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A traveller's guide to the geology of Everest (a traverse from Lukla to Everest)

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2016

http://hdl.handle.net/10539/21688

Hochreiter, Rene Carlo (2016) A traveller's guide to the geology of Everest (a traverse from Lukla to Everest), University of Witwatersrand, Johannesburg, <http://wiredspace.wits.ac.za/handle/10539/21688>

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Prof. R. Bolhar

Correction made in response to Examiners Comments

Date of Comments 14th December 2015

Comments received 14th March 2016

Date to be handed in: 31 July 2016

Title of Dissertation: A traveller's guide to the geology of Everest (a traverse from Lukla to Everest)

Part 1: A literature synthesis of the subject with all pertinent up-to-date literature and references showing an understanding of the historical and current issues.

Part 2: A stand-alone-public geological guide on the same subject as Part 1 explained at the appropriate level.

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Part 1

Corrections made to Part 1 of the dissertation.

The many comments made by the examiner are much appreciated. I have made all the changes as suggested.

Please note: All page numbers refer to the copies of the annotated dissertations that were received by me on 14th March 2016. The page numbers in the corrected version of the dissertations have different page numbers and are referred to as new page 51, for example. When a new page number is indicated, this refers to the corrected dissertation.

Original text is specified and if replaced, then this has been indicated as such. Text replaced or added is between quotation marks.

Abstract

1. "two part" should be "two-part"
2. "60 km in thickness at least" should be "at least 60 km in thickness"
3. 6.2±0.7 kbar to 2.9±0.6 kbar swopped to align with depth.
4. Comma inserted after °C and after the bracket in the last line.
5. Original text "Intense glacial erosion and earthquake activity (as the 25th April 2015 magnitude 7.8, and 12th May 2015, of magnitude 7.3 earthquakes attest) balance uplift of the Himalaya."

   Has been replaced with "Intense erosion through the action of glaciers, rivers, landslides and earthquakes (as the 25th April 2015 magnitude 7.8, and 12th May 2015, of magnitude 7.3 earthquakes attest) balance uplift of the Himalaya."

Page xv: Table of contents (new page iv)

1. 12 capitalised letters were reduced to lower case

Chapter1: Introduction (new page 1)

1. "~50km long " was inserted
2. "(see Maps 1-3, p57-59) was inserted
3. Comma after Khumbu Icefall was inserted

Page 2: Methodology (new page 2)

1. Comma inserted"(see Map 1 & 3, p 57 & 59) inserted
2. "World-famously" changed to "world famous"
3. Page numbers inserted after each of the 4 Maps
4. "the route taken shown with" deleted

Page 3: The geology of the Himalayas and the Study Area (new page 3)

1. "M.R" deleted
2. Reference inserted "Copley, et al., 2010"
3. "Lighter" replaced with "less dense"

4. Hyphen inserted between “micro” and “continental”
5. Sentence starting with “India had “ inserted before sentence starting with “Between 75 and 50Ma”
6. Text after Figure 1.1 inserted in the space at the bottom of page 3.
7. Figure 1.1: “has” inserted between “India” and “moved”

Page 5 (new page 3)

1. Semi-colons inserted
2. Capital “F” inserted in “figure 1.1”

Page 7 (new page 6)

1. “Amazingly” deleted
2. Commas inserted
3. “entitled” inserted

Page 9 (new page 8)

1. Geological Journal italicised
2. Space inserted between T. and Sharma
3. “geological survey” capitalised G and S
4. Comma inserted after Hunt
5. “which” changed to “that”

Page 10 (new page 9)

1. Dhital does not give any references referring to this; he just states that these ideas occurred in the 60s.

Page 11 (new page 10)

1. Semi-colon inserted and year bracketed after Tapponnier et al.
2. “Which” changed to “that”
3. Hyphen inserted
4. Caption for Figure 1.3 put on same page.

Page 12 (new page 11)

1. “has” deleted
2. Hyphen inserted “left-lateral”
3. Global replace done for hyphenation of strike-slip and dip-slip
4. Reference for Transhimalayan batholith formation: Searle et al., 1987
5. Comma removed
6. “also” inserted
7. Oldest reference first implemented
8. “GHS” first reference written out in full and (GHS) bracketed
9. “do” replaced with “did”
10. Comma deleted and year bracketed.

Page 13 (new page 12)

1. Comma deleted after Harrison and inserted after et al.
2. Hyphen inserted between “high” and “temperature”

3. The words “interpreted” and “less viscous” inserted
4. Original text: “Data gathered by satellite”

   Has been replaced by “Data gathered by a study of shear-coupled teleseismic P waves recorded by temporary broadband networks across Tibet suggests that the crust of the northern plateau is partially melted due to high temperatures and that a relatively cool mantle….”

p.13: metamorphic heat does not only come from radioactive decay – there is primordial heat, magmatic advection, shear heating, etc. To imply that burial of radioactive elements caused the Himalayan metamorphism is overly simplistic.

5. Original text: “This occurs because of radioactive decay of small amounts of uranium and thorium contained within rocks which causes them to heat up. Because rocks conduct heat slowly, once they reach significant depths the trapped radiogenic heat can cause them to reach very high temperatures.” Deleted.

6. References added.
7. Comma inserted

Page 14 (new page 13 and 14))

1. “east” and “west” swapped around
2. “respectively” inserted.
3. Commas deleted and brackets inserted
4. The model is Royden et al’s model. “The” has been replaced with “Their model”.
5. “due” replaced by “owing”
6. Hyphen inserted
7. The words “between crustal blocks” added.

Page 15 (new page 14)

1. Ref added: USGS, Thailand, Figure 4.3
2. Space inserted
3. “crusts” replaced with “blocks”

Page 16: Chapter 2: Geology of the Mt. Everest Region (new page 15)

1. Using lower case in titles like “tectonic zones”
2. Comma and semi-colon inserted
3. Paragraph starting with “On a broad scale..” moved to the top of this chapter
4. “have” deleted and “d” deleted
5. Hyphen deleted in southwards
6. Fig 2.1: “the” added and “Tibetan Plateau” added

Page 18 (new page 17)

1. Semi colons, hyphens and commas added.
2. References have been added
3. Original text: “500°C and higher” and “ ~600°C” contradiction.

   Replaced by: “>500°C at relatively low pressure”.

4. Semi colon and comma added
5. Reference inserted: “(Yardley, 1989)”
6. Comma and semi colon added

Page 19 (new page 18)

1. Space added between 40 and Ma
2. Full stop added, “after” deleted and semi colon added
3. “that existed between the Indian and Asian continents” inserted after “Tethys Sea”
4. Reference added: “Rowley, 1996”.
5. “they are considered to be a large-scale **part of a shear zone, accommodating shear caused by the collision of the Himalayas** (Searle, et al., 2006)” expanded by the text in bold.
6. “The MCT zone, for example, is a zone of high strain between 3km and 5 km thick which dips 10° to 30° to the north (Hubbard, 1988)” added.
7. Double reference to Searle deleted.
8. The word “dark” moved to before “sillimanite gneiss”

Page 20 (new page 19)

1. Reference added: “Searle, 1999a”
2. Darker and lighter changed.
3. “so special” changed to “significant”
4. Reference inserted: “(Searle, 1999a)”
5. “Stretching” replaced with “extension”
6. “is” changed to “was”
7. “dip-slip” inserted between “normal” and “STD”
8. “dip-slip” inserted after “normal”
9. Hyphen inserted

Page 21 (new pages 20 and 21)

1. Original text “STD” changed to “KT”
2. Point No. 4 added: ” 4. The Main Frontal Thrust (MFT): This is a large fault located at the base of the extruding wedge (and the base of the Lesser Himalayan Sequence and the Siwaliks) and at the top of the subducting Indian upper crust.”
3. Fig 2.3 reference inserted
4. Figure 2.2 caption changed to: ” *Figure 2.2: The location of the three main faults in Nepal, Bhutan and China. A zone about 30 km wide, bounded by the South Tibetan Detachment (STD) in the north and the Main Central Thrust (MCT) in the south, is referred to as the Greater Himalayan Sequence or High Himalaya. Further to the south from the MCT are the foothills of the Himalayas, the so-called Siwaliks or Lesser Himalaya, which are separated from the Indian lowlands by the Main Frontal Thrust (MFT) and Main Basal Thrust (MBT). The Khumbu Thrust (KT) is located very close to the STD and is not shown in this image, but is shown in Figure 2.3. The base map is an image taken from Google™ Maps.”*
5. Location of the Siwaliks or Lesser Himalayas shown in Figure 2.2

Page 22 (new pages 21 and 22)

6. The “repeated statements” have been re-written to avoid confusion. “The Greater Himalayan Sequence occurs immediately south of Mt Everest and extends past the town of Lukla towards the foothills of the Himalayas (Figure 2.3). It forms a 10 km thick sequence of crystalline gneiss with metamorphic minerals including sillimanite, kyanite and staurolite

(Jessup et al. 2008). The lower parts of the Everest massif, below the STD, are made up of the high-grade gneiss of the Greater Himalayan Sequence, and intruded by many pegmatites and leucogranites.“ Has been replaced by: “The northern limits of the Greater Himalayan Sequence occur immediately south of Mt Everest and extends past the town of Lukla towards the foothills of the Himalayas (Figure 2.3). It comprises a 10 km thick sequence of crystalline orthogneiss (the Namche migmatites)and biotite sillimanite gneiss (Jessup et al. 2008). Large and small scale recumbent folds (with shallow northwards dipping fold axes) were observed along the route. “

7. The reference to staurolite, etc. has been inserted.
8. The other observations are my own, made in the field, but these have been removed to avoid repetition.
9. Figure 2.3: dividers inserted.

Page 23 (new pages 22 and 23)

1. Small scale detail deleted.
2. Repetition on page 22 removed, references inserted
3. Second repetition deleted
4. References added: “(Yin and Kuo, 1978; Sakai et al. 2005; Myrow et al. 2009)”.
5. “These are highly deformed rocks which show evidence of intense folding, plastic deformation and melting.” Deleted.
6. The words “Biotite, calc-silicates and amphibolites” inserted

Page 24 (new page 24)

1. Comma inserted, “comprised of” changed to “comprising”
2. References inserted: “(Yin and Kuo, 1978)”
3. Paragraph on Qomolongma formation moved to end of new page 24.
4. “These low-grade metamorphic rocks are the product of the metamorphism of deep-sea flysch deposits (mudstone, clayey and calcareous sandstone, greywacke and sandy limestone).” deleted

Page 25

1. Quaternary – I believe this needs to stay in Fig. 2.4
2. Figure 2.4 is my own work.

Page 26

1. Figure 2.5 deleted.

Page 27 (new page 26)

1. “Big picture “ narrative deleted

   The geological features superimposed on Everest have been done for clarity and “in order to give a better illustration of the geology of Everest and to show the physical stratigraphy on the mountain itself.” Added to clarify

Page 28 (new page 26)

1. Fig 2.5: Yellow band too high? I disagree with the examiner’s comment about the position of the Yellow Band in part 1, if you check Searle et al 2003, he shows the position of the QD and it's the same here. I also think that the thrust symbol in Fig 2.5 is appropriate.

2. Figure 2.6 new Figure2.5, thrust's T capitalised, "A fault called" deleted , comma inserted
3. Reference inserted on the age of intrusion (Searle et al. 2003
4. Source of sketch: this is my own sketch.

Page 29 (new page 27)

1. "which" replaced with "that"
2. Restated sentence deleted
3. Reference is Yin and Kuo, 1978
4. "rocks" and "overlying" inserted and "adjacent to (i.e. above)" deleted
5. "The" deleted in heading 2.4
6. Language "un-dramatised" and made more efficient.
7. "which" replaced with "that"

Page 30 (new page 28)

1. The font is supposed to be the same as 2.4. Fonts have been checked throughout the document.
2. Added new text: "whilst the GHS records eclogite facies metamorphism with pressures of > 14 kbar (>45 km depth) before being exhumed to granulite facies conditions of 4-6 kbar. "
3. Kbar pressures swopped around
4. "which " changed to "that"
5. "and temperatures" added
6. Comma inserted, "s" added
7. "s" deleted
8. "the reacting bulk composition and, consequently in the" added
9. "(i.e. during the burial and heating)" deleted
10. Differential stress question, original text: "This early deformation event (the result of burial) resulted in the formation of the early S_1 fabric, which was subsequently overgrown by garnet and staurolite as the temperature and pressure increased (Figure 2.6B)."

    Reworded to: "This early deformation event occurred during the burial of these sediments during early collisional thrusting (Jessup et al. 2008). This resulted in the formation of the early S_1 fabric, which was subsequently overgrown by garnet and staurolite as the temperature and pressure increased (Figure 2.6B)."

11. Reference added: "Jessup et al. 2008"
12. Garnet question: did staurolite consume garnet? It is **suggested** that staurolite grew through a reaction that consumed garnet, even though this is not shown in Figure 2.7C.
13. Exhumation question" the result of exhumation"
    Re-worded: "consistent with exhumation" and examiner's comment noted.

Page 31 (new page 29)

1. Timing relationship: The low pressure minerals and textures are retrograde and clearly post D_2
2. "Amorphous" deleted
3. "Rapidly" deleted
4. Last paragraph deleted

Last paragraph replaced by: "The P-T path involving prograde P increase followed by peak-to-retrograde P decrease is consistent with a continuously evolving history from burial o exhumation. The D_2 features are related to the LD/QD shearing and which have been linked to exhumation (Jessup et al. 2008). The D_1 to D_2 switch is the point at which channel flow starts. The P-T-t-D path discussion in Jessup et al 2008 suggests that the M_1 and M_2 (consistent with D_1 and D_2) are related to burial and decompression/exhumation respectively."

5. Relation of D_2 features to the LD/OD: The D_2 features are linked to exhumation by Jessup et al (2008).
6. **Examiners question: Is the D_1 to D_2 switch the point when channel flow starts?** Yes, it is. The P-T-t-D path discussion in Jessup et al 2008 suggests that the M_1 and M_2 (consistent with D_1 and D_2) are related to burial and decompression/exhumation respectively.
7. Question regarding the orientation of S_1 and S_2: Added: "The orientation of S_1 and S_2 are both sub-horizontal and resulted from the D_1 and D_2 episodes."

Page 32 – no changes.

Page 33 (new page 31)

1. Hyphen inserted
2. "equilibrium to be reached between minerals" replaced by "re-equilibrium to remove prograde growth zoning"
3. "700°C seems too low" comment noted
4. Fig 2.8 (new Figure 2.7) is my own drawing, hence no Reference inserted.

Page 34 (new page 32)

1. Hyphen inserted
2. Figure 2.8 added
3. "or depth" replaced by "i.e."
4. Original text: "in granulite facies metamorphism (and hence they are granulitised eclogites). This decompression and heating resulted in metamorphic overprinting of the eclogite facies minerals by granulite facies minerals."

   Replaced by: "a partial granulite facies metamorphic overprint in which omphacite has been replaced by clinopyroxene-plagioclase symplectites, and Ca-rich garnet has been surrounded by coronas of hornblende, orthopyroxene, biotite and plagioclase (Lombardo & Rolfo, 2000) (Figure 2.9B)."

5. "as" inserted
6. Examiner's question: Are the S-C fabrics S_2 or something else? Answer: No, they are essentially the same: "It is likely that the S_1 fabric formed during burial (as per Jessup et al. 2008) and S_2 (which includes the S-C fabric) was the start of exhumation." Added to the text.
7. Figure 2.7 reference (new number) inserted
8. Top-down-to-the-north hyphens inserted
9. Figure of top down to the north movement: Figure 2.3 (new and old).
10. Comment regarding retrograde fluid noted.

Page 35 (new page 33 and 34))

1. D_1 is a likely S_1 fabric. This diagram is a composite from different areas – it is unclear how S_1 differs in eclogite/granulite facies conditions.
2. Reference to S_2 made in Caption to Figure 2.9 (new Figure 2.8)
3. Which reference is Fig 2.9 from? This is an original diagram drawn/modified from information from Lombardo and Rolfo, (2000) and Jessup et al. (2008).
4. "A general model for orogens would place the high-grade rocks centrally in the orogen on the basis that the greatest thickening led to highest grades and greatest subsequent exhumation. Here, however, the grade varies not laterally so much as vertically, with T decreasing both upwards and downwards, hence the Channel Flow Model (Examiner, 2016)." Inserted at beginning of section 2.4.3

Page 36 (new page 35)

1. "enhanced" replaced by "emphasised"
2. Retrograde mineral growth is related to shearing: "i.e. the contrasting shear direction, top-to-north in the N vs. top-to-south in the S and the nature of the shearing (extension vs. thrusting." inserted

Page 37 (new page 36)

1. Fabric timing relative to mineral growth question: The GHS and the Everest Series are different and distinct and have been juxtaposed by the STD. Hence, there is no influence on each other.
2. Figure for extensional shear bands top-down-to-the-north: "Figure 2.3" added to text as reference to this.
3. "million years ago" removed
4. "showing how they were constructed" removed

   And replaced by "of the orogen/belt"
5. Semi colon inserted

Page 38 (new page 37)

1. "and" replaced by "these were covered by"
2. Original text: "were being deposited in the Tethys Sea at this time." Deleted.
3. "At" inserted before "approximately"
4. "Approximately 25 million years later (Figure 2.10C), sediments deposited on the Indian continent were brought down to mid-crustal levels…"

   Replaced by "Approximately 25 million years later (Figure 2.10C), sediments deposited on the leading edge of the Indian continent had been buried to mid-crustal levels"

5. "a basin" replaced by "basins"
6. "only" moved to after "experienced"
7. "Himalayas" replaced by "sediments"
8. Hot Iron heating question: additional commentary added from Goscombe et al. 2006

9. “On a subsiding foreland” deleted

Page 39 (new page 38)

1. Caption inserted

Page 40 (new page 39)

1. Caption modified
2. “on the Indian plate” inserted after Tethys Sea
3. “Accretionary”, “Forearc” and “The” converted to lower case

Page 41 (new page 40)

1. Comma deleted
2. Orientation of the S_1 fabric is unknown as it is now intra-folial to S_2
3. M_1 defined in Figures 2.7 and 2.9 (new Figures 2.6 and 2.8).
4. Amphibolite facies peak: This is an error; greenschist facies should have been “amphibolite facies”.

Page 42 (new page 43)

1. “metamorphic” inserted
2. Refs inserted Visona and Lombardo, 2002 ; Le Fort et al., 1987)
3. “which and commas inserted
4. Leucogranites “s” added
5. “along” deleted and “forming” inserted
6. “The location of” inserted
7. “being found” deleted
8. Misunderstanding on buoyancy without channel flow; this section re-written.

Page 43 (new page 42)

1. Source of Fig 2.12 inserted.
2. “Individual” thickness inserted
3. “are all” replaced by “forms part” and “just” replaced with “immediately”.
4. Reference inserted:” (Inger and Harris, 2007)”
5. Proof of leucogranite being the result of low degree of partial melting: “

Page 44 (new page 43)

1. “Figure 2.12” inserted.
2. “similar” replaced with “uniform”
3. “high Himalaya crystallines” replaced with “GHS”
4. Refs added: Le fort et al., 1987, Visona and Lombardo, 2002.
5. “a” added; hyphen added
6. “cold’ changed to “cooler”
7. Original text: “These intruded upwards by “dyking” and “silling”, and solidified below the cooler rocks of the STD (Visona and Lombardo, 2002). “
   Replace with: “. These intruded upwards by a network of dykes and sills, and solidified below the cooler rocks of the STD (Visona and Lombardo, 2002).”

8. “which form from the Higher Himalayan Leucogranites” deleted
9. “mica” deleted
10. Hyphen inserted
11. “This high alumina composition also indicates a pelitic origin for the source anatectites (Searle et al., 1997).”

    Changed to “This high-alumina composition also indicates a pelitic source (Searle et al., 1997).”

12. Re: In many leucogranites, only weakly deformed quartz and plagioclase may be interpreted as having crystallised directly from a melt (Reichardt et al., 2010). Examiner asks if the leucogranites are mylonitised with only rare igneous textures preserved?

    Reply: No they are not very deformed.

13. I have re-written : “melting during simple shear near the top of the sillimanite” contradicts that melts came from deeper”

Page 45 (new page 44)

1. Commas inserted, “intrusive” deleted.
2. “uniformly” deleted
3. “black” replaced by “dark”
4. “Immediately” replaces “just” (twice)
5. “The Makalu granite (20km southeast of Everest)” location of Makalu inserted.
6. I graduated in 1979 and am disappointed that Rb/Sr is an “old technique”
7. Capitalised letters reduced to lower case
8. Semi-colons inserted

Page 46 (new page 45)

1. Comma deleted
2. “a wedge” deleted (the Himalayas are mountains, not a wedge)
3. “below” and “above” added
4. “a shallowly dipping” added
5. “led by Doug Nelson” deleted.

Page 47 (new page 46)

1. “has now become the accepted model of current thinking. It” deleted
2. “due” deleted
3. Comma deleted
4. “Khumbu Thrust” deleted
5. “et al.,” replaced with “et al.” in 167 places
6. “the” inserted
7. “to” replaced with “through”
8. “concurrent” inserted
9. “different” timing of metamorphism inserted.

Page 48 (new page 47)

1. “dip-slip” inserted
2. Reference to Figure 2.9 (old Figure 2.10) inserted
3. “and” deleted

Page 49 (new page 48)

1. “upright” replaced with
2. “right-way-up”
3. Reference to Figure 2.9 inserted again
4. “rapidly towards the north across the STD.” replaced with “drop off rapidly northwards towards the STD”
5. “ground-breaking” deleted
6. Refs inserted: “(Searle, 1999b).” and (Nelson et al. 1996)
7. “in which” inserted
8. “outcrops, which crystallized in the Miocene period and were extruded to the south (Searle, 1999b).” replaced with: :
9. “(23 to 5.3 Ma)” inserted
10. “which were subsequently” inserted
11. “They concluded that gravitationally driven mid-crustal channel flows are most likely to occur in the Tibetan-Himalayan system (Beaumont et al. 2006)” inserted.

Page 50 (new page 49)

1. “(Jessup et al. 2006)” reference inserted
2. Jessup et al. indicate that Wm numbers and channel flow ARE linked. The examiner questions this in the annotated copy of Part 1.
3. Leucogranite emplacement occurred circa 17-16 Ma
4. “Deforming at different times”: this is what Searle’s model proposes.
5. “These models are not discounted here, but each model on its own fails, in the view of the writer, to explain other features and processes present in the Himalayas. The channel flow model together with Tapponnier’s crustal flow studies incorporates many aspects of the models to be part of a more interconnected process.” Inserted in response to the examiner’s question as to why these models are discounted.

Page 51 (new page 50)

1. “and cooled” replaced with “with cooling”
2. “as evidence of channel flow” added
3. “The age of the normal shear zone formation is bracketed at 17 Ma from the age of parallel shearing in the leucogranite dykes (Murphy and Harrison, 1999) and the age of strongly sheared schists (16.9 ± 0.2 Ma) from immediately below the STD, which could have assisted recrystallization of the sample by increased fluid flux from the fault above (Searle et al. 2003).” Inserted to explain how the STD age is bracketed at 17Ma.
4. “has, just below it” deleted and replaced with “overlies”
5. “This shows” replaced with “These suggest”
6. “an orogenic belt” replaced with “of the land surface”

Page 52 (new page 51)

1. “is akin to trying to push a cork underwater” deleted and “low density” inserted

2. “This is the result of the equilibrium of the Earth's crust (known as isostasy): where the forces that commonly elevate landmasses balance out those forces that commonly depress landmasses.”
   Replaced with : “Exhumation can also be tectonic by thinning of the overlying crust along extensional faults or even by ductile flow.”

Page 53 (new page 52)

3. “ replaced with “slab”
4. “as well as extensional thinning assisted by erosion.” Added
5. “and also extensional unroofing” added
6. “As a result of this lower friction, wedges of rock are exhumed more rapidly along thrust planes, and exhumation takes place along gently-dipping thrusts” replaced with: ” As a result of this lower friction, wedges of rock are exhumed more rapidly along thrust planes, and exhumation takes place along gently-dipping thrusts (Bose et al. 2010). The lower friction allows more rapid tectonic thickening, compensating for the extra erosion, so balance is maintained. Rapid erosion and exhumation allows material to be underplated at a greater rate (Figure 2.14).”
7. Fig 5.6 deleted as it is the same as Fig 9.6

Page 54 (new page 55)

8. “Because of the gravitational instability of mountain belts,” deleted
9. Semi colons inserted
10. Figure 2.13 changed to Figure 2.14

Page 55 (new page 56)

1. Spaces put in between 8 and Ma, twice
2. The KT in
3. “or the Khumbu Thrust” replaced with “the MCT”
4. “the presence of leucogranite which, together with the Greater Himalayan Sequence, represents the weak crustal channel, the lower thrust zone (the Main Central Thrust and the Main Boundary Fault)” inserted to avoid confusion with the Khumbu Thrust being near the top of the extruded channel.

Page 56 (new page 55)

1. “just” replaced with “slightly”
2. “Along the route, key geological features are described, and their relationships with the theories discussed in Chapter Two are discussed.” Deleted
3. “, and the lateral extent of the India-Asia collision zone.” Deleted

Pages 57, 58 and 59 (new pages are the same as the old ones)

These are Maps 1 to 3 which have been re-drafted and corrected. They are presented at the end of these corrections.

Page 60 (new page is the same)

1. “Stop 3 on Map3” inserted
2. Ref inserted “, described by Carosi et al. (1999)”

3. Rock description of granite gneiss inserted “The rock typically contains compositional banding of mafic and felsic minerals. This gneissic fabric likely represents the S_1 fabric formed during burial of the Greater Himalayan Sequence. The rock contains quartz, plagioclase feldspar, K-feldspar/microcline, biotite, and minor muscovite. Large microcline (K-feldspar) grains have small rounded inclusions of quartz and thin films of quartz are found along grain boundaries. The rounded inclusions and thin films of quartz are indicative of the rock having melted. Myrmekitic textures (a fine intergrowth of quartz and feldspar) confirm crystallization of a melt. The planar fabric of aligned biotite grains, as well as both strained and unstrained quartz found in the rock, indicate that the rock has experienced deformation followed by partial melting.”
4. “in granite gneiss” inserted.
5. “and they are visible in the granite gneiss that outcrops just above the town of Namche Bazaar” replaced with “of this part of the route, outcropping above the town of Namche Bazaar”
6. “near-outcropping” replaces “outcropping”

Page 61 (new page 62)

1. “immediately” replaces “just”
2. “This led to granite melt injection into dykes and sills through hydraulic fracturing (Searle, 1999)” deleted as it is out of place
3. “seen in later stops.” Inserted
4. ‘Melting’ replaced by “deformation”
5. “(near Stop 3 on Map 3)” inserted

Page 62 (new page 63)

1. “ text on granite melt injection into dykes and sills through hydraulic fracturing “deleted”
2. “Lighter” deleted
3. “(near Stop 4 on Map 3)” inserted

4. The following original text was re-written: “Migmatisation led to the separation of leucosome from biotite-rich restite. This led to granite melt injection into dykes and sills through hydraulic fracturing (Searle, 1999). The buoyancy of the lighter granite melt resulted in migration upwards into the zone between the dark sillimanite-biotite gneiss and the STD, a zone of non-coaxial simple shear. Late stage intrusion resulted in a stockwork of sills and dykes seen at the top of the plutons in the west shoulder of Everest and the top of the Nuptse pluton.

   Replaced by: “Migmatisation led to the separation of leucosome from biotite-rich restite. The buoyancy of the granite melt resulted in migration upwards into the zone between the dark sillimanite-biotite gneiss and the STD, a zone of non-coaxial simple shear (Searle, 1999). The emplacement of this granite into plutons on the west shoulder of Everest and the top of the Nuptse are seen in later stops.

5. He examiner suggested that the “volume of magma generated through migmatisation to generate the large 2000m to 3000m thick plutons was speculative. Migmatisation was widespread at the time of melting with both boudinaged and discordant veins (new Figure 3.2), and could therefore have produced enough volume of magma to generate the large

2000 m to 3000 m thick plutons or channel-flow extrusive that are in evidence today in what is termed the axial core of the Himalayas (Searle et al., 2003).

Page 63 (new page 64)

1. “above” replaced with “northeast of “
2. “Neosomes are discordant to the planar fabric defined by the leucosome” replaced by “Leucosome are discordant to the planar fabric defined by the neosomes.”
3. “Label” Ptygmatic folds“ inserted on Figure 3.3
4. “which was possibly the biotite-sillimanite gneiss” added.
5. Also deleted
6. Comma inserted
7. “which could be the Khumbu Thrust” added
8. Original text: “This is consistent with channel-flow mechanism of extrusion of a weak crustal channel (Figure 2.12) along the Khumbu Thrust (KT) plane.”

   Replaced by “This may be the result of a fold-thrust association but may also be consistent with channel-flow mechanism of extrusion of a weak crustal channel (Figure 2.12)”

Page 64 (new pages 65 and 66)

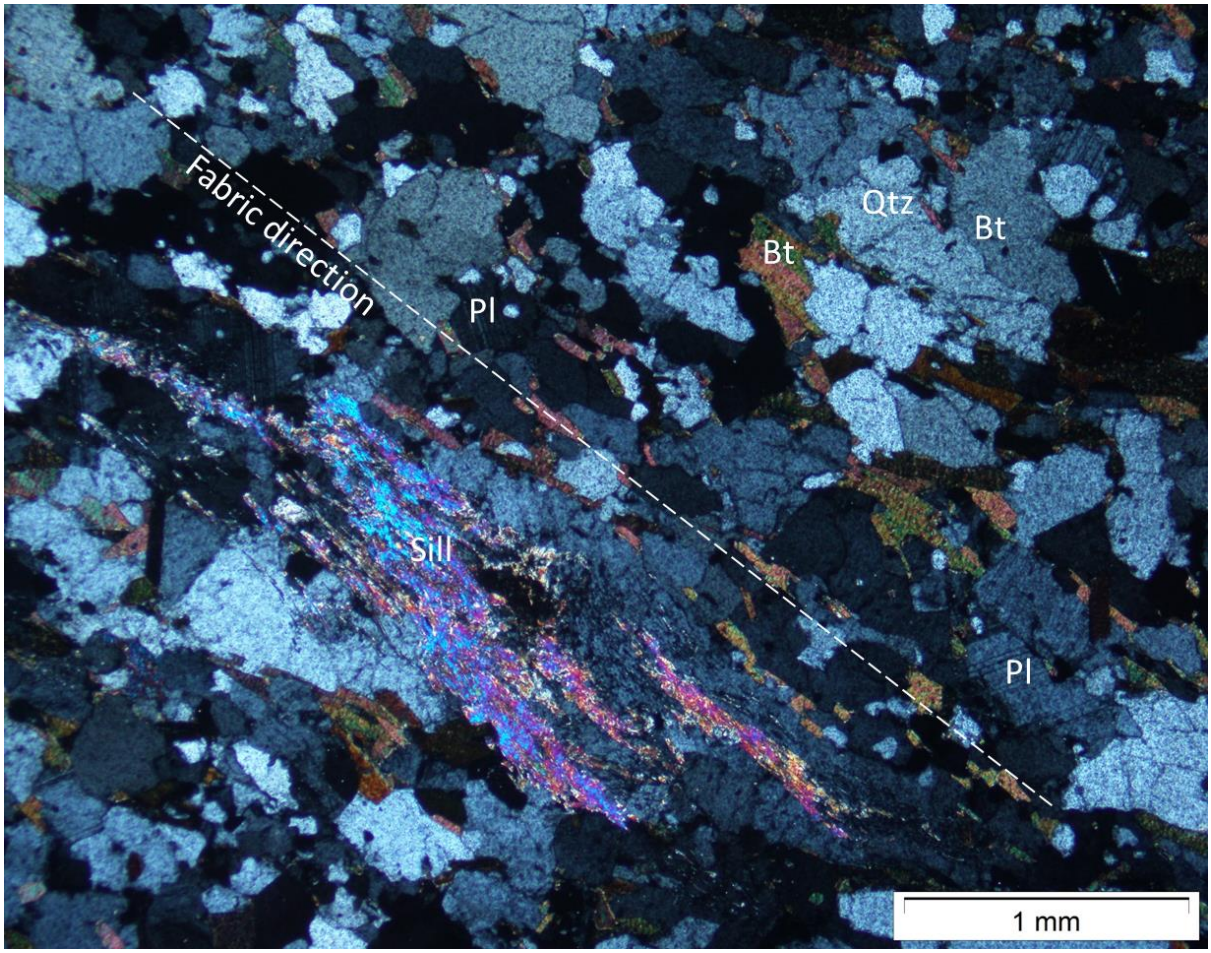
1. The lines are right – and their projection through the hill below the snow-covered peaks approximately correct.
2. KT labels inserted on Fig 3.4
3. “bearing” deleted
4. “above” replaced with “northeast and north of”
5. “seen” replaced with “crops out”
6. Ref inserted (Searle et al. 2002)
7. The LD is not visible on Map3. Its is on Map 4.
8. “Geochemical investigations by Le Fort et al., (1987) concluded that the Himalayan leucogranites were extracted by anatexis of the underlying Tibetan Slab gneisses.” Inserted as proof and referenced.
9. “The town of Namche Bazaar therefore lies at the contact of the granite gneiss and the migmatites.” Added

Page 65 (new pages 66and 67)

1. “Dark coloured” replaced with “Grey/black”)
2. “makes up” replaced with “underlies”
3. “white-to-clear” replaced with :” translucent”
4. Ref inserted:” (Yardley, 1989).”
5. “Plagioclase, quartz, biotite and minor amounts of muscovite make up the remainder of the sample.” Deleted
6. “muscovite” added
7. There was no ilmenite or magnetite in the slide.
8. Small changes all made
9. “often” replaced with “commonly”
10. I did not find any cordierite in the Fig 3.5
11. “Sample of schist taken from Ama Dablam Base Camp. GPS co-ordinates: 27°51’17”N, 86°49’36”E” inserted in Fig 3.5

12. Original Figure 3.5 removed.

    And replaced with:



With following caption: *Figure 3.5: Photomicrograph (XPL) of sillimanite-biotite schist (sample RH2). A strong fabric of aligned biotite and sillimanite grains is present. Quartz (Qtz), plagioclase (Pl) and minor amounts of K-feldspar muscovite make up the remainder of this rock. Quartz and plagioclase grains may have inclusions of fine-grained sillimanite. Note the irregular shape of the quartz grains and the numerous small, rounded grains of quartz, indicating high degrees of strain (MacKenzie & Guilford, 1980). Sample of schist taken from near Laboche. GPS co-ordinates: 27°57'23"N, 86°4724"E.*

Page 66 (new page 68)

1. Original text: "The rock has a very strong fabric defined by the alignment of biotite and highly recrystallized quartz, which is also elongated and aligned. A fabric is visible in most samples." Deleted
2. "resulting from" replaced with "related to"
3. "and low pressure" deleted

Page 67

1. Ref inserted "(after Lombardo & Rolfo, 2000; Jessup et al. 2008)."
2. Figure 3.6 deleted as it is the same as Figure 2.8, which is referred to in the new text
3. "around" replaced with approximately

4. “Stop 6” inserted.
5. “Granite” inserted
6. “-biotite” inserted
7. “inclusions of” deleted

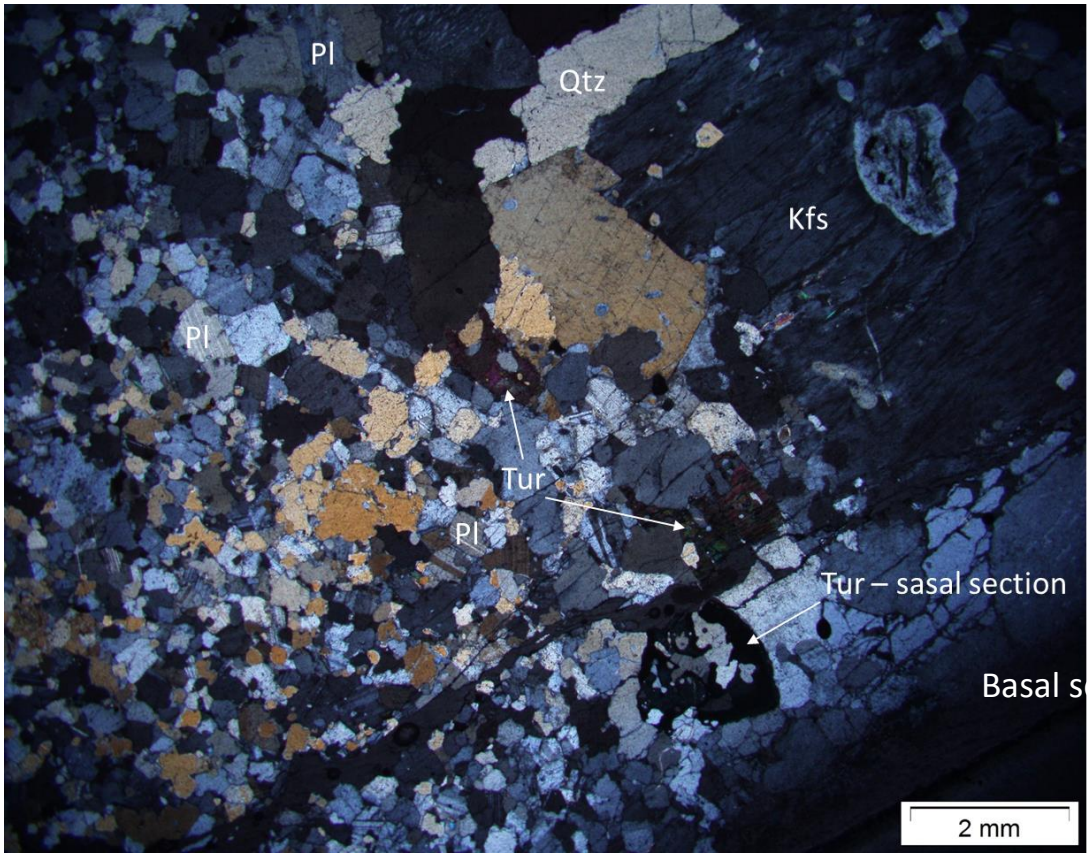
Page 68 (new page 69)

1. The white leucosome is actually snow in Figure 3.7
2. Xenolith in Fig 3.7 is a sill-biot xenolith
3. Caption to Fig 3.7 re-written: “The black rock on the left hand side is an amphibolite xenolith with tourmaline granite on the right. The black specks on the granite are tourmaline crystals. The white rock with large crystals to the right of the climbers is a pegmatite. The layering above the yellow helmet of the climber is part of a sillimanite-biotite gneiss xenolith”
4. There is some evidence of anatexis in the outcrop in Fig 3.7
5. “in a zone of compressional simple shear and ductile deformation.” Deleted

Page 69 (new page 70)

1. “Feldspar has been altered to sericite in places” has been included
2. “although needles of tourmaline are aligned along planes dipping vertically.” Added
3. “Some large crystals of black tourmaline up to 5 cm in length are present.” Deleted
4. Figure 3.8 photomicrograph has been deleted:

   And replaced with:



5. And Caption changed to: “*Figure 3.8 Photomicrograph (XPL) of tourmaline granite (sample C2-1). The rock is made up of quartz (Qtz), plagioclase (Pl) and K-feldspar (Kfs), tourmaline (Tur) and minor amounts of biotite. Some of the quartz is strained, indicating deformation after crystallisation of this granite. GPS co-ordinates 27°51’9.95”N, 86°51’4.30”E.*

Page 70 (new page 71 and 72)

1. First sentence now starts with Visona and Lombardo…
2. Ref inserted (Searle, 1999)
3. “or in-situ crystallisation” deleted.
4. “Unroofing of overburden along the hanging wall of the LD removed cooled magma and also contributed to the rafts of xenoliths which can be seen along the southeast summit ridge Ama Dablam” means that unroofing of the hangingwall overburden below the LD resulted in rafts of sill-biot xenoliths occurring throughout the leucogranites as can be seen on the SE ridge of Ama Dablam.
5. “The difference between the two granites is essentially grain size as later intrusions can be observed in outcrops of leucogranite on Ama Dablam and at Base Camp.” Added

Page 71 (new page 73)

1. Map 3 has been cropped and re-draughted and shown at the end of these corrections as well as, obviously, new page 73
2. Original text “incorporating further cross-section lines” and added “not included in this part of the dissertation”

Page 72 (new page 74)

1. W and E replaced by N and S
2. “just” replaced with “immediately”
3. “T” replaced with “t”
4. “crown” replaced with “roof”
5. “South Col” and “Lhotse Ridge” labels inserted
6. Missing arrow on LD inserted
7. Missing arrow on lower part of KT inserted
8. “runs” deleted

Page 73 (new page 74)

1. “(Yin and Kuo, 1978; Sakai et al., 2005, Myrow et al., 2009)” ref inserted in Figure 3.9.
2. “greater and greater” replaced by “ progressively larger”
3. “and” inserted, “S” replaced by “s”, “its” inserted, ”just” deleted, semi colon inserted

Page 74 (new page 76)

1. “Figure 3.11” moved to just after “Nuptse”
2. Fig 3.10 crosses removed and Bluish grey inserted
3. “north eastwards” replaced by ENE.

Page 75 (new page 77)

1. “pelitic” deleted
2. “intruding” deleted
3. “light” replaced with “ cream/brown-“
4. “intruding sillimanite-biotite gneiss” inserted
5. “eastwards” replaced by “ESE”
6. “left and right” replaced by “N”
7. “The granite stockwork extends across the entire base of Nuptse below the level of the photograph.” Inserted

8. “and is most likely the same pluton as that below Nuptse.” Deleted as it was my own observation and has no ref.
9. “north of and” inserted
10. The tourmaline granite was observed by me on Kala Pattar and has no reference. Below the granite intrusions there are zones of dykes and sills shown on Searle’s 2007 map and it may have been such a zone.
11. “up” deleted

Page 76 (new page 78)

1. Deleted original text: “This suggests that tourmaline may be present only in the sheeted pegmatite sills and dykes as it is an incompatible mineral that is mostly associated with pegmatites.”
2. “This could be a xenolith in the leucogranite (Figure 3.12).” deleted
3. NW changed to W and NE changed to E on Fig 3.12
4. “front” replaced with “S face”
5. “View N across KP hill to Pumori, showing sillimanite gneiss in the foreground and the overlying leucogranite. The KT that separates the units is hidden by topography.” Inserted in Fig 3.12.
6. “The granite follows the layering in the gneiss and appears to have been folded.” Deleted.

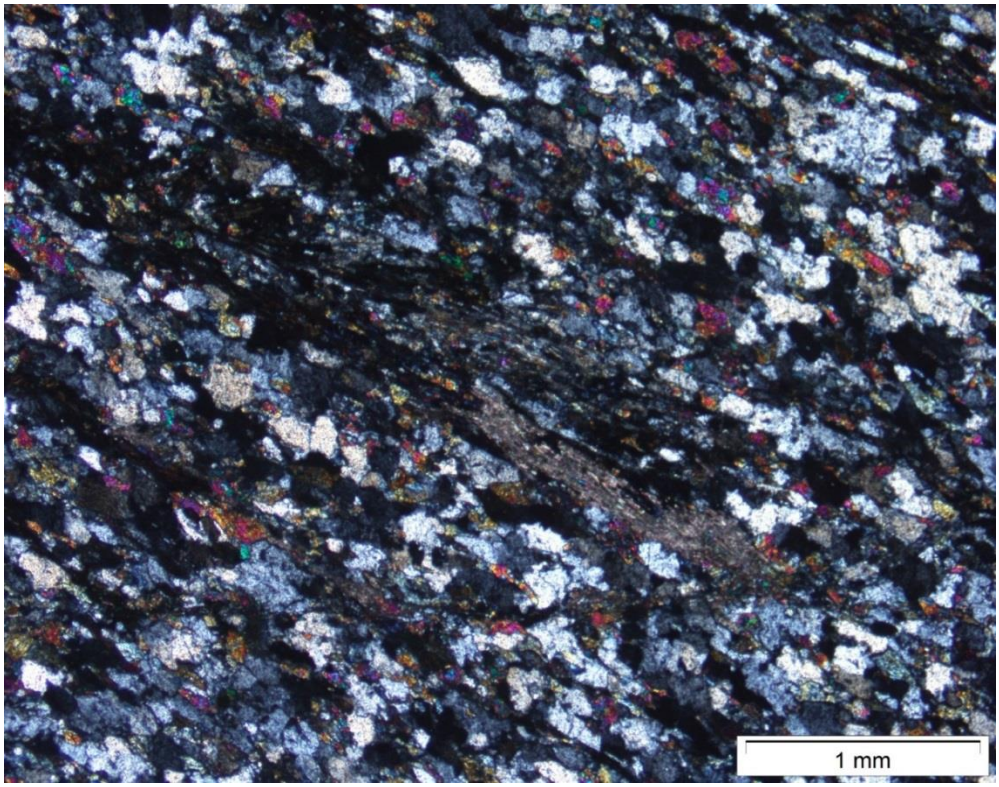
Page 77 (new page 79)

1. Evidence of sheared leucogranite and mylonite is evident in “Figure 3.14” – inserted.
2. “Evidence of this is from the preponderance of float samples containing mylonite from Gorak Shep, Base Camp and Camp 2.” Inserted as proof of widespread occurrence of mylonite.
3. “apparent” deleted as Searle (1999) proves it is real.
4. Folded layering indicated on Fig 3.13
5. Comma deleted, “ed” inserted (past tense), “were” replaced with “are”
6. Photo labelled

Page 78 (new page 80)

7. Fig 3.14B is moraine rock from BC – changed in caption
8. Added labels to Figure 3.14 (new Figure 3.13): “Fish-head Boudins” inserted and Boudin strung out mentioned in caption.
9. “A Boudin with a granite vein in it, which is very “strung-out” at the top can also be seen in B indicating very ductile conditions. *“ “Fish-head” boudins can be seen in the sheared granite in B indicating continued deformation and thinning at the edges of the black amphibolite inclusions with the less viscous amphibolite elongated and leucosome melt forming between the inclusions*.” inserted in the caption in Fig 3.14
10. “which may be the KT.” Added
11. Photomicrograph of Figure 3.15 has been deleted:

And replaced with:



12. Caption has been changed to: "*Figure 3.15: Photomicrograph (XPL) of a mylonite sample collected near Camp II (sample RH11). The rock predominantly fine-grained quartz, biotite and plagioclase.. The rock is very fine grained and platy biotite and quartz are aligned in a strong fabric. Intense deformation has led to a grain size reduction through dynamic recrystallization, a texture typical of mylonite. GPS co-ordinates 28°0'6.58"N, 86°51'49.03"E.*

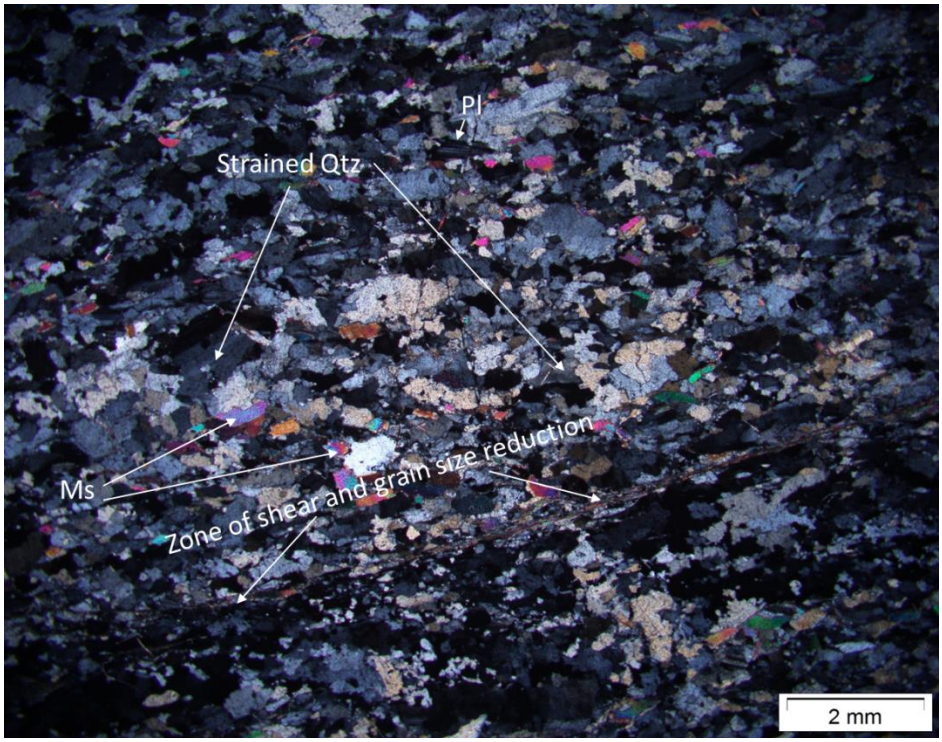
Page 79 (new page 81)

1. Fig 3.15 replaced with new figure 3.14
2. "often" replaced with "commonly"
3. "white" inserted
4. P changed to lower case
5. "part of the major extensional detachment system known as the South Tibetan Detachment" deleted
6. "underlying" added

Page 80 (new page 82)

1. Image Fig 3.16 replaced with new Figure 3.15.

2. Original: Replaced with:



3. And caption changed to to Figure 3.16: *" Figure 3.16 Photomicrograph (XPL) of strongly deformed protomylonite of leucogranitic origin collected from near Camp 2 (sample RH7). The rock is very pale and has few mafic minerals. It is composed of quartz (Qtz), which is often strained, plagioclase (Pl), K-feldspar and lesser amounts of muscovite. Fine to medium grained muscovite mica grains are aligned to form a fabric, and quartz shows evidence of straining and grain size reduction. Note the zone of shear and intense grain size reduction cutting the sample.. GPS co-ordinates 28°58'39.68"N, 86°53'58.89"E."*

4. "intensely sheared leucogranite" replaced with "strongly deformed protomylonite of leucogranitic origin"
5. "west" changed to "NW"
6. "with strong sill sheeting as well (Map4)" added

Page 81 and 82 (new pages 83 to 86))

7. **All of the following was replaced**: "This ridge shows good examples of the relationship between channel flow and an extruding crustal block in a palaeochannel as described in Figure 2.13. The base of the weak crustal palaeochannel (Figure 2.13, point 5) could, conceivably, have been near the base of the Pumori-Lingtren ridge (the lower thrust zone of the extruding block, Figure 2.13 point 11) and the top of the channel, sub-parallel and above the peaks of the ridge (the upper shear zone, Figure 2.13 point 12). The direction of "flow" would have been upwards and towards the left (south) with schematic velocity profiles as in Figure 2.13, point 7. The isotherm, above which partial melting occurs, would have been located above the gneiss but below the granite (Figure 2.13, point 8). The rheological tip of the channel

would have been to the left of the granite which has been eroded, as in Figure 2.13, point 9). The large amount of rubble and glacial moraine seen in Figure 3.17 confirms the focussed surface denudation described in Figure 2.13 point 13.

This above is valid, based on the assumption that the leucogranite represents a separate channel, bounded by the KT and the LD. An alternative would be that the sillimanite gneiss (Figures 3.17 and 3.18) contains migmatites (the light coloured bands between those which are darker), and melt generated here has migrated upwards to accumulate and form the granite above. It is likely that both situations are valid, i.e. there was melting and granite accumulation, followed by exhumation of the granite channel as described above (Longridge, 2015, pers. comm.).

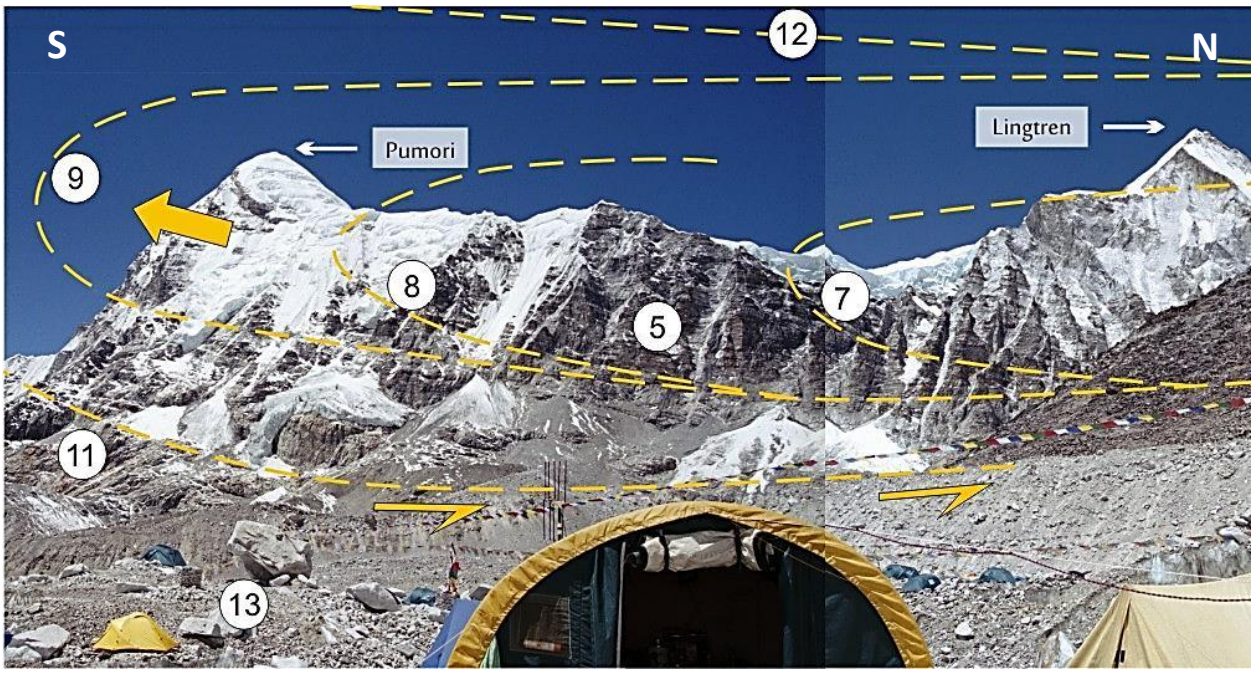


Figure 3.17: The Lingtren Pumori ridge to the west of base camp. Dark sillimanite gneiss underlies sheeted leucogranitic sills and dykes which, in turn, are overlain by leucogranite. The circled numbers shown in this figure are the same as those shown in Figure 2.13 and are placed to show how this ridge could be an example of an extruding crustal block. Photograph taken from GPS co-ordinates 28°0'6.58"N, 86°51'49.03"E looking westwards.

Figure 3.18 shows more detail of the Lingtren part of the ridge. The lower thrust zone (Figure 2.13, point 11) is located at the base of Lingtren in the banded rocks of sillimanite gneiss. The movement of the channel was to the left, as shown by the yellow arrow. It ripped up part of the underlying gneiss, as indicated by the xenolith of dark sillimanite

gneiss, and this can be seen high up on the face of Lingtren and also on the summit of Lingtren II.

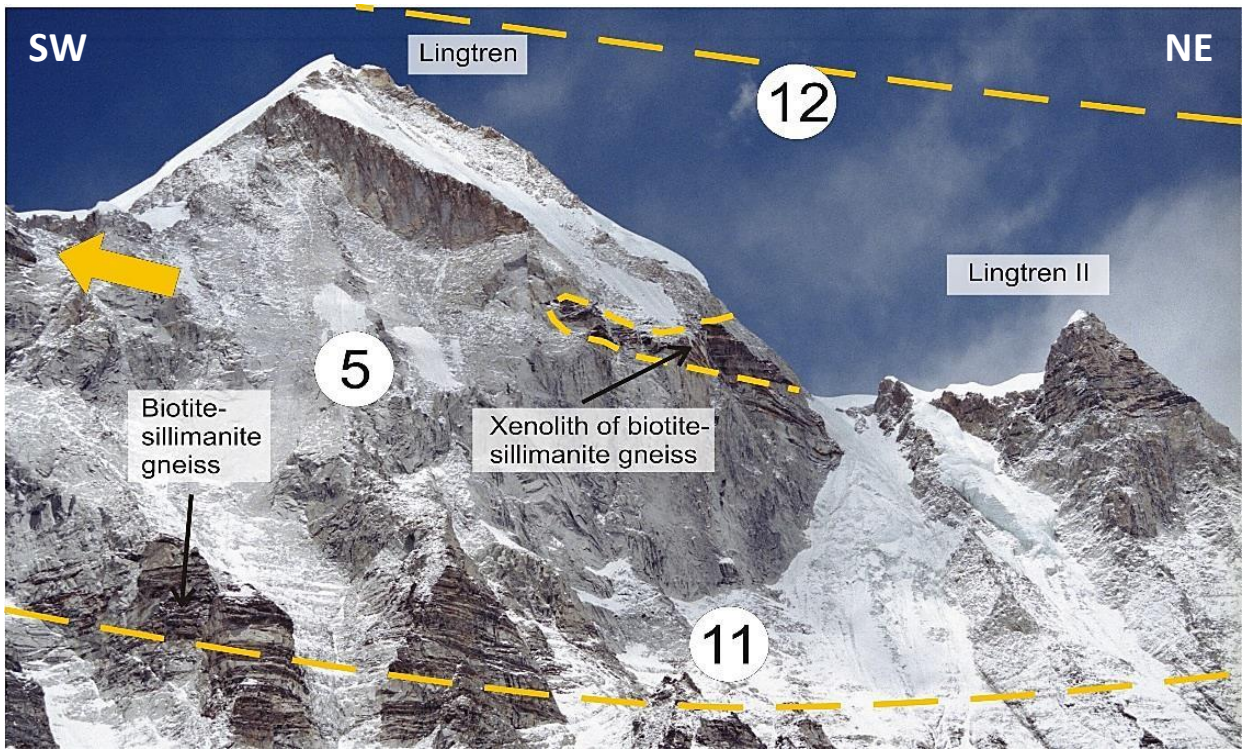


Figure 3.18: The Lingtren and Lingtren II leucogranite massif to the north-west of Everest Base Camp, underlain by dark and light banded sillimanite gneiss. Photograph taken from GPS co-ordinates 28°0'42.75"N, 86°51'24.57"E looking northwest towards Lingtren.

Replaced by:

The geology of the Pumori-Lingtren ridge (as seen from base camp, looking west) is shown in Figure 3.17. Sillimanite-biotite gneiss with numerous leucogranite sills underlies the thick leucogranite pluton of Pumori and Lingtren, and dips gently to the north. The dip of the layering is sub-parallel to the dip of the major structures along which exhumation has taken place.

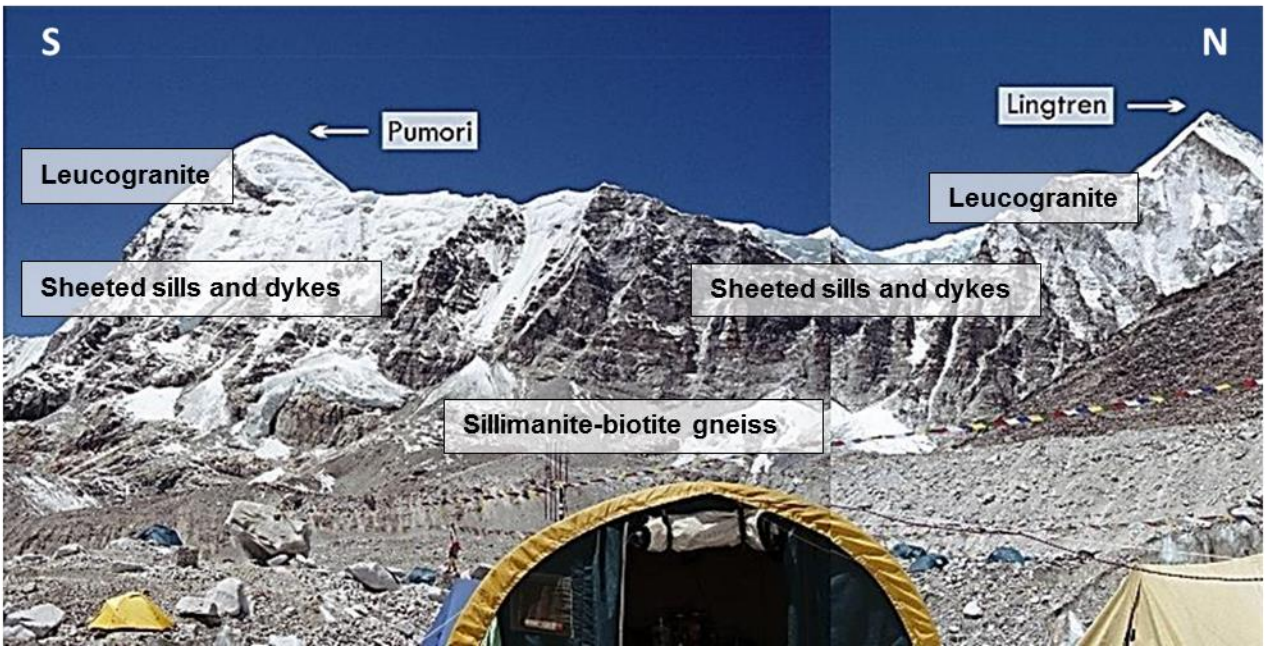


Figure 3.17: The east faces of Pumori and Lingtren above the Khumbu glacier showing exhumed leucogranite intruding sillimanite-biotite gneiss.

A closer look at the east face of Lingtren and Lingtren II, as seen from Base Camp, shows it is composed almost entirely of leucogranite (Figure 3.18), which contains xenoliths of sillimanite-biotite gneiss, and lies above biotite-sillimanite gneiss intruded by numerous sills of leucogranite.

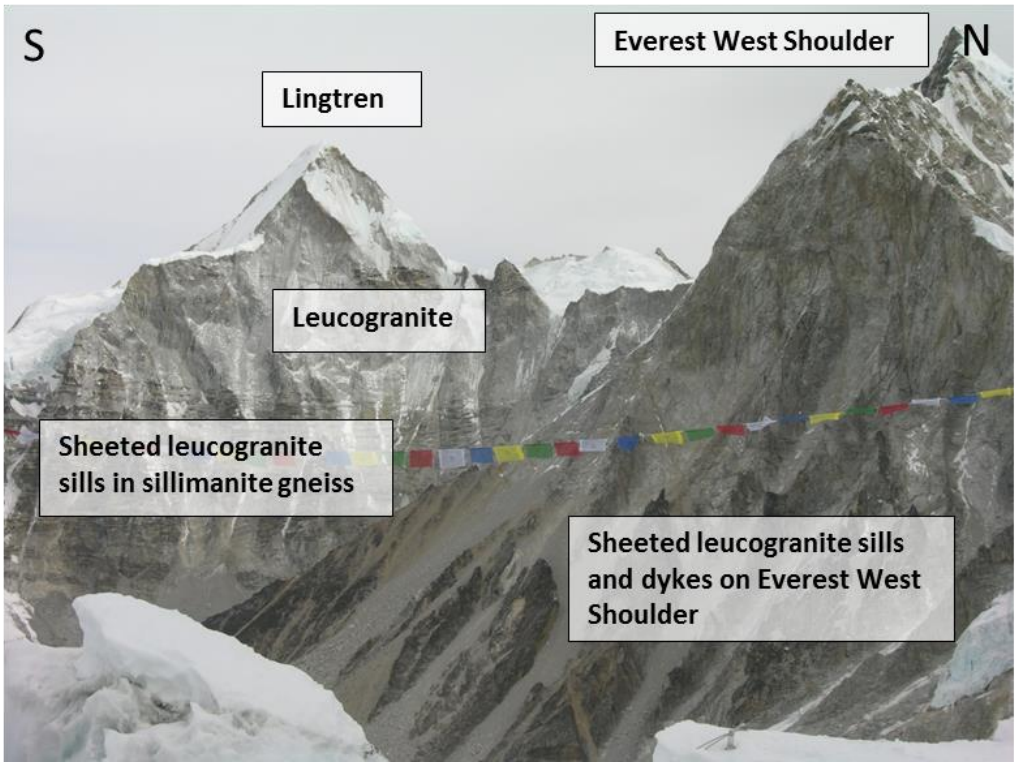


Figure 3.18: The east face of Lingtren viewed from Camp 1 (in the Khumbu Icefall) showing sheeted leucogranite sills in sillimanite-biotite gneiss below the leucogranite that forms the summit of Lingtren, and sheeted leucogranite sills and dykes on the West Shoulder of Everest.

Leucogranite can be examined in an outcrop just east of Base Camp on the other side of the Khumbu icefall. There is evidence of a number of intrusive episodes of granite with fine grained granite intruding into coarse-grained rocks. There is also evidence of younger granite intruding sillimanite-biotite gneiss and pre-existing granite, with numerous xenoliths (Figure 3.18).

The ridge is interpreted as an intrusion of leucogranite between the sillimanite-biotite gneiss and the Lhotse Detachment (Searle et al. 2003). Restoration of the Pumori Lingtren Everest profile (Figure 3.19) shows that melting of the leucogranite occurred at around 20km depth (P=7 kb) and, depending on the dip of the LD samples taken from Kala Pattar show that these rocks have been displaced southwards for a distance of between 90 to 216km (Searle et al. 2003). The Pumori – Lingtren ridge is therefore the top part of a channel extruded between the STD (of which the LD and the QD for part of) and the MCT.

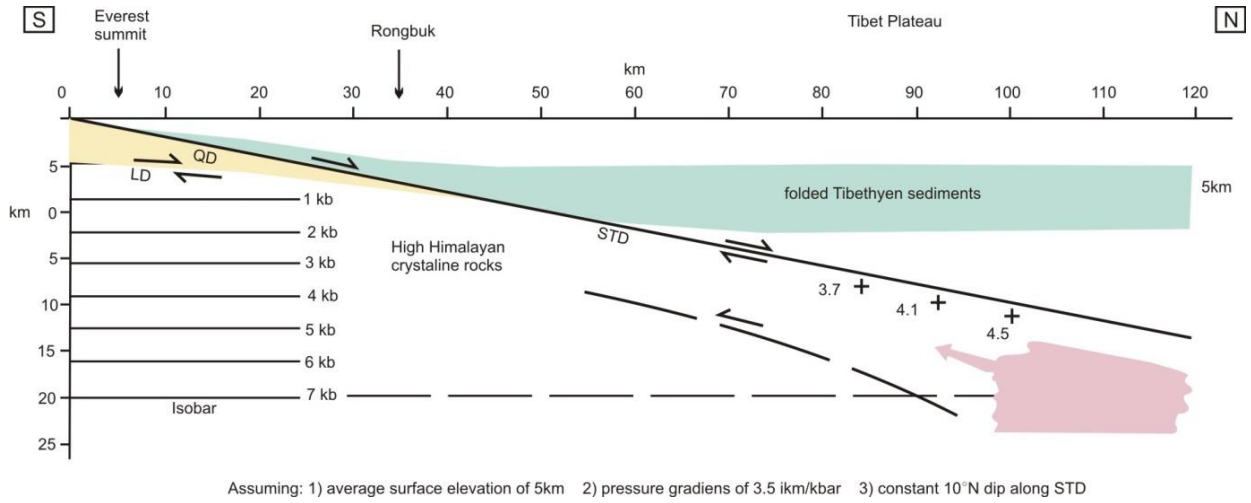


Figure 3.19: Restored Pumori – Everest profile before emplacement of the leucogranite. Crosses mark samples from Kala Pattar, 12km west of Everest (Map 4) which record pressures of 3.7, 4.1 and 4.5kb. at a true dip of 3° to 5°N measured on the N face of Everest, relative displacement is would be 180-216km (After Searle et al. 2003).

Partial melting (migmatisation) of the GHS took place between 25 and 22 Ma (Viskupic & Hodges (2001), and these melts segregated from the migmatites and ascended to the top of the GHS to form the leucogranites that we see on surface today. Higher Himalayan Leucogranites range in age from 20.5–21.3 Ma (Simpson et al. 2000) to as young as 16.8–16.5 Ma (Murphy & Harrison 1999). The age differences between deformed and undeformed leucogranite sills and cross-cutting dykes constrains final stages of ductile shearing associated with sillimanite grade metamorphism at 17 Ma, whilst brittle faulting along the top of the South Tibetan Detachment shear zone must be younger than 16 Ma (Searle et al. 2003)

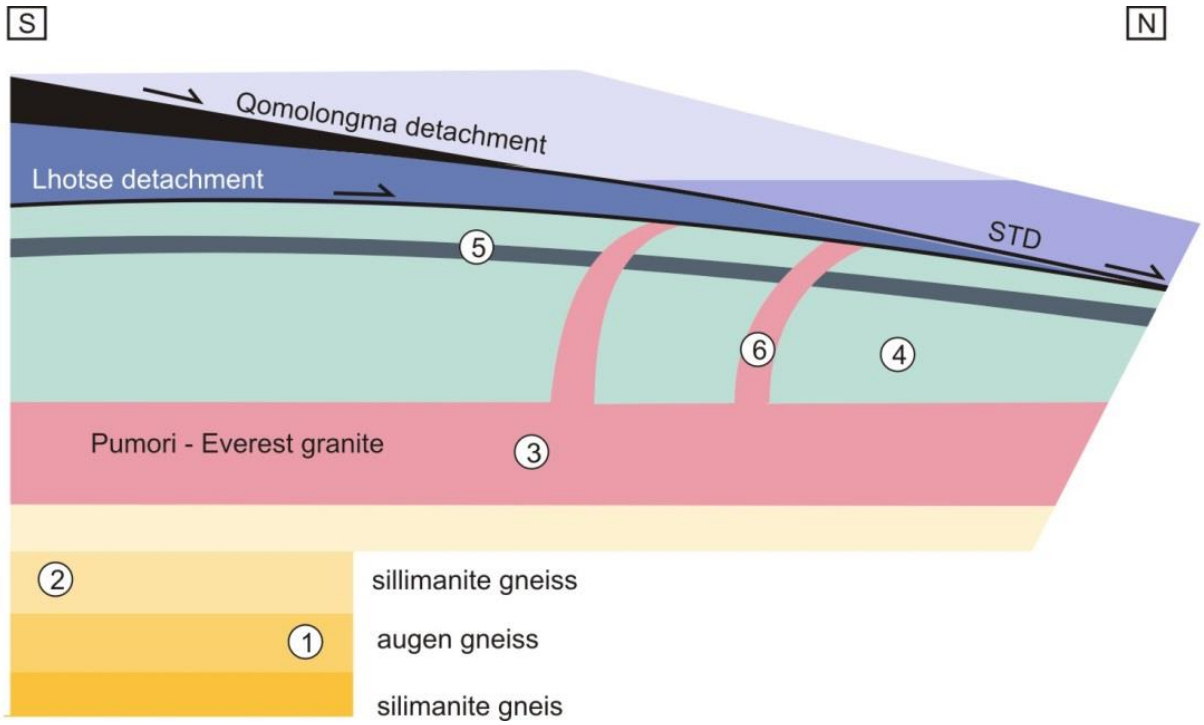


Figure 3.20: The age relationship between metamorphism (M_1 and M_2), the leucogranite of the Pumori-Lingtren-Everest ridge, the Rongbuk metamorphism, the deformed sills and dykes and ductile and brittle faulting on the STD (After Searle et al. 2003). 1 – Age of maximum pressure metamorphism (M1) 32.2 ± 0.4 Ma (Simpson et al. 2000). 2 – Age of low pressure cordierite metamorphism (M2) 22.7 ± 0.2 Ma (Simpson et al. 2000). 3 – Anatexis resulting in melts that formed leucogranites fund on Everest 20.5–21.3 Ma (Simpson et al. 2000). 4 – Youngest metamorphism 17.9 ± 0.5 Ma (Simpson et al. 2000). 5 – Deformed leucogranite sills, 16.67–16.2 Ma (Hodges et al. 1998; Murphy & Harrison 1999). 6 - Undeformed cross-cutting dykes 16.8– 16.37 Ma, (Hodges et al. 1998; Murphy & Harrison 1999).

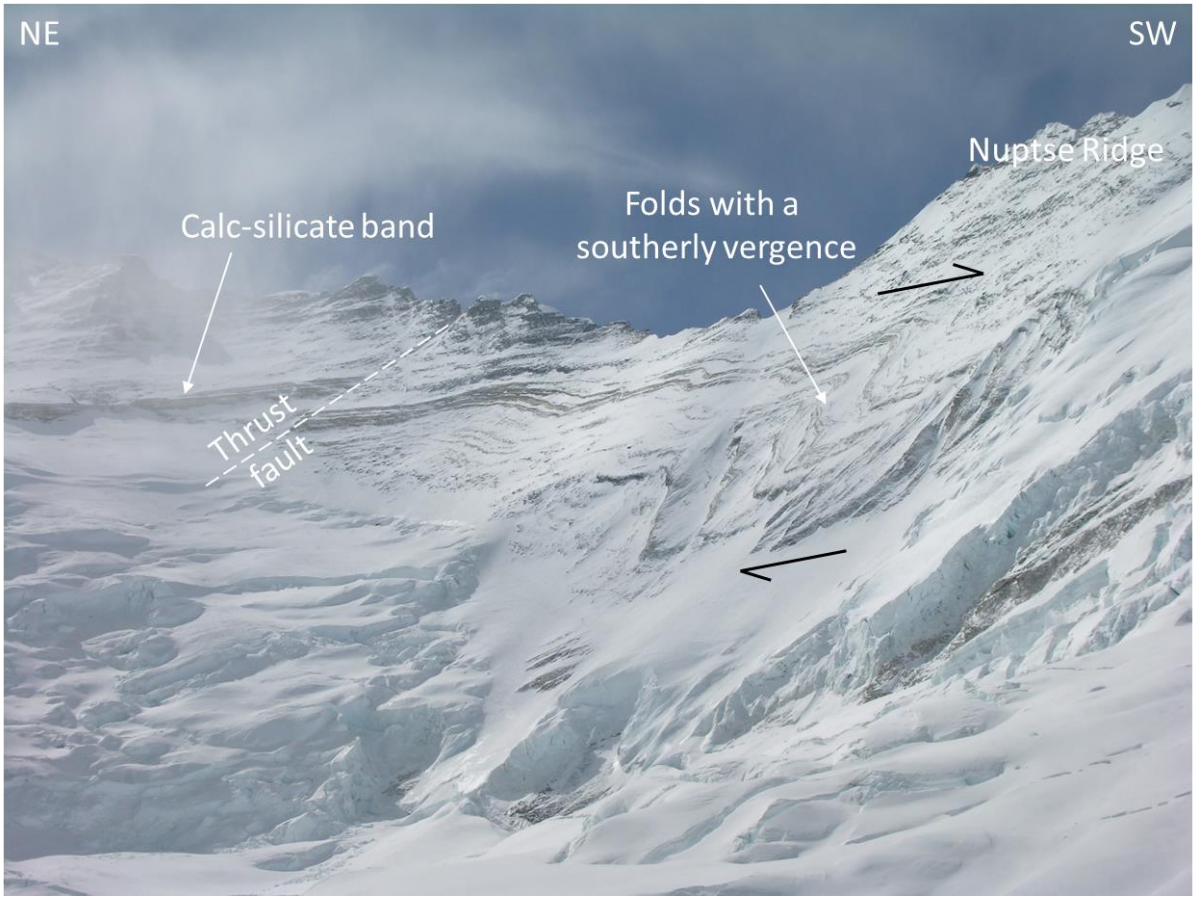
In the western Cwm, around 1000 m above Base Camp, a fold structure in the Lhotse-Nuptse ridge (Figure 3.21) supports the recumbent fold shown by Searle, (2007) on his map of the area. The fold is located in the Rongbuk formation immediately beneath the STD and has experienced P-T conditions of ~660 °C and ~4 kbar.

Pages 81 and 82 (new pages 83 to 86)

1. Replaced as indicated above

Page 83 (new page 87)

1. This photograph (originally Figure 3.19) was replaced:
   By:



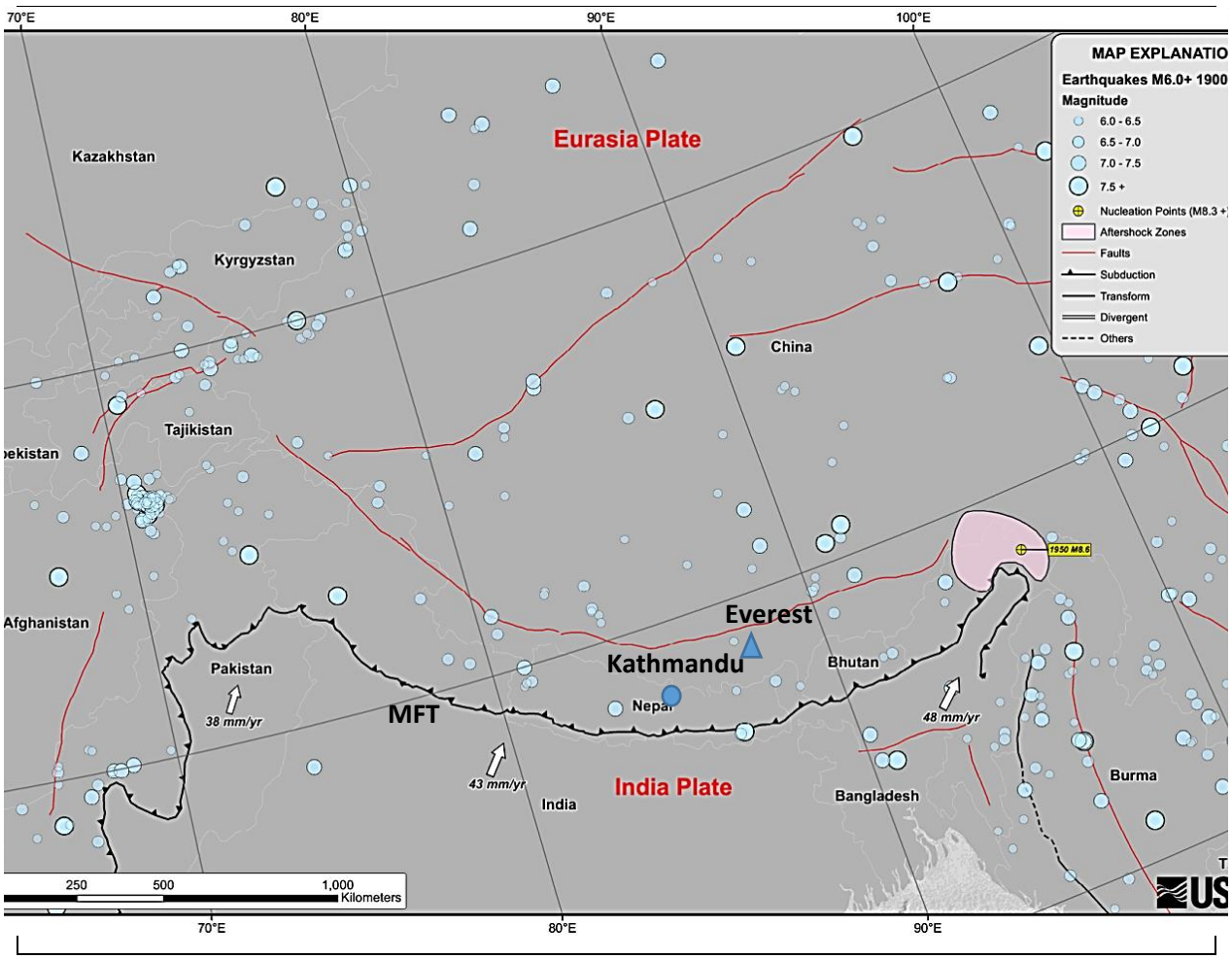
2. And the caption changed to: *Figure 3.21: The Western Cwm fold structure as seen from Camp 2. The low angle of the northwards dipping metasediments and detachments are clearly visible. Note the thrust fault and folded calc-silicate bands with a south-westerly vergence, suggested to be related to the Lhotse Detachment (Searle, 1999). Photograph taken from GPS co-ordinates 28°0'42.75"N, 86°51'24.57"E looking northwest.*

Page 84 (new pages 87 and 88)

1. Reference is personal observation
2. In the high Himalayas, the snow line is around 4000m even in summer and with global warming. From Laboche upwards, there are no rivers or rain, only ice and snowfall. Hence my statement that glaciers must be the major erosive force, normally even though earthquakes, when they do occur, have a major once-off impact at the time of the quake.
3. "(Google Earth/DLR Earth Observation Center/Sentinel-1 satellite operated by ESA, Figure 3.22)" added as Ref."
4. "(Wikipedia and USGS Earthquake Hazards Program)" replace by : "MCT (Wikipedia and USGS Earthquake Hazards Program http://earthquake.usgs.gov accessed June 2015)."

Page 85 (new page 89)

1. "earthquakes (http://earthobservatory.nasa.gov/IOTD/view.php?id=85871, accessed" added.
2. Inserted: "Earthquakes recorded in the India-Eurasia area since 1900 are shown in Figure 3.22." (new Figure 3.21) to show all the earthquakes in the India-Eurasia area since 1900.
3. Regarding the decadal slip, Searle et al. 2003 indicate that: "Extrusion of footwall gneisses and leucogranites is estimated at 200km southwards and brittle faulting in the QD which cuts all leucogranites in the footwall was post-16Ma (Searle et al. 2003)." This suggests a decadal slip/extrusion rate of 12.5cm.
4. Figure 3.20 (new Figure 3.21): Added: "MFT", "Kathmandu" and "Everest"



And caption changed to: Figure 3.21: Earthquake epicentres and their magnitude recorded in the India-Eurasia area between 1900 and 2014. Note the greater number of earthquakes west of the Himalayas (in Uzbekistan, Tajikistan and Kyrgyzstan) and east of the Himalayas (in Burma), compared to the Himalayan Mountain chain (Pakistan, Nepal and Bhutan). (Source: http://earthquake.usgs.gov/earthquakes/tectonic/images/himalayatsum.pdf, accessed July 2014).

Page 86 (new page 90)

1. Added the following text: “Erosion rates dictate the thickness of the Himalayan orogen. If erosion rates in the high mountains are too low, then the orogen thickens as the vertical extrusion of a channel of rock exceeds the rate at which it is eroded, and vice versa. If the extrusion rate as calculated from Searle et al (2003) is correct, then the vertical rate of movement at a dip angle of 10° is 2.17cm/decade. Hence the rate of erosion needs to match this to maintain the height of the mountains.”
2. References added: “(Malavielle 2010, Bose & Mandal 2010)”

Page 87 (new page 91)

1. “Oblique” added
2. “from the south“ added
3. Original text: “Glaciers are the most important erosive force in the concentrated denudation of the high Himalayas.”

   Replaced by: “Glaciers are a powerful erosive force in the concentrated denudation of the high Himalayas.”
4. All glaciers and main summits in Fig 3.21 (now Fig 3.24 labelled
5. Reference added: “*(Egholm et al. 2009)” in Figure 3.24.*

Page 88 (new pages 92 and 93)

1. No changes

Page 89 (new pages 93 and 94)

1. “likely to be” deleted and “generally” added
2. “from below the LD to the QD” added.

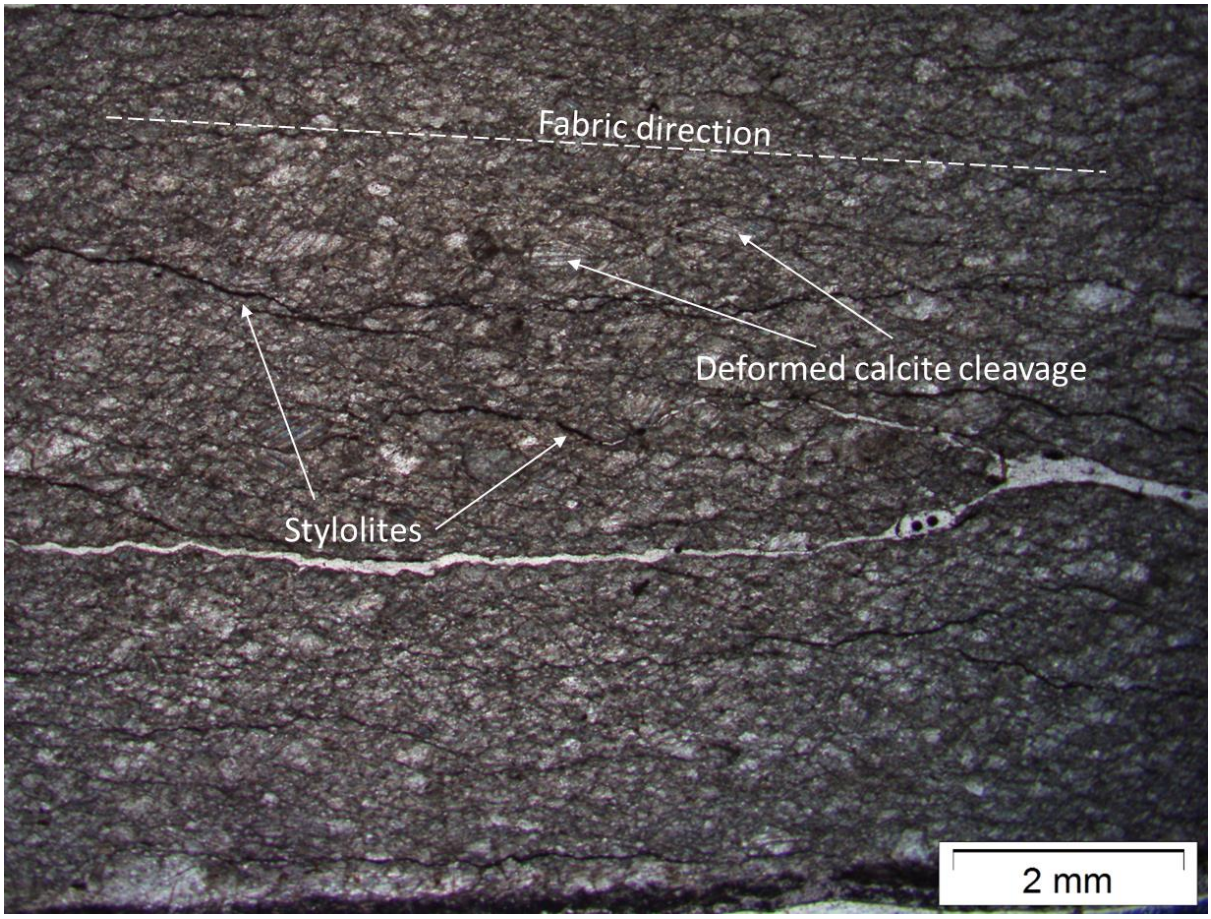
Page 90 (new page 95)

1. “of pre-existing” added
2. The name “Sean” added
3. Evidence of pre-existing fossils is given in the caption of new Figures 3.27, 3.28, and 3.29 in the form of “carbonaceous material, stylolites and carbonaceous grains.
4. “W” and “E” indicators’ style changed
5. Sample sites indicated
6. Hillary Step indicated

Page 91 (new page 96)

1. “single “ added
2. “or fluid ingress related to shears or fractures” added
3. “s” deleted

4. Photomicrograph of Figure 3.25 in the original was replaced with:



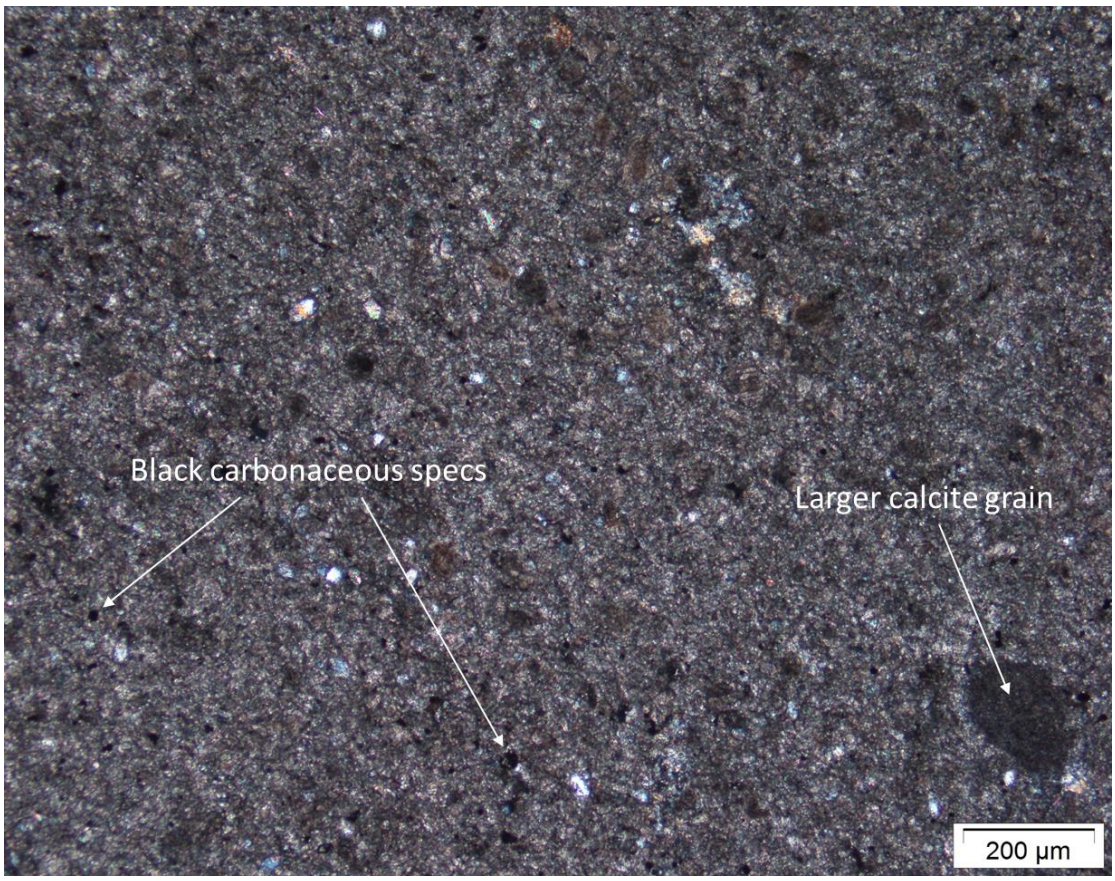
5. And the Caption replaced by: *Figure 3.27: Photomicrograph (PPL) of a rock sample from South Summit (sample RH16), within the Yellow Band. The rock is a marble and is composed almost entirely of sparry calcite with a large number of crystals showing twinning. Black carbonaceous material is present as stylolites parallel to the fabric direction. These wavy, black carbonaceous layers may have originated from fossiliferous material on stylolite dissolution planes. The rock is medium to fine grained (<0.3 mm grains) with some coarser calcite crystals. Numerous shears cut through the sample. Calcite grains tend to form elongate lenses between the shear planes, and some calcite shows deformed cleavage bands. GPS co-ordinates 27°59'5.25"N, 86°55'31.17"E.*

Page 92 (new page 97)

1. Sherpas mentioned fossil shells from south col to the summit. I do not know if what they saw were fossils as I never saw any fossils myself. Furthermore, even the low grade metamorphism of the upper Everest Series may have seen these shells re-crystallised to calcite. The paragraph has been re-written as: The sample collected from the Hillary Step (Figure 3.29) is composed of extremely fine-grained calcite with small carbonaceous grains and minor muscovite and epidote. The fine-grained, highly deformed nature of this sample

suggests it comes from a fault zone (possibly a minor fault associated with the QD). As it is Ordovician limestone it should contain fossils, however these have also been deformed and the carbonaceous specs in the sample are all that remain of them. Sherpas have mentioned to the author that the South Col area (just above the LD) has many fossils contained in the slaty rocks. However, the author did not manage to locate such fossils.

2. The photomicrograph on this page, originally Figure 3.26 has been replaced with:



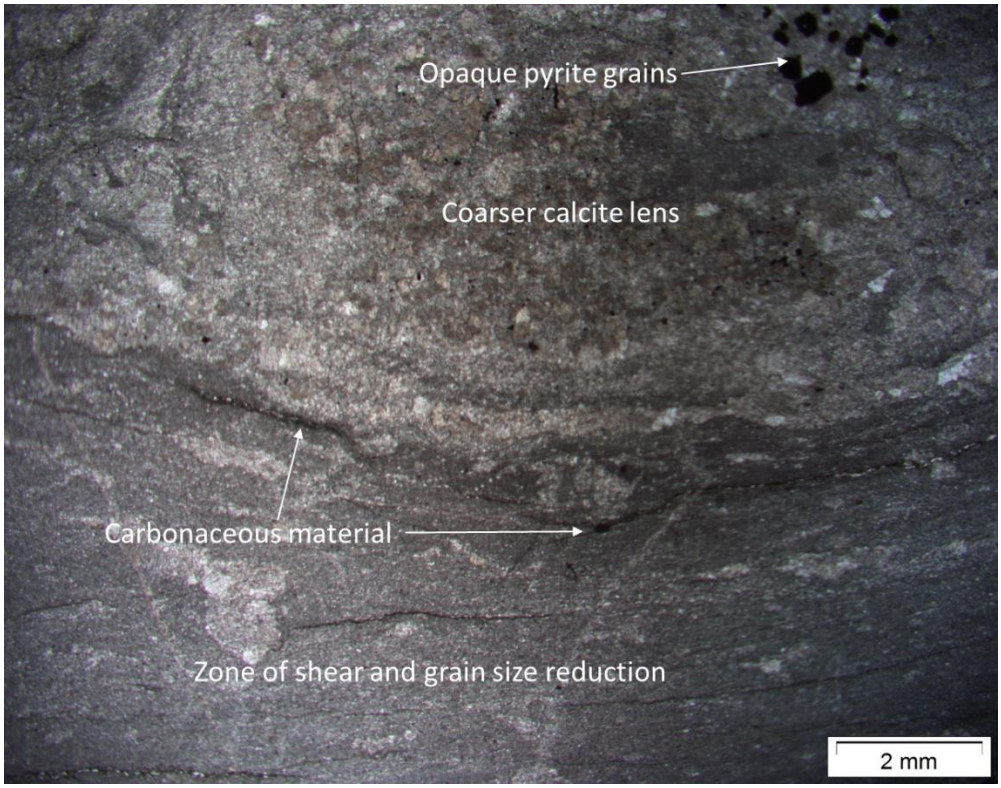
3. The Caption has been re-written: *Figure 3.28: Photomicrograph (XPL) of rock sample RH17 from the Hillary Step (Figure 3.27). The rock is composed mostly of calcite with minor muscovite and, rarely, epidote. The sample is fine-grained although there are some coarser calcite grains present. Small carbon-rich (graphite) grains are visible. The fine-grained nature of this sample suggests it has experienced intense deformation. GPS co-ordinates 27°59'12.31"N, 86°55'26.76"E.*

4. Sample site has been indicated on Figure 3.24 (now Figure 3.27).
5. "(graphite)" added

Page 93 (new pages 98 and 99)

1. "The sample taken 5 metres from an outcrop from the summit" replaced with "The sample taken from an outcrop 5 metres from the summit"

2. “The original sedimentary layering is preserved as fine banding, with darker organic-rich layers.” Deleted
3. Added: “with larger calcite grains forming a lens surrounded by extremely fine-grained calcite (an ultramylonite).”
4. Also added: “The extremely fine-grained nature of much of the sample is as a result of shearing and associated grain size reduction.”
5. Original photomicrograph, Figure 3.27, on this page deleted:
6. And replaced with:



7. Caption changed to: “*Figure 3.29: Photomicrograph of rock sample near the summit of Mount Everest. It is composed almost entirely of calcite grains. Small amounts of mica are also found, in addition to a number of opaque grains of pyrite and darker bands of organic-rich (carbonaceous) layers. The majority of the sample is fine grained due to shearing which has caused grain size reduction. This shearing has resulted in breccia zones with further evidence for deformation found in folded carbonate layers and bent cleavage planes in some of the calcite crystals. GPS co-ordinates 27°59’16.37”N, 86°55’30.23”E.”*

Page 94 (new page 100)

1. Hyphen added
2. “almost perfect” deleted

Page 95 (new page 101)

1. Tethys Himalayas and trans-Himalayan Batholiths labelled in Figure 3.29, now Figure 3.32
2. Et al. "," comma after full stop deleted throughout document.
3. (New) Figure 1.2 shows the lower crustal flow directions postulated by Tapponnier and Molnar

Page 96 (new page 102)

1. "s" added
2. Dhital's miss-spelling of leucogranite and suture corrected in Figure 3.29, new Figure 3.31

Page 97 (new page 103)

1. Original text: "Other continent-continent collision zones, like the Usagaran/Pan African gneiss and migmatite belt which cross-cuts the African continent, may yet reveal channel flow mechanisms for their origin." – this is my own thinking, especially when observing the Nelspruit (leuco)granites along the N4 which look so similar in colour to the Everest Base Camp and Lingtren leucos. The granites in the Juliasdale/Riparara area of E Zim and in the Serengeti are also very pale-grey; this comparison is unsubstantiated, but is my line of thinking when making this statement.

2. "Granitic protolith" "metasedimentary" question has been re-written: "The granite gneiss of the Greater Himalayan Sequence (GHS), observed in the early part of the traverse from Lukla towards Everest, represents a granitic protolith…."

3. The mylonite zones above and below recumbent folds is my own observation.

4. "This is not the only explanation and they may simply have been generated by thrusts during collision. Much of the granite gneiss in the Lukla to Periche area, and even to Laboche, may have been brought to surface from below Tibet through exhumation resulting from high erosion rates in the Himalayas or through a channel flow mechanism" added.

Page 98 (new page 104)

1. "minerals, such as" deleted.
2. "and pressures of 6.7±1.0 kbar (Searle et al. 2003)," Ref and pressure added

Page 99 (new page 105)

1. "620 to 730 °C" replaced with " 837 ± 59 °C"
2. Deleted the following: "This differs significantly from the low-grade metamorphism of the Everest Series schists which experienced only greenschist metamorphism and burial depths of <15 km (Searle, et al. 2003). "
3. Deleted the following: "Additionally, the STD juxtaposes the older sedimentary rocks of the Everest Series with the younger magmatic rocks of the Higher Himalayan leucogranites. "
4. Space added between Figures and the number.

Page 100 (new page 106)

1. Agree that thin section petrography would show this.
2. “The leucogranite massif of Lingtren/Pumori may be interpreted as a molten weak crustal channel extruded in a southward direction as described in Figure 3.17.” deleted

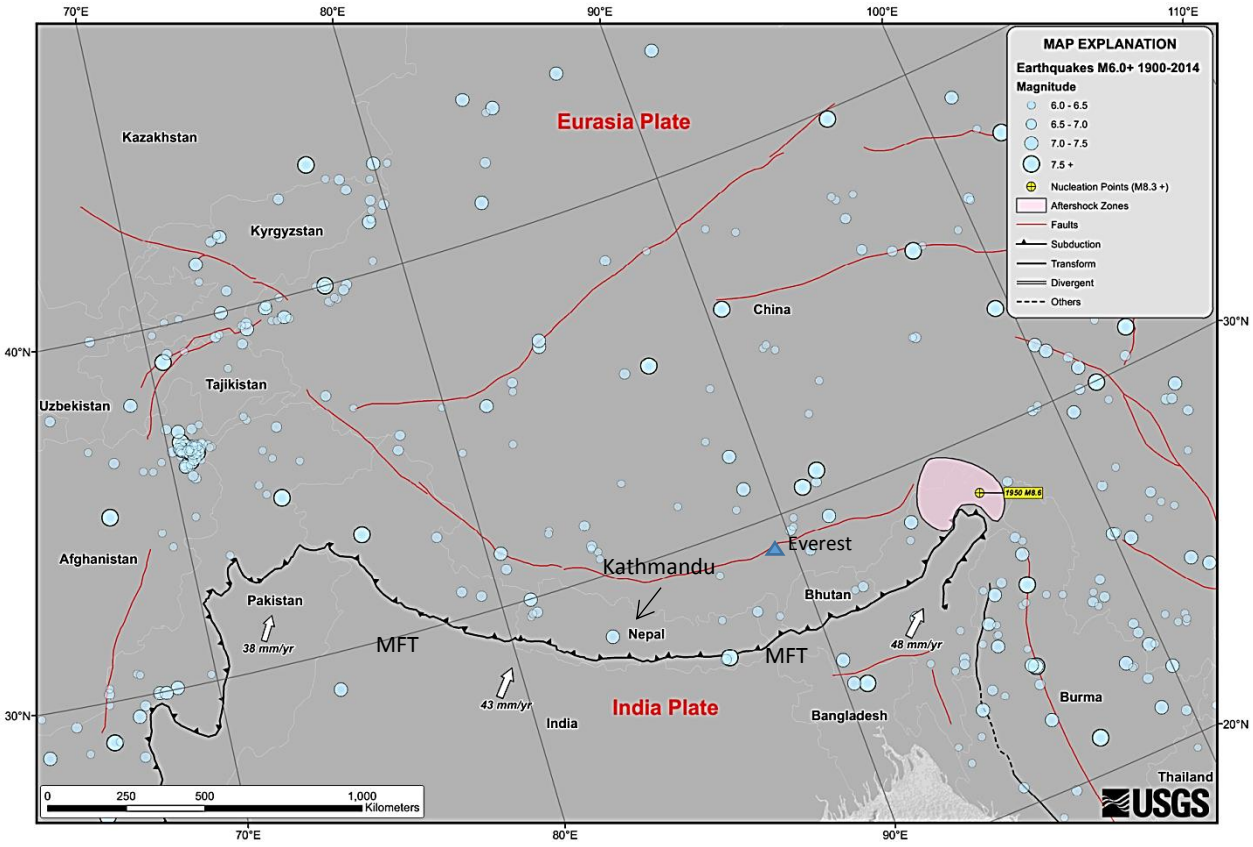
Page 101 (new page 107)

1. “and extrusion” added in Figure 4.2.
2. “southern front of the” added.
3. “(Personal observation)” added as this was done on several occasions while I was at Base Camp and Camps 1 and 2.

4. “, one could speculate that rivers could replace glaciers with continued global warming. “ added.

Page 102 (new page 108)

1. Source of map in Figure 4.3 added: http://earthquake.usgs.gov/earthquakes/tectonic/images/himalaya_tsum.pdf
2. Deleted reference to MCT and added:” Movement most likely occurred on the Main Boundary Thrust or the Main Frontal Thrust as Kathmandu lies above both. (Figures 2.2 and 3.22).”
3. Added labels to Figure 3.22: MFT, Everest, Kathmandu.
4. Figure 3.22 labels added:



Page 103 (new page 109)

1. “(Figures 1.2, 1.4 and 3.32)” added to explain ear-like structures.

2. Commas deleted

Page 104 (new page 110)

1. “High elevations are shown in white (5000 m to 8850 m) red (4000 m to 5000 m) and low elevations in blue (1000 m to 2000 m) and purple (<1000m).” added.

Page 105 (new page 111)

1. Agreed – not appropriate: “There is one more thing. Whilst in the study area, there was a constant hum in a very low frequency that was not associated with a mechanical generator or electrical system as it could be heard by me and the Sherpas in the Khumbu Icefall, and on some of the leucogranite outcrops and even down the valley as far as Periche. This straining noise was possibly the active shearing taking place in the vicinity of the KT or in the sillimanite-biotite schist shear zone. I have not heard of anyone else hearing this hum, except possibly the Buddhists who use the “OHMMM” sound with which to mediate. The sound is possibly no longer there, following the recent release of energy through the devastating earthquakes.” Deleted.

New page 112

1. Reference to authors on channel flow added: “(Beaumont et al. 2006; Brown and Gibson, 2006; Godin et al. 2006; Grujic, 2006; Hodges 2006; Jessup et al. 2006; Law et al. 2006; Scaillet and Searle, 2006; Searle et al. 2006)”

Part 2

Corrections made to Part 2 of the dissertation - the public geological guide.

The following corrections have been done in response to the MSC BY RESEARCH EXAMINER'S REPORT dated 14-12-2015

Corrections done in response to the copy of Part 2 annotated by the Examiner follow directly after these corrections

The examiners comments are appreciated and relatively positive compared to Part 1. I have, again, taken on board ALL the changes suggested and I must admit that the Guidebook has a much better flow and logic to it than it had before.

The page numbers in the corrected version of the dissertations have different page numbers and are shown as "new page 45", for example. When a new page number is indicated, this refers to the corrected dissertation.

In the first part of this Part 2, the comments from the Examiner's report are addressed. In the second part, the comments from the annotated copy of Part 2 are addressed.

In the first two paragraphs there are no changes suggested or made.

"Abstract":

"A whimsical journey 50 million years back in time" raises questions. According to the online thesaurus, "whimsical" can mean "fanciful, quirky, unusual, imaginative, creative, impulsive or capricious". Its opposite is "practical", so I am at a loss to see the significance of such a title. "Time-traveller Geo-rge" is mentioned only here, so is not a throughgoing feature of the guide. Technically, the title should be ".. 50 million years through time". The use of "George" raises obvious questions that complicate matters – time-travel is not real, nor is a Jules Verne capsule capable of penetrating the crust; one could not "observe" India and Asia converging in the conventional sense. None of the organisms mentioned actually appear in the traverse text; there is no proof that folding occurred "hundreds of times"; there is confusion between the "orange pip" and "great sheets of rock". "Fifty million years go by so quickly

The "whimsical journey with Geo-rge" has been deleted.

Table 1 on p. 2 lists the 10 highest peaks on Earth, all from the Himalayas. The purpose of the list is not discussed.

The purpose of Table 1 has now been discussed and the text and table re-arranged to improve the flow of the guidebook.

Foreword (p. 3):

There appears to be significant overlap with the Introduction.

It is not clear if the photo is from a source other than the author. It has no caption.

Everest metamorphism starting 50 Ma ago does not conform to the text.

The overlap between the Foreword and Introduction has been removed as far as possible.

The photo of Everest has been sourced and a caption added

Everest Series metamorphism starting 32 Ma ago conforms to the text as stated on page 29. The 50m year referred to the metamorphism in the GHS.

Introduction (p. 4):

Overlap with Foreword, and somewhat repetitive and disjointed (text can be tightened – see suggestion).

Para 5 introduces a complex set of terms that are not explained adequately.

Introduction overlap has been deleted

The complex set of terms in Para 5 has been expanded upon and clarified. These are all discussed in detail later in the guidebook.

Fig. 1 caption illustrates the inconsistencies and gaps that characterize many parts of the text – an age is given for only one rock type, the caption lists rock types, but the diagram lists "Rongbuk" and "North Col Formation" only

Fig. 1 caption has been amended and the date of the one unit deleted.

Page numbers should be specified, rather than "..[appears] near the front.."

"near the front " has been replaced with "page 14 " and "page 19"

Stops..:

If this is a Table, shouldn't it have a number?

The table of stops has been labelled Table 1.

As much of Part 2 has been re-arranged, the themes of Stop 1 and Stop 4 have been changed to account for the new content of the stop.

Maps 1-4:

The maps are poorly drafted and inconsistent; for instance, the geology of Map 3 bears no resemblance to Map 1 in terms of the location of the leucogranites. The colours of the same unit on different maps may also vary. The text in Maps 3 and 4 is too small and slightly blurred, making reading difficult; it also doesn't help that words or numbers are superimposed on lines (esp. Map 2, but also 3 and 4). The maps have inconsistent font, N arrow and scale styles; the Keys contain several spelling mistakes or omissions and, except for Map 4, Latitudes and Longitudes are missing. Several drafting errors are noted, particularly on Map 3, not least "gnesses", "kilometeres". I would question the usefulness of much of the top left part of Map 4 – enlarging and rotating the southern half of the map (and reducing the size of the Key box) would allow the complex detail to be seen better. Colours should not be so dark that they mask the lettering.

Maps

Map 1 has been re-draughted and the major faults included.

Map 2 has been uncluttered and re-draughted.

Map 3 has been re-drafted and spelling corrected.

Map 4 has been re-draughted, cropped and re-sized and superfluous sections omitted.

Glossary:

I found this disappointing on several counts. First, the definitions used do not seem to be consistently derived from an authoritative source. Second, many use technical terms that are themselves not explained for the lay reader (e.g., "Recumbent fold" uses the term "axial plane", which is not explained). Third, a random selection of terms in the text turned up many omissions from the glossary; e.g., 'isostacy', which is one of the central concepts to explain the Himalayas, is not included; neither is 'erosion'! Fourth, some definitions are wrong (e.g., Vergence; Sill; the definition of Extrusion is actually for Intrusion; Felsic refers to FELdspar + Silica – the "l" has nothing to do with "leucocratic"), incomplete (e.g., Migmatite, Leucosome) or just plain strange (e.g.: Folding – the formation of folds in rocks). I did not have time to correct all the mistakes or omissions.

Glossary

The Glossary has been corrected with omissions inserted. Authoritative sources (*the Glossary of Geology (Bates and Jackson, 1987), and Penguin Dictionary of Geology, (Whitten and Brookes, 1972).)* were used and translated into layman's language as far as possible. Further undefined words resulting from the additions were added and explained in the glossary.

Axial plane, isostasy and erosion have been defined.

Wrong definitions have been corrected: Vergence, sill, Felsic, Migmatite, Leucosome

"Folding" deleted from Glossary.

Terrane definition inserted

The Geology of the Himalayas

This part has been extensively re-arranged as recommended by the Examiner

Aitchison reference added

“have a mean elevation” inserted

“lighter replaced by “less dense”

Figure 2 thrust faults and detachments inserted in the figure, symbols explained

The town of Lukla shown on the figure

“This occurs because there is a geothermal gradient that increases with depth at between 10°C to 20°C/km depth. This increase in heat is the result of primordial heat, conductive heat from the mantle and the core, frictional heating from faults and shearing and radioactive decay of small amounts of uranium and thorium contained within rocks that cause them to heat up.” Has been inserted

The mantle is mentioned because the reference mentions it.

“Mantle” has been defined.”

“this”, semi colon and “it” edited

“partial” deleted

“of the main collision zone” added

“These displaced rocks have “escaped” laterally” deleted

“China” and Afghanistan” shown in Figure 7.

The section on earthquakes has been moved to a Box (10.2) and the corrections in the annotated copy made by the examiner have been made.

Source of Fig 10.7 inserted

“(Source: Google Earth/DLR earth Observation Centre/Sentinel -1 satellite operated by ESA)” moved to Fig 10.9 caption.

Geological tour in the Himalayas:

This is a little confused - para 2, for instance, describes the layout of the guide rather than the geology. The text is inconsistent – sillimanite is described as forming at low pressures, with no depth (km) given, yet the next sentence gives a depth for eclogite facies metamorphism; towards the end a very specific age range is given for the summit rocks, yet no other age is mentioned. Whilst time is taken to explain that sillimanite signifies an original mudrock, para 7 is a bewildering array of unexplained terms and detail that would surely confuse a lay reader.

It seems strange that the Lukla-Everest geology is explained before "The Geology of the Himalayas" (p. 19-23).

The first box should have been an explanation of plate tectonics (including the internal structure of the Earth – continental and oceanic crust, mantle, etc.), a second should have been to summarise how weathering and erosion compete with dynamic mountain building and isostatic forces to exhume deep crustal rocks; i.e., what is a mountain (range)? As explained in my comment on p. 22, the layman enters the geological narrative through the landscape with little understanding of deep time and the fluctuating nature of conditions below the surface. The lack of a general cross-section across the Himalayas at this point does not allow the reader to understand subduction and collision processes visually. : would say that the time sequence in Fig. 1.2 should have been placed here rather than under Stop 1.

The text misses an opportunity to relate the slowing of the convergence rate to the onset of continent-continent collision; the 'big picture' approach breaks down on p. 22 into too much detail about the 2015 earthquake – just dumping information and failing to see how this cannot be unpacked by a lay reader is counterproductive.

Geological Tour in the Himalayas (new page 28)

The title of this chapter has been changed to "The Geology of the Himalayas"

Paragraph 2 has been deleted

Depth and temperature of formation of sillimanite has been inserted

"Ordovician (485 to 443 million year old)" has been deleted.

Paragraph 7 has been expanded to explain certain terms.

"The Geology of the Himalayas" section has been placed before "the Lukla-Everest geology" section

A general cross section across the Himalayas has been included. And the time sequence to understand subduction and collision has been included here (old Figure 1,2).

Figure 1 (which shows the detailed geology of Everest from Base Camp to the summit) has been moved to here to complete the logic of going from continental geology to the detailed geology of Mt Everest (this was not requested by the examiner).

Box with Plate tectonics and structure of the earth inserted.

Box with how weathering and erosion compete with dynamic mountain building and isostatic forces to exhume deep crustal rocks has been added.

The big picture approach has been adopted here.

The section on the earthquake has been moved to the base camp stop and included in a Box (10.2) as this is where the earthquake had a major effect on loss of life.

General comments about the Stops

Whilst a good idea in principle, the inclusion of a cut-out of the larger geological map at each stop does not work if there is no key or scale, or if the text is indecipherable. Constantly having to refer back to the

main map is awkward. I also fail to see why the miniscule Earth globe has been overlaid on each of these maps, inevitably cutting off text.

General Comments on the stops

The cut-outs of the larger geological map have all been deleted.

Stop 1: As in several places, the text veers off into irrelevance using excerpts from the author's travel diary. Personally, I don't think it is appropriate as a component in the text; more importantly, however, it should not come at the expense of other things. For instance, what is the nature of the vegetation mentioned in the synopsis (is it all rhodedendrons, as implied by Stop 2, or are there also trees)? The fact that the first rock type shown is as 'bricks' in a wall is interesting, but it's a poor advertisement for geology after the intro describes 'great walls of rock some 2000 m high'. Terms like 'fold', 'leucosome', 'micro-faulting', boudinage', etc., are mentioned for the first time here, but no images are shown. I have no idea if the party spends some time in Lukla (apparently not, based on the first line of Stop 2), but where are the directions to sites to see these features, even if it is to point out a particular cliff face en route? Again, the absence of reference to the geomorphological features, which are the prism through which a lay person will see the geology, is irregular. For instance, are there landslide scars, have any been linked to earthquakes in recent memory, or are there any that relate to monsoon cycles; what is the profile of the river valley and its tributaries, what is the gradient, what forms rapids or waterfalls, has there been any measurement of downcutting rates, what is the size of the boulders in the river, are there boulders on the slopes, when is maximum river flow relative to the climbing season, etc.?

The geological interpretation on p. 30 is far too cursory, and incorrect – granite is an intrusive igneous rock, so it cannot have been 'deposited in a forearc basin' (besides which, no such basin is shown on the Indian Plate, as suggested). There is no indication of its age. For instance, if it is part of the Indian continental crust formed before even Gondwana existed, and the oldest rocks the reader encounters, say so! Explaining how it changed from a granite to a gneiss is also lacking; e.g., was it a gneiss before the collision or is every fabric element Himalayan?

Box 1.1 is crucial but I believe it is in the wrong place for maximum effect. It also needs serious restructuring on many points, as indicated in the text. It also goes too far -- it provides too much detail on Everest geology for so early in the guide (this is a repeat failing).

Notwithstanding the problems with the clarity of the maps and cross sections, I found the quality of the hand specimen and photomicrograph images universally particularly poor, as per the comments in the text. There is also a difficult challenge in explaining what plane-polarised and cross-polarised light images really are, which is omitted. The sample descriptions lack modal proportions – again, this helps the lay reader understand what is important to look for.

Most descriptions lack any form of structural reference frame; for instance, at Stop 1, what is the orientation of the gneissosity? Can it be seen dipping to the N, and at what angle? Are there folds or boudins with scales of tens to hundreds of metres that deflect the foliation? And are there any faults in outcrop that allow the concept of slip to be introduced?

Stop 1 (on new page 41)

Original text: "these gneissic rocks were deposited in the forearc basin"

> Replaced by: "The original rocks that were metamorphosed into these gneissic rocks were deposited in the forearc basin". A forearc basin is shown on (new) Figure 8, Box 3. The reference to granite was incorrect and deleted.

Some of Box 1.1 has been removed and its contents inserted in the "Geology of the Himalayas" section. The stratigraphy part of Box 1.1 has been left in place.

The photos and the photomicrographs have been re-taken. Modal proportions have been inserted in the text.

Rock descriptions regarding orientation of gneissosity are very difficult to make at the first 4 stops as there is very little outcrop and even the outcrop that is seen e.g. the Namche migmatites above Namche may not be their original orientation. At Stop 1 there is no outcrop and no measurements with 100% certainty can be

taken. There are some folds in the rock underfoot as they are in the gneiss bricks shown in the photo in Figure 1.3 (Now photo in Figure 1.6) but there are no large folds on the scale of hundreds of metres that deflect the foliation. On the faces of the mountains near Stop 2 and Stop 3 there are some large folds that have been pointed out in the text, but there is nothing that one can access easily or from which one can get a clinometer reading. No faults in outcrops were observed.

"Unlike above 4000m, the slopes are heavily vegetated" added to Fig. 1.1 caption

Figure 1.7 – replaced with photomicrograph of granite gneiss, new Figure 1.8

Stop 2: The Namche migmatite includes both orthogneisses and amphibolites, calc-silicate and pelitic gneisses. I have serious doubts that Fig. 2.2. is migmatitic granite gneiss (as implied in the text) – the banding and lack of augen suggest amphibolite or metapelite. Fig. 2.3 also looks like a calc-silicate rock.

This stop is used to introduce the structural history. Unfortunately, I have doubts as to the structural interpretations of both Fig. 2.2 and 2.3, and Fig. 2.3 would certainly confuse a lay reader, given that it is described as a thrust but normal dip-slip movement is shown, and the banding dips S, not N. The contrasting of S-C thrust and esb (S-C') microstructures could certainly have benefitted from (a) both being sketched in Fig. 2.1, and (b) photomicrograph(s). Although according to the Box it appears that the fabrics shown in the specimens are S2, the reader is never explicitly told this. In fact, in Fig. 2.4, the gneissosity is called S1. Nowhere is it explicitly stated that the thin sections were cut perpendicular to foliation and parallel to lineation, which would be necessary to make sense of microstructures.

Fig. 2.4 microtextural description is extremely vague/simplistic, if not naïve. This will leave the reader either confused (not enough information to agree with the interpretation) or misinformed. "Strained quartz has wavy parallel lines running across..." – I wouldn't accept this from an undergraduate.

Stop 2 (on new page 49)

Figure 2.4 is a calc-silicate rock and not gneiss – deleted as it does not add any value to the text.

Thin sections cut perpendicular to the fabric to make sense of structures.

Stop 3: I notice that distances covered between the stops are not indicated – only altitude differences.

Inappropriate: "In the afternoon it may snow ..." Then again it may not!

Fig. 3.4 is poorly labelled – the dashed lines overlap both foreground and background ridges; the image is insufficiently clear to judge if the dashed lines actually follow outcrop structures, but I have concerns that the lines are not parallel to the features. I have serious concerns about the interpretation of Fig. 3.4 as representing Channel Flow, as discussed previously.

Stop 3 (new page 53)

"In the afternoon it may snow" deleted

Distances between stops inserted as: "Distance to next stop: XXkm" at ALL Stops

Figure 3.4 dotted lines eliminated and re-drawn

New photomicrograph (Figure 3.6) of Sill-Biot schist and gneiss added.

Stop 4: Inappropriate: "Buddhist monks will likely be playing a game of soccer …"

So how do the Bt-Sill schists/gneisses (confusing interchangeable use of terms for the layman) precursors relate to the granite gneiss precursor – tell the story if they were younger sediments deposited on granite basement off the Indian continent before collision.

Personally, I feel that the erosion discussion on p. 44 should be done at Stop 1. There is potential for a dangerous misconception implied in the text and its placing, namely, that only the "high peaks of the Himalayas" are shaped by the uplift-erosion interactions, when in fact the entire chain's topography and elevation need to be considered holistically in this context.

Box 4.1 contains a lot of terminology that is either not (or not well) defined – see comments in text.

Stop 4 (New Page 60)

"Buddhist monks will likely be playing a game of soccer in the afternoon" deleted.

"Biotite sillimanite schists" replaced with "biotite sillimanite gneiss"

Box 4.1 has been moved to Stop 1 and the terminology defined as indicated in the text

New Figure 4.5 added to describe a migmatite. (new page 64)

Stop 5: The geological content significantly overlaps Stop 4. The text would benefit greatly from cutting of unnecessary repetition and introducing and thoroughly explaining concepts in the right sequence. A recurring issue is the lack of hard numbers, e.g., what is the T at which melting started, and what is the age of the granites? Use of abbreviations is not something that sits well in a text for lay readers.

Stop 5 (new page 65)

Text overlap with Stop 4 has been reduced. Temperatures and ages of the leucogranite have been inserted

The text has been sequenced more correctly.

Abbreviations have been eliminated.

Stop 6: Largely repetitive of Stop 5, in terms of content, so things need to be very well structured to avoid duplication. I doubt there is tourmaline in the amphibolite (Fig. 6.5). The interpretation of S1 is not explained.

Stop 6 (new page 71)

Duplication has been avoided by concentrating on the composition of the tourmaline leucogranite in Box 6.1 vs the origin of leucogranite in Box 5.1 (old page 49)

Tourmaline in the amphibolite is not likely – agreed, sample replaced with description of Tourmaline granite, now Figure 6.4 .

The interpretation of S_1 is explained

Stop 7: The map is impossible to read. Forcing the reader to refer back to another map elsewhere in the book (which is little better in terms of legibility) is unlikely to be welcomed.

Whilst glaciers are important agents of erosion and create an array of important features in the region, the conflation of glacial erosion with the exhumation of the Himalayas must be guarded against.

Stop 7 (new page 76)

All miniaturised Stop maps have been deleted

"…the conflation of glacial erosion with the exhumation of the Himalayas must be guarded against." Noted. Above 4000m it does generally not rain and there are no rivers as yet (this obviously depends on the speed of global warming which will raise the snowline inexorably in the next few decades, until this is reversed). Below 4000m and in the Lesser Himalayas, there is rain, river erosion landslide erosion, etc. the text has been amended to include this.

Stop 8: It is not clear why Box 8.2 is a box, given its title and the first 2 paragraphs. The box should rather focus on a geological process, like magma emplacement. I have already dealt at length with the misinterpretation of the Khumbu Thrust – Lhotse Detachment structures as evidence of Channel Flow, which contradicts the interpretation of Searle (1999). This appears on p. 63.

The statements on p. 64 about earthquakes "shattering" the rock to form the stockwork fractures and the reference to exhumation, are very naïve, unsubstantiated , and misleading. Yes, fracturing will be a rapid process, but it is nowhere at the scale of the earthquakes discussed elsewhere.

Stop 8 (new page 78)

Box 8.2 focus changed to magma emplacement as a geological process.

"was shattered by earthquakes" was replaced by "was due to a brittle deforming layer above a rising pluton of granite"

Evidence of channel flow has been removed from Stop 8

Stop 9: Fig. 9.3 is singularly lacking in labels and an interpretive caption. I question why Fig. 9.6 adds any more value than Fig. 5.6, and the microstructural interpretation is poor.

Stop 9 (new page 83)

Fig 9.3 labels inserted

Fig 9.6 deleted and replaced with new Figure 3.6 on new page 59.

Stop 10: There is no real issue about Channel Flow (although some terms and concepts could be better explained/expanded), but there is a serious issue with it being applied to the Pumori-Lingtren Ridge (p.72, 75) – see my previous comments. Attributing polyphase granite injections to Channel Flow is also unsubstantiated. As with many of the samples, which look like they were retrieved from rivers, the mylonite sample in Fig. 10.7 appears to be unconstrained scree float. Given the reported amount of time spent doing fieldwork, I would have expected more detail on the orientation and the exact shear zone generation that it represents (e.g., is it retrograde extension or thrusting?). The poor quality of the images makes it difficult to examine the noteworthy features that could help to check for monoclinic asymmetry. The mylonite presented an opportunity to deal with cooling of the rocks and how shearing influences grain size and mineralogy.

Stop 10 (new page 89)

Channel Flow interpretation deleted.

Figure 10.7 deleted.

Stop 11: The "funny" story is not appropriate in the general text, but a box on avalanches triggered by snow melting, weight of snow or earthquakes would be appropriate. Unfortunately, the interpretation of the grandly-titled "Western Cwn Nappe" is confused and misleading: the text says it is an extension-related fold (which would make it impossible to be a nappe, even if the scale were larger), but the vergence is one of a thrust, and is shown as such in Fig. 11.1 (which, by the way, consists of 2 photos, but no A or B labels), and then in Box 11.1 caption to Fig. 11.2 it is implied it is part of a buckled nappe limb. The "Z-fold" is actually a thrust fault (as stated in the text) – so why is it labelled as a fold in Fig. 11.1? A N plunge for the fold hinges would make this a sheath fold.

Box 11.1's images are blurry. Its final statement also contradicts the earlier text and Fig. 11.1.

The caption to Fig. 11.3 and last para on p. 82 again refer to channel flow without anything to substantiate this (see previous comments).

Fig. 11.4's photomicrographs are disappointingly lacking in shear features – was the section cut properly, i.e. parallel to the lineation?

Stop 11 (new page 99)

Funny story deleted

Nappe renamed a fold

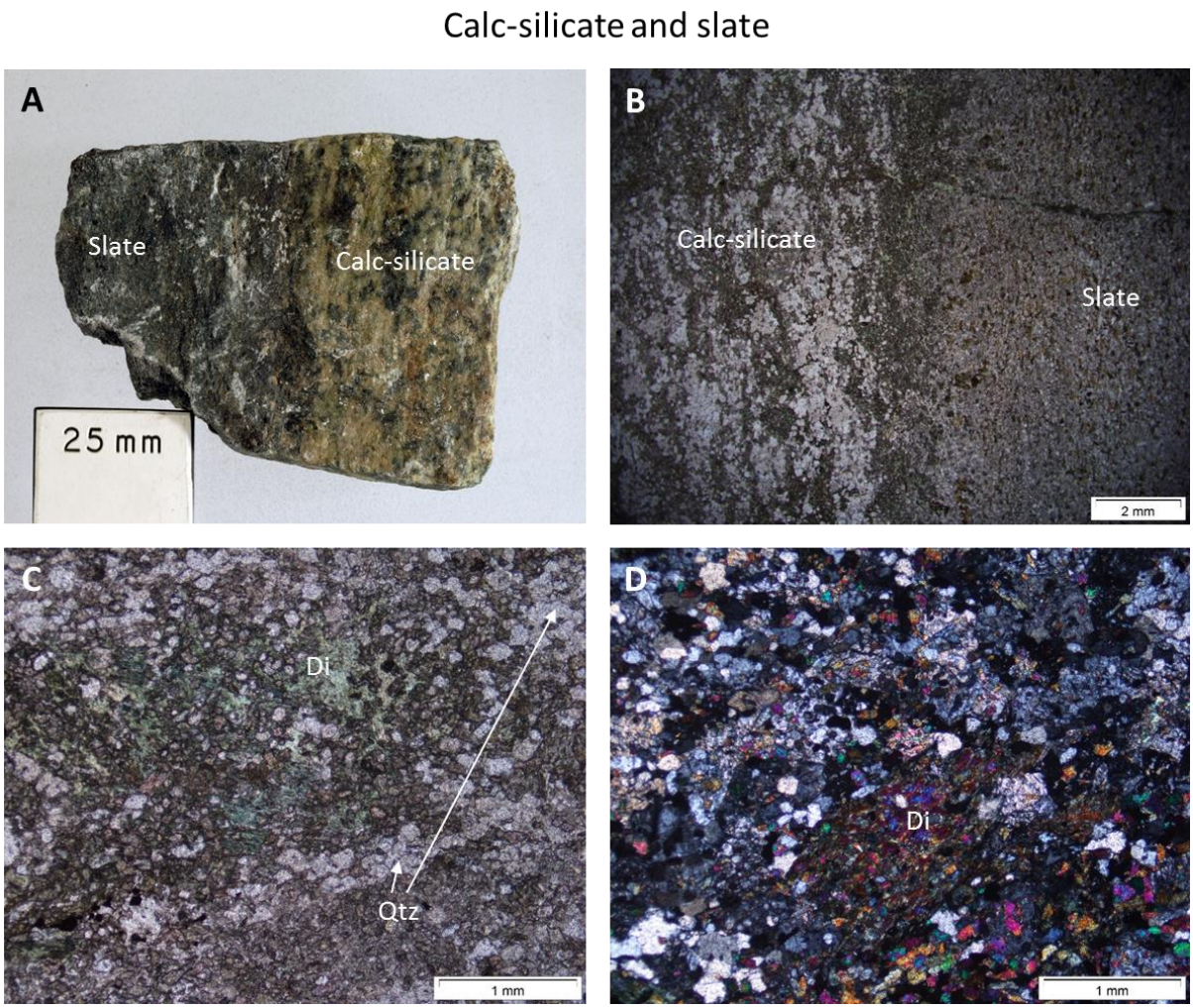
A and B labels inserted for Fig 11.1

"Z-fold" (named by Searle on his map) relabelled a "thrust"

Box 11.1 deleted – not necessary anymore.

Fig 11.3 – reference to channel flow deleted.

Fig 11.4 deleted and replaced with:



And Caption: "*Figure 11.4: Sample with slate in contact with calc-silicate. A – hand sample, showing dark, fine-grained slate on the left, and yellow and green calc-silicate on the right. B: Photomicrograph (PPL) showing the contact between calc-silicate (left) and slate (right). C: Photomicrograph (PPL) of calc-silicate, showing green diopside (calcium pyroxene) and quartz. D: Photomicrograph (XPL) of brightly coloured, highly birefringent diopside in the calc-silicate." Re-written and a*dded.

Stop 12: p. 88 incorrectly states that intense shearing (crystalplastic flow) causes "granulation" and melting via friction. Granulation is generally linked to brittle cataclasis and sliding; friction melts (pseudotachylites) are a very specific phenomenon that has not been demonstrated by the descriptions here.

Stop 12 (new page 104)

"These are extremely fine-grained rocks formed from intense shearing, the result of extreme granulation of rocks during ductile deformation" replaced with "These are extremely fine-grained rocks are formed from tectonic sliding of rock masses, resulting in brittle deformation of some minerals. In the field it is difficult to distinguish between mylonite formed from brittle deformation and one formed by crystalplastic flow, which

have a different “fine-ness” to their matrix. In the field, therefore, these are all defined by the term “Mylonite”.(Brodie et al. 2007).” And a reference to Brodie et al. 2007 added.

Stop 13: The Box 13.1 detailing the metamorphic history of the Everest Series is not fully contrasted with that of the GHS via diagrams (Box 3.1). Again, the reader doesn't get a sense of how hot/deep rocks went or when metamorphism happened because key numerical facts are missing.

Fig. 13.5's caption is inadequate – no mention is made in the text that D2 forms kink bands.

Stop 13 (new page 109)

The following has been inserted to give a sense of how deep and how hot the rocks went and the metamorphic grade:

“Searle (1999a) mapped a large scale, low angle normal fault, the Lhotse Detachment, which separates the biotite-sillimanite gneisses and leucogranites below from the greenschist grade rocks of the Everest Series above. From the mineral assemblages in the Everest Series rocks that were collected by climbers at South Col and above, none contained minerals necessary to accurately determine temperatures and pressures experienced by the rocks, but the minerals assemblages present suggests middle to upper greenschist facies grade of metamorphism (Searle, 1999a). This implies temperatures of 350°C to 500°C and depths of burial of 20 to 30km.”

Figure 13.5 deleted – doesn't really add anything.

Stop 14: Fig. 14.3 and the accompanying text certainly seem to me to be out of place – these should have been dealt with in the general introduction before Stop 1. The text on p. 100 is riddled with poor terminology and phrasing.

Stop 14 (new page 114)

Text on page 100 moved to before Stop 1

Conclusion:

The final statement about being able to “hear the strain” on the Khumbu Thrust, and speculation that it is no longer present since the 2015 earthquake is unscientific and is misleading to the lay reader.

Conclusion (new page 119)

Final statement about “hearing the strain” removed.

Images

I found the images consistently blurred, particularly the labels/lettering. Formatting of the captions is inconsistent – sometimes the caption is in a (often poorly aligned) box, at other times it is not. Above all, however, as Part II is the main product of this dissertation, the failure to redraft and sharpen images, and to apply consistent fonts and formatting, is a major factor in my assessment. The failure to acknowledge several images is careless.

The large labels, usually with white backgrounds, have a tendency to obscure parts of the image. The font size seems more appropriate to a powerpoint presentation than a text.

I have serious doubts about how the interpretive structures have been oriented on several photos.

Images

The Part 2 that I handed in was wire-bound and was NOT the annotated poor quality copy that I received back, which I can only assume was printed off the CD I handed in and printed on almost a DRAFT setting ??. I agree, however, that they were sub-standard, apologies.

Nevertheless, virtually all the images, Maps and Figures have now actually been re-drawn and photomicrographs re-take. The whole quality of the figures in both Parts 1 and 2 is now much improved.

Part 2 Corrections of the examiner's annotated comments

Page i (new page 1)

1. "Thesis" replaced with "dissertation" twice
2. "which" replaced with "that"

Page 1

1. "Whimsical journey " entirely deleted

Page 3 (new pages 3 and 4)

1. "Earth" capitalised
2. Source of photo inserted
3. Metamorphism started 32Ma not 50Ma

Page 4 (new page 7)

1. Introduction re-written

Page 5

1. Figure 1 caption re-arranged and edited and moved to new page 40 (new Figure 12) to improve flow of the guidebook

Page 6 (new pages 7 and 8)

1. "takes the traveller" replaced with " follows the journey"
2. "each of the 14 stops" inserted
3. "near the beginning of the guidebook on pages 9 to 12." Inserted
4. Page numbers for the glossary and the abbreviations inserted
5. Capitalised words reduced to lower case.
6. Comma inserted
7. Deleted original text: "Stop 1 to Stop 14 are then individually discussed. This forms the main body of the guidebook"

   Replaced with: "via 14 stops along the route".

Page 7 (new page 9)

1. Table named "Table 1"
2. "Earth" and "Base Camp" capitalised.
3. "Recent earthquakes in the Everest region attest to the continued exhumation along this channel" added to Stop 10

Maps 1, 2, 3 and 4 on pages 8 ,9,10 and 11 have all been re-draughted and are much easier to read now. These are on new pages 11 to 14.

Glossary

I have re-written the Glossary entirely and used the *Glossary of Geology (Bates and Jackson, 1987), and Penguin Dictionary of Geology, (Whitten and Brookes, 1972, mainly the former, as a reputabl source.* I then chose the definition or explanation that looked the most appropriate for the layman to understand. Therefore I have tried to keep the definition simple and yet accurate.

ORIGINAL Glossary:

Glossary of Geological, Mineral & Related Terms

In many parts of the text, geological terms are used which may not be familiar to the lay person and as such, a glossary has been included right up front which explains the technical terms used in the text.

Accretionary Wedge	Sediments that are scraped off the top of the downgoing oceanic crustal plate and are appended to the edge of the over-riding continental plate. These sediments accumulate and deform where oceanic and continental plates collide, in an accretionary wedge or accretionary prism.
Ammonite	Fossil sea shell.
Amorphous	Having no distinct crystal shape.
Anatexis	Melting of pre-existing rock.
Andean-type arc	A linear volcanic arc found where oceanic crust is subducted below continental crust (as is the case in the Andes, along the western margin of South America).
Augen	From the German word meaning 'eyes', Augen are large, eye-shaped mineral grains or mineral aggregates visible in some foliated metamorphic rocks such as gneisses.
Barrovian Metamorphism	A state of metamorphism characterized by intermediate temperature and pressure as found in mountain belts and characterized by metamorphic minerals such as chlorite, biotite, garnet, staurolite, kyanite and sillimanite.
Batholith	A discordant pluton that increases in size downwards, has no determinable floor and has a surface exposure area of >100 km^2.
Biotite	A dark brown/green flat, platy mineