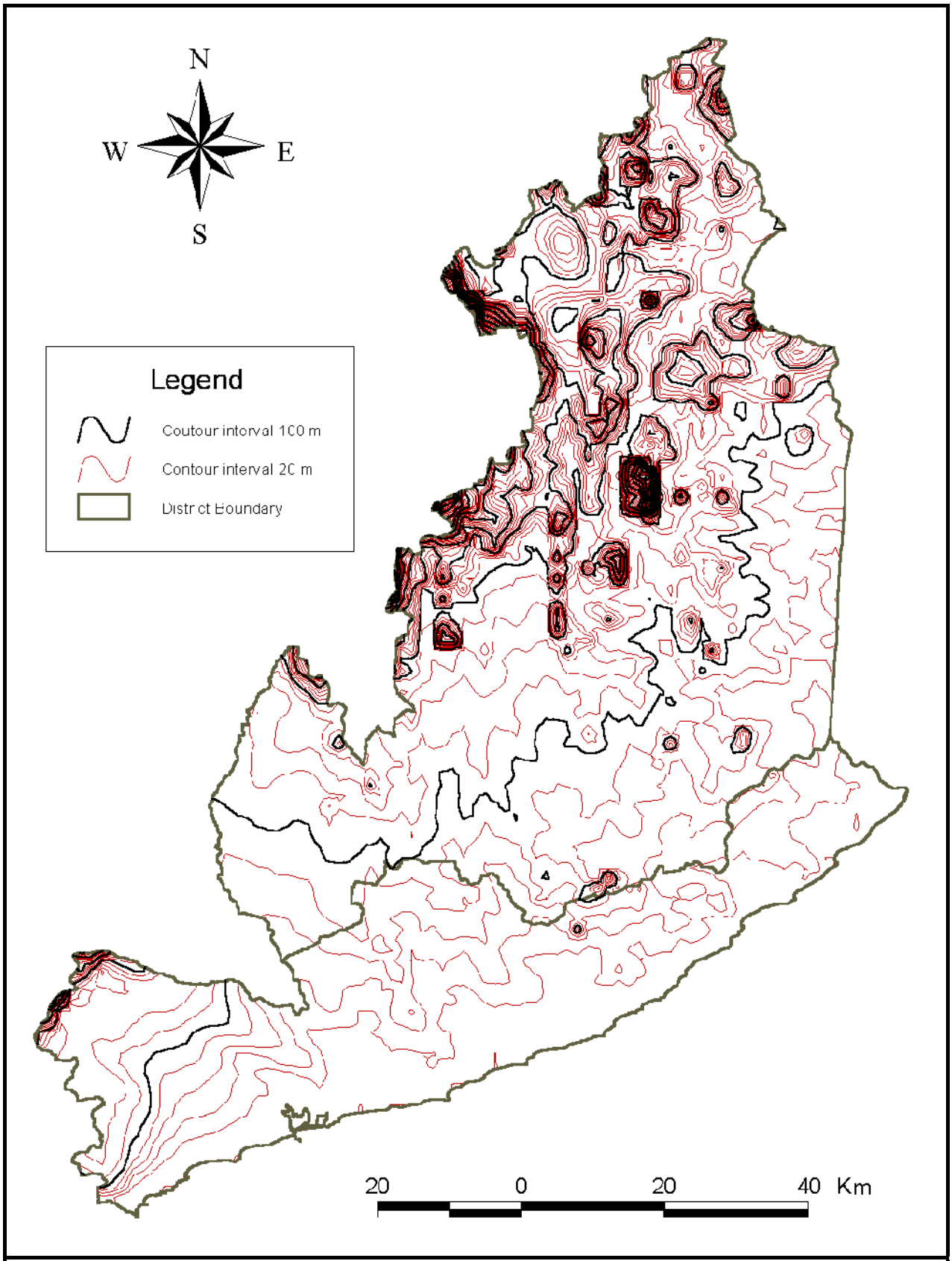

FIGURE 1.1 TOPOGRAPHIC MAP OF THE STUDY AREA

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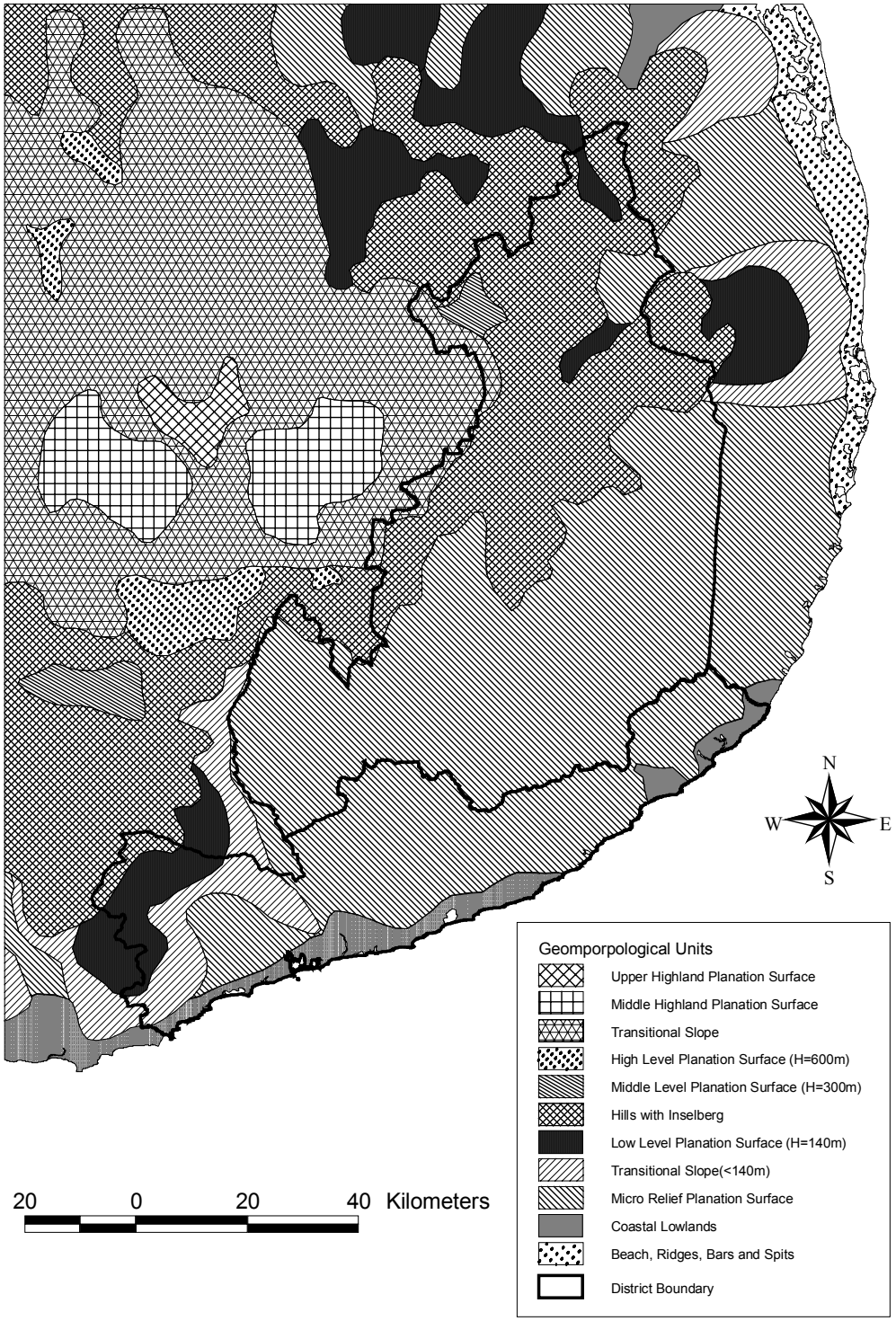

FIGURE 1.2 GEOMORPHOLOGIC CLASSIFICATION

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**

1.3 GEOLOGY

1.3.1 GENERAL GEOLOGY OF THE COUNTRY

Precambrian high-grade metamorphic rocks underlie ninety percent of the Island of Sri Lanka. Previously, the Precambrian rocks had been divided into major three groups, which are, Highland Group, Vijayan Group and South Western Group (Cooray, 1984). The latest geological maps published by Geological Survey and Mines Bureau of Sri Lanka, 2001, also have divided the Precambrian basement into three lithotectonic units. These three units, however, are slightly different. The three units are named Highland Complex that consists of the former South Western Group and the Highland Group (Voll, 1991), Vijayan Complex (formerly the Eastern Vijayan Group) and Wanni Complex (formerly the Western Vijayan Group). The distribution of these Complexes is shown in *Figure 1.3*.

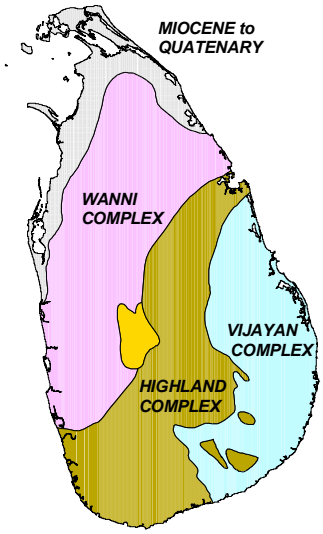

Figure 1.3 Lithotectonic Units

The Highland Complex is distinguished by a sequence of NW-SE to NE-SW trending metasediments and granulitic orthogneisses, which form the central belt including the rugged high ground occupying the central part of Sri Lanka. The metasediments are initimately tectonically interlayered with granitoid rocks and subordinate metabasic intrusive. These metasediments are Palaeoproterozoic to Archaean-age continental mass. Sedimentation was complete at 1980 Ma which is the oldest age determination for rocks intrusive into the metasediments (Silva, 1981). The common occurrence of thick quartzites and carbonates (dolomitic marble and calcsilicate gneiss) suggests a general correlation with other Palaeo- to Mesoproterozoic shelf sequences.

The Vijayan Complex is distributed in the southeastern part of the Island of Sri Lanka. The most abundant rock type in the Vijayan Complex is a hornblende-biotite-bearing sequence of granodioritic to granitic orthogneiss (Liew et.al, 1991). Structures, metamorphic grade (Prame, 1991), shear-sense indicators (Hatherton, 1975) and gravity data (Schenk, 1991), are interpreted that sub-horizontal thrusting is likely to have been responsible for the emplacement of the Highland Complex over the structurally lower Vijayan Complex. According to Vitanage (1985), however, the Kataragama outlier is interpreted as a rotated raft but it may be a thrust klippe.

The distributed area of the Wanni Complex is the northwestern part of the Island. The Wanni Complex is characterized by thick sequences of orthogneisses comprising amphibolite-grade migmatitic, granitic and granodioritic gneisses, and at lower structural levels, dioritic orthogneisses with minor gabbro. The relationship of the structurally highest metamorphic complex, the Wanni Complex (formerly the West Vijayan), to the Highland Complex, is equally difficult to determine at the present time. The structurally lowest levels of the Wanni Complex are considerably more mafic and lithologically similar to gneisses described below the Kadugannawa Complex (Milisenda, 1991).

A geological map of the country is presented is *Figure 1.4*. The Study area is mainly underlain by the Highland Complex and the Vijayan Complex. Highland Complex mostly lies in western and northwestern hilly area and the Vijayan Complex exists in the eastern flat region. The major events in geological history are presented in *Table 1.1*.

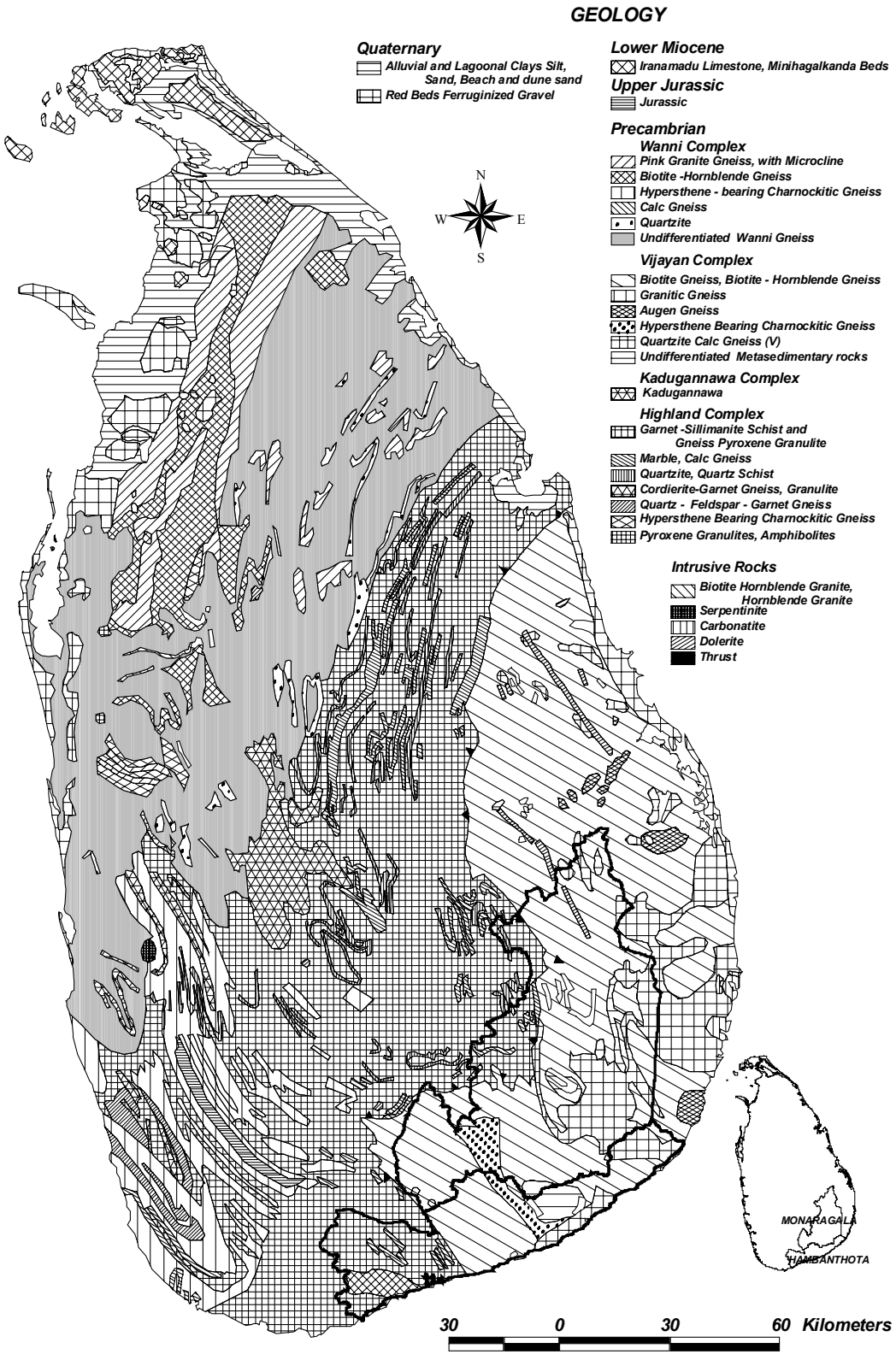

FIGURE 1.4 GEOLOGICAL MAP OF SRI LANKA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**

Table 1.1 Major Events in Geological History of Sri Lanka. After Cooray, 1984.

ERA	SYSTEM/SERIES	AGE (m.y.)	SRI LANKA		Comparison with INDIA SHIELD
			GEOLOGICAL EVENT	FORMATION	
CENOZOIC	QUATERNARY	2	Sea level fluctuations, climatic and drainage changes Sedimentation on margins	Laterite, coral reefs YOUNGER GROUP - sands etc. OLDER GROUP - Red earth	Coastal deposits
	PLIOCENE	7	Uplift, erosion		
	TERTIARY MIOCENE	26	Submergence, sedimentation	JAFFNA LIMESTONE Minihagal kade Beds	
	TERTIARY OLIGOCENE	37			
	TERTIARY EOCENE	53		*Unconformity*	
	TERTIARY PALEOCENE	65			
MESOZOIC	CRETACEOUS	136	Uplift, penaplanation, down-faulting	?Dolerite dyke intrusion	Rajamahal lavas
	JURASSIC	190	Sub-mergence, sedimentation	TABBOWA, ANDIGAMA Beds	Upper Gondwana deposits of Madras Coast
	TRIASSIC	225			
PALEOZOIC	PERMIAN	280	?Uplift, erosion, peneplanation	*Unconformity*	
	CARBONIFEROUS	345			
	DEVONIAN	395			
	SILURIAN	430			
	ORDOVICLAN	500	Metamorphic "overprint"		
	CAMBRIAN	570			
PRECAMBRIAN	PROTEROZOIC	600			
		800	Metamorphic "overprint"	Pegmatites	Pegmatites, Chamundi Hill granite
		1000			
		1200	Granitic intrusion	TONIGALA GRANITE	Porphyry dykes, Sivamalai syenite
		1400	Granitisation, migma tisation, remobilisation	VIJAYAN COMPLEX charnockites in SW Group rocks	Biotite ages S. Maharashtra
		1600	Metamorphism, Deformation D3		
		1800		SOUTH WESTERN	
		2000	Metamorphism, granulite facies, deformation D2	GROUP HIGHLAND SERIES Kataragama, maligawila complexea	Gneisses of Kerala & Tamizhagam; ? Gneisses of Vizagapatam Closepet granite. Dharwar Super Group
		2200			
		2400			
	ARCHAEAN	2600	?Metamorphism Deformation D1	Relics in Highland series	Granulite Mobile Belt, Kerala charcockititc gneiss
		2800			
		3000			

1.3.2 GEOLOGY OF THE STUDY AREA

Most part of the Study area is covered by the 1:100,000 geological maps of Sheet No.17, 18, 20 and 21. Based on the description of these maps, general geology of the study area was summarized as below.

Geological map of the Study area is shown in *Figure 1.5*. Legend of Geological symbols is shown in *Table 1.2*. Rocks of the Vijayan Complex underlie widely in the area while the Highland Complex is restricted to the northwestern hilly part and the western part of the Study area. The Highland Complex rocks also occur in the form of outliers within the Vijayan Complex. Recent sediments occur in the southern and southeastern coastal belt.

(1) Highland Complex

Rocks of the Highland Complex predominate in the western and northwestern part of the area and are characterized by an interlayered metasedimentary rocks including garnet-biotite-sillimanite-graphite gneiss, crystalline limestone, calc-gneiss, quartzofeldspathic gneiss, garnet-biotite gneiss and garnet-bearing charnockitic gneiss. These metasedimentary rocks are also interlayered with more massive charnockites, probably of both sedimentary and igneous origin.

(2) Highland Complex Outliers

The outliers which are named the Buttala Klippe, the Monaragala Range, the Kataragama Complex and others occur within the Vijayan Complex in the area. These outliers may be large remnants of the Highland Complex that escaped deformation and retrogression to form Vijayan Complex gneisses or thrust klippe.

(3) Vijayan Complex

The Vijayan Complex contains variably migmatised, upper-amphibolite facies gneisses with a wide variation in the proportion of hornblende and biotite. The gneisses range in composition from gabbro-diorite to syenogranite, with the dominant rock types, hornblende-biotite gneiss and biotite-hornblende gneiss, being of tonalite to quartz-diorite composition. Isolated occurrences of pink feldspar granite, often controlled by numerous shear zones, typically form narrow elongated ridges a few metres to tens of kilometres long. Chemically, this Vijayan Complex rock suite defines a marked calc-alkaline trend that could probably be attributed to subduction-related magmatism at an active continental margin.

Major structural trends within the Vijayan Complex of the area are discontinuous and rather complexly oriented, forming several circular or dome-like structures (e.g., south of the Buttala Klippe). Numerous shear zones, mainly oriented NNW-SSE, dissect the area.

(4) Ranna Rock Unit

A distinct amphibolite-grade outlier of Vijayan Complex is located within granulite grade Highland Complex rocks in the area around Ranna. This rock unit consists mainly of orthogneisses including partly migmatized hornblende-biotite and biotite-hornblende gneisses, amphibolite, granitic gneiss, charnockitic gneiss and minor paragneisses including garnet-bearing gneiss and calc-sillcate rocks.

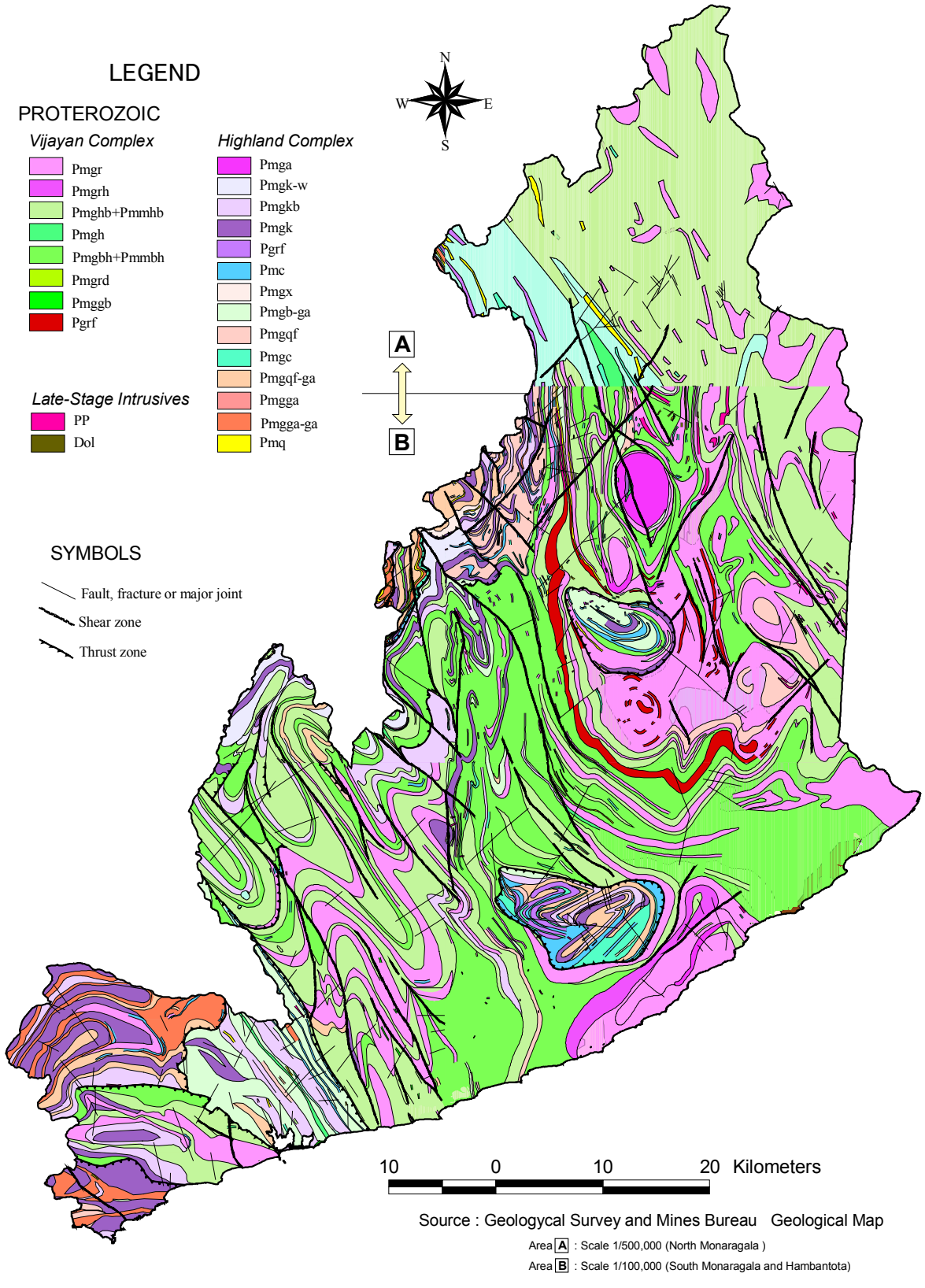

FIGURE 1.5 GEOLOGICAL MAP OF THE STUDY AREA

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Table 1.2 Legend of Geological Symbols

Code	Explanation
PROTEROZOIC METAMORPHIC ROCKS	
Vijayan Complex	
Pmgr	Granite gneiss: massive leucrocratic quartzofeldspathic gneiss with quartz >20%; few mafics
Pmgrh	Hornblende granite: leucocratic granite with a prominent mineral lineation (hornblende)
Pmghb	Hornblende-biotite gneiss: massive to compositionally layered gray gneiss with quartz >20% and plagioclase <10% +_garnet; tonalite composition
Pmmhb	Hornblende-biotite migmatite: compositionally layered gray gneiss typically with white pegmatoid leucosomes
Pmgh	Hornblende gneiss or amphibolite: mafic orthogneiss with quartz generally <10% and Plagioclase <20%; may contain small amounts of garnet and pyroxene
Pmgbh	Biotite-hornblende gneiss: medium to dark gray gneiss with plagioclase >K-feldspar and quartz <15%; quartz monzodiorite to leucodiorite composition
Pmmbh	Biotite-hornblende migmatite: medium to dark gray gneiss with plagioclase >K-feldspar; often white pegmatoid leucosomes; quartz <15%
Pmgrd	Granodioritic gneiss: massive to weakly layered with quartz >20%; few mafics
Pmggb	Metagabro: includes pyroxene granulite and other dense mafic orthogneiss; garnet often present
Pgrf	Alkali feldspar granite, gneiss and migmatite: unfoliated to foliated K-feldspar-rich intrusions and melts T = Tonigala-type pink microcline granite.
Highland Complex	
Pmga	Augen gneiss: highly deformed gneiss with very large (up to 30 cm) "eye-shaped" alkali feldspar phenocrysts >66%; quartz < 10% with minor biotite and hornblende
Pmgk-W	Walawe gneisses: suite of variably migmatised and charnockitised black & white layered (TTG) orthogneisses, mainly tonalite-quartzdiorite composition probable equivalent to "Polonnaruwa-Mahiyanagari gneisses"; charnockitic biotite-gneisses most abundant with late monzo-granitic pegmatite veins common
Pmgk-b	Charnockitic gneiss and charnocitic biotite gneiss: extensive sequences of charnockitic-looking gray gneiss usually lacking hypersthene, though commonly with boudinaged orthophroxene-bearing mafic layers; may include some paragneiss
Pmgk	Charnockite: often ridge-forming outcrops; typically coarse-grained with characteristic green greasy appearance and scattered hypersthene
Pmg-kt	Garnet-hornblende-graphite-quartz-feldspar gneiss (Kataragama gneiss); pale greenish-gray strongly lineated but poorly foliated gneiss; hornblende <8%, garnet < 10% graphite < 2%; augen-shaped feldspars common; usually ride-forming
Pmc	Marble: usually coarse-grained and dolomitic; locally calcite dominant
Pmgx	Undifferentiated paragneiss: well layered, extensive and compositionally variable gneiss locally containing garnet, biotite and sillimanite
Pmgb-ga	Garnet-biotite gneiss +- graphite: compositionally layered paragneiss
Pmgqf	Quartzofeldspathic gneiss: leucocratic gneiss weakly compositionally layered; granoblastic, Color Index <10%, may include both para and orthogneisses; augen gneiss (au)
Pmgc	Calc-gneiss and/or granulite: calc-silicate gneiss with variable mineralogy
Pmgqf-ga	Garnetiferous quartzofeldspathic gneiss (formerly "garnet granulite"): leucocratic quartz-feldspar gneiss with abundant pink garnet often >20%; weathers to iron-rich residual deposits
Pmgga	Garnet-sillimanite-biotite gneiss +- graphite: pelitic schist or gneiss
Pmgga-ga	Garnet-sillimanite-biotite gneiss +- graphite with up to 30% large (1-3cm) red garnet; formally "khondalite"
Pmq	Quartzite: pure coarse-grained ridge-forming quartzite locally with <5% each of sillimanite, kaolinised feldspar and/or biotite
LATE-STAGE INTRUSIVES (in general younger than 550 Ma)	
PP	Pegmatite: quartz-feldspar pegmatite with magnetic
Dol	Dolerite: quartz-normative tholeiite (K-Ar ages ca, 152 and 143 Ma)

source; Sri Lanka 1 : 100,000 Geology (Provisional Map Series) Geological Survey and Mains Bureau (2001)

1.3.3 GEOLOGICAL STRUCTURES

(1) General Geological Structure

Several phases of deformation have been identified in the Precambrian metamorphic rocks observed in the area. The first event is manifest by the presence of internal fabrics in garnet porphyroblasts in hinges of microfolds. Lithological units within the area are duplicated by tight to isoclinal folding that was produced during the second deformation. Evidence for tight to isoclinal folding exists in all lithologies at all structural levels and on all scales. The rocks have been subjected to the third deformation event forming large-scale relatively open fold systems.

An important feature of the area is the orientation of regional structural trends in a NNW-SSE / NW-SE direction. Major shear zones that run either sub parallel or obliquely to the regional strike, divide the area into several blocks. Prominent joint systems are developed in NW-SE and E-W orientations.

Regional structural trends in the Ranna rock unit are mainly E-W to WNW-ESE with an average bearing of 280 degrees which is distinct from the NW-SE orientations of the adjacent Highland Complex located towards the east of this zone.

(2) Results of Lineament Analysis

Lineaments Interpretation Image and Bedding Interpretation Image are shown in *Figure 1.6* and *Figure 1.7,* respectively. General features of the imagery are as follows,

- The faults in the direction of NW-SE and NE-SW were confirmed.
- Major lineaments are likely in a specific orientation and continuous on the image. The NW-SE, NE-SW and E-W orientations are predominant.
- Minor lineaments are mainly developed in EW, NW-SE, NE-SW and NS directions, and are slightly developed in WNW-ESE and ENE-WSW directions. The minor lineaments are continuously dense from the southwest region to the north region in the Study area.
- There are some long but intermittent faults and lineaments extended in a certain direction.
- Many folds can be extracted from bedding (schistosity and stratification). Some of them have the ring structure.

1) Distribution of lineaments in the areas

Northwestern part of Hambantota

Lineaments with various lengths, which were developed in N-S direction and in the area with 40 km width, were extracted on the image.

Northeastern part of Hambantota

Lineaments in E-W and WNW-ESE directions are distributed in spots. Some ENE-WSW lineaments also occur in this area.

Southwestern part of Monaragala

Major lineaments in EW, NW-SE and N-S directions are distributed intermittently and minor lineaments aggregates in the west. The other lineaments occur in NE-SW direction.

Southeastern part of Monaragala

Mainly lineaments in E-W, N-S and NW-SE directions are distributed in spots.

Northwestern part of Monaragala

Major lineaments are distributed intermittently in NW-SE, NE-SW and E-W directions. Numbers of minor lineaments in N-S, NW-SE and ENE-WSW directions are distributed in the west. The minor lineaments aggregate in the area underlain by the Highland Complex.

Northeastern part of Monaragala

Lineaments in NE-SW and EW directions lie scattered. Some NW-SE lineaments also exist.

2) Historical relation of deformation

The fault in NW-SE direction occurring in the western Monaragala is displaced in left lateral direction by the E-W lineament (or fault). In the northeastern Monaragala, the major lineament in NE-SW direction seems to be displaced in left lateral direction. A minor lineament in E-W direction crosscuts another lineament in N-S direction in the same area. Additionally a lineament in NW-SE direction is crosscut by another lineament in NE-SW direction. Consequently, deformation or fractures were presumably formed in the order of NW-SE, NE-SW, S-W, E-W from an old one.

3) Bedding

Figure 1.7 shows folds, bedding and intrusive rocks. Bedding develops considerably both in the Highland Complex and the Vijayan Complex. There are some cases that a lineament runs parallel to a fold axis in NW-SE direction in the northwest of Hambantota. In the other areas the direction of a fold axis is different from the direction of lineaments.

4) Ring structure

Some ring structures accompanied with folding structures were observed in the Study Area.

5) Density of lineaments

Figure 1.8 Lineament Density Map shows that the lineaments are dense from the west area of Hambantota to the southwest area of Monaragala, from the southeast area of Monaragala to the northeast area, and the northwest area of Monaragala. High density areas exist in NW-SE direction from the west area of Hambantota to the southwest area of Monaragala and in NE-SW direction in the northwest area of Monaragala.

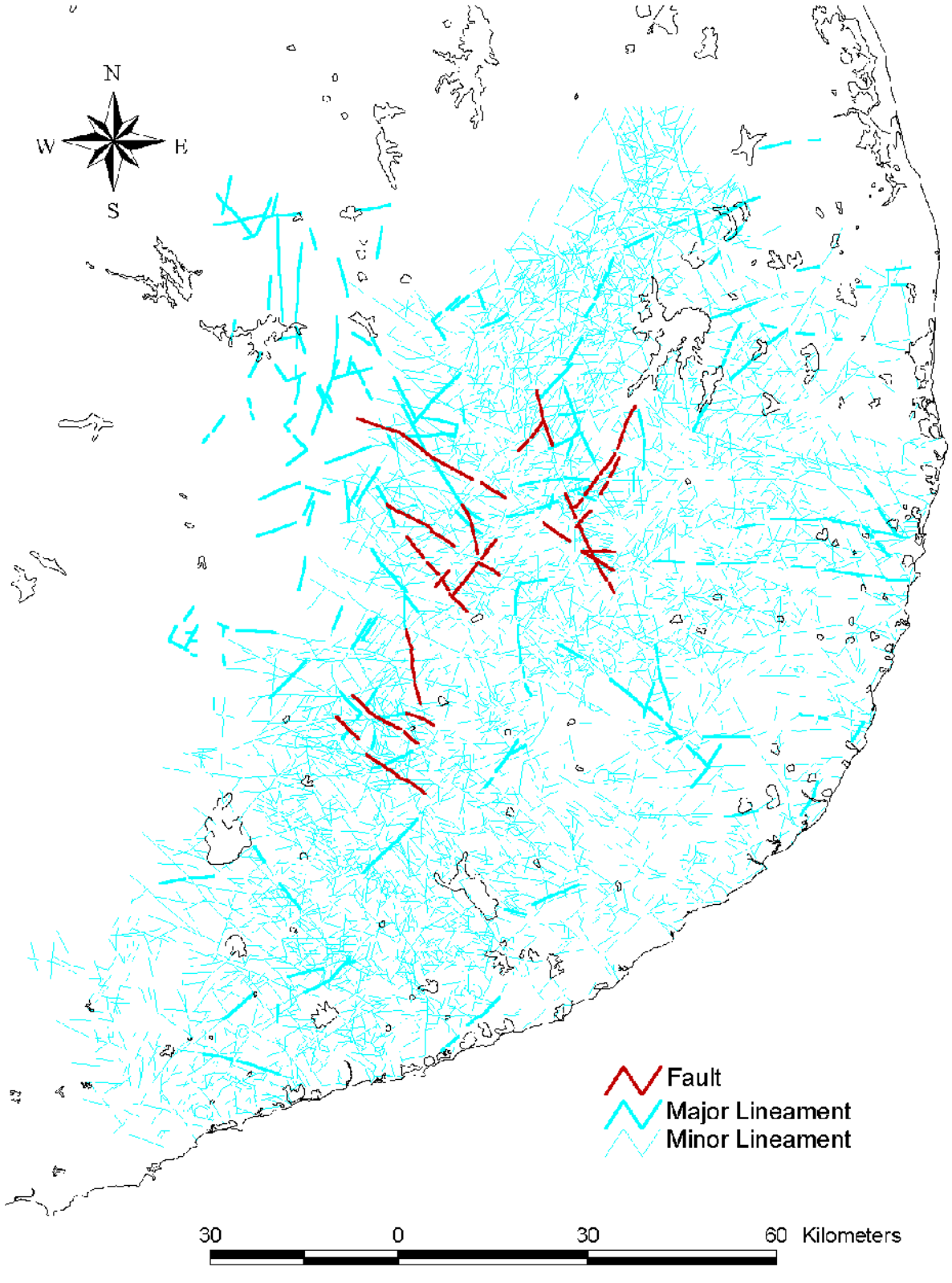

FIGURE 1.6 LINEAMENT INTERPRETATION IMAGE

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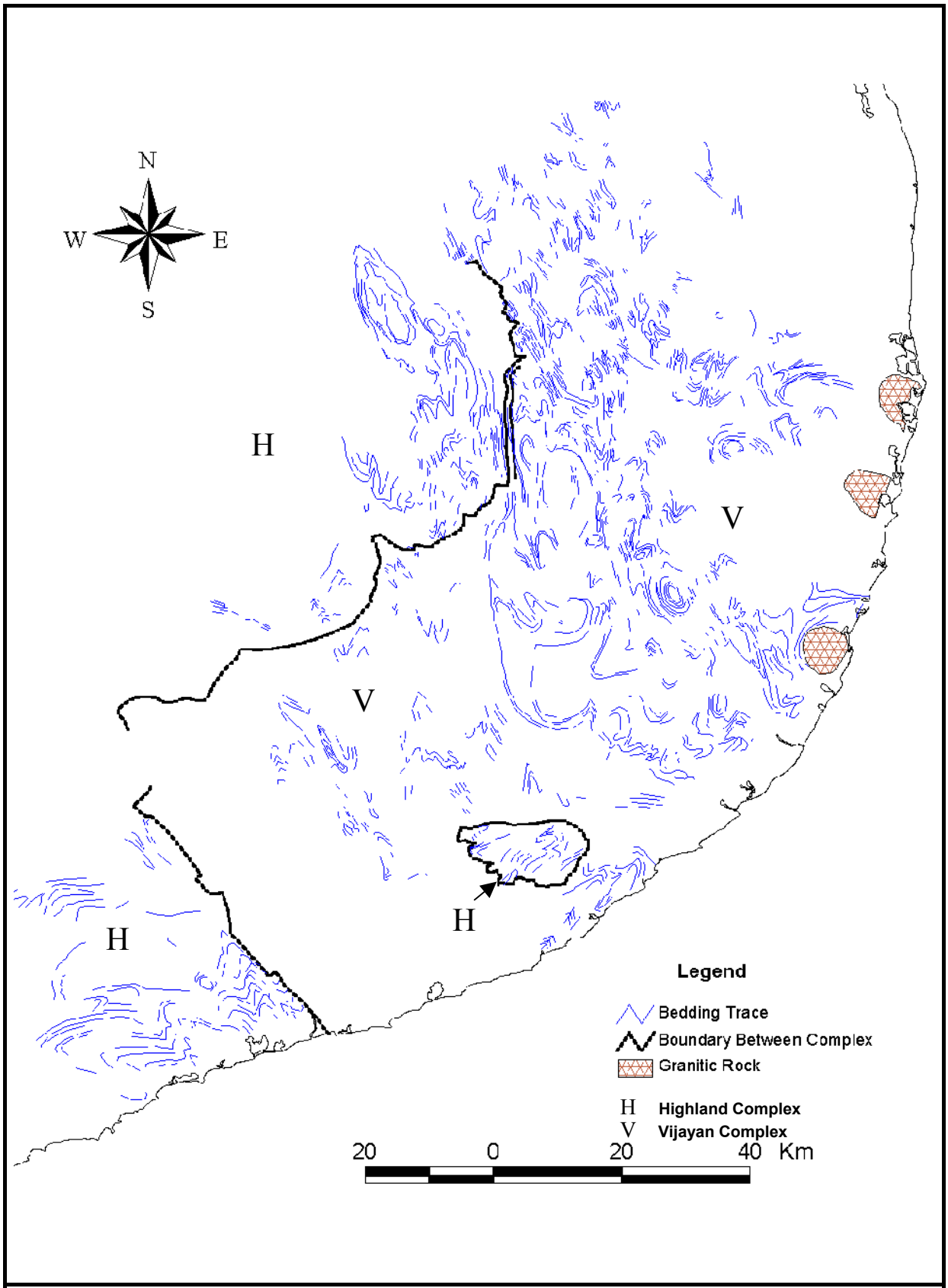

FIGURE 1.7 BEDDING INTERPRETATION IMAGE

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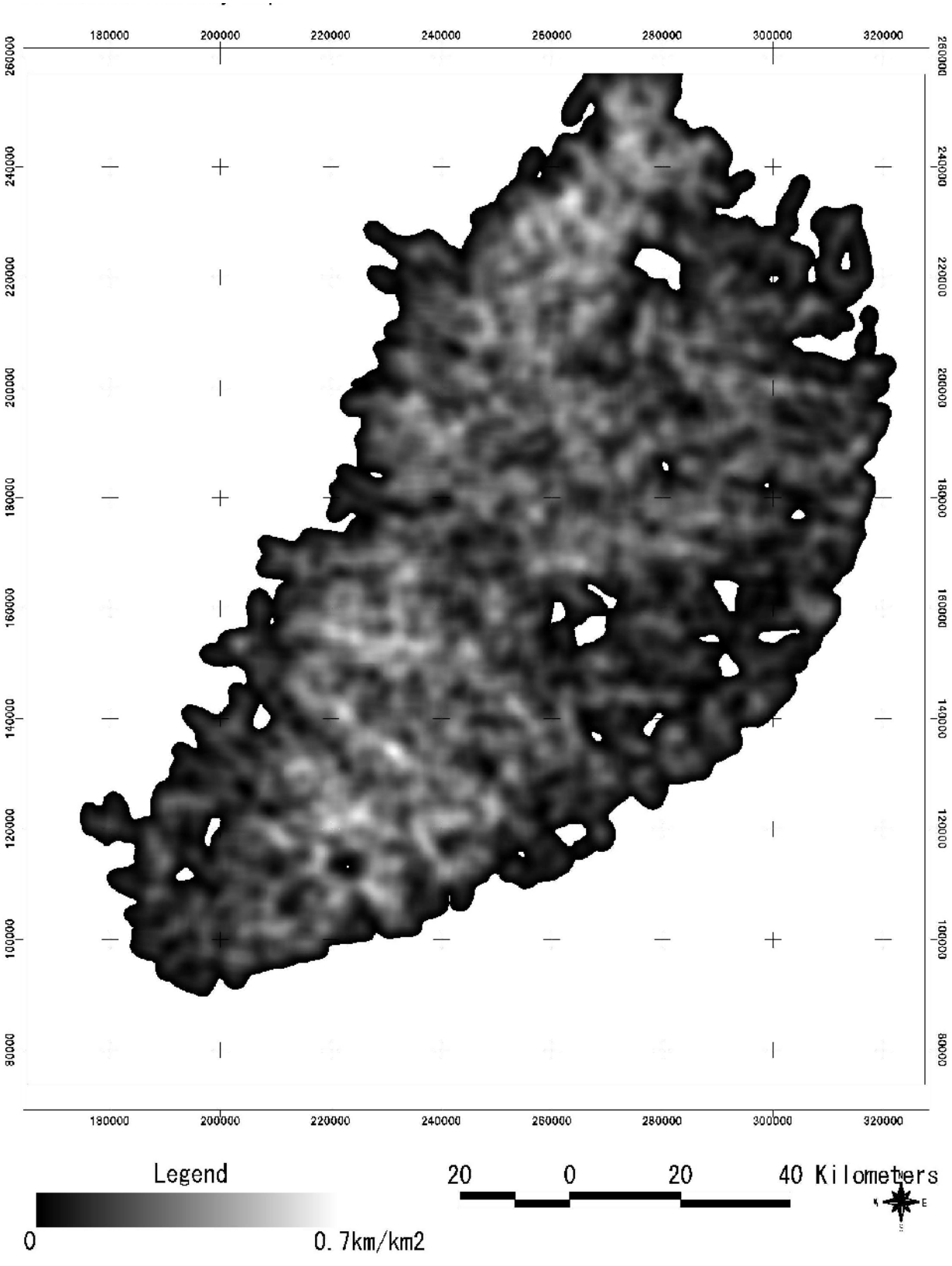

FIGURE 1.8 LINEAMENT DENSITY MAP

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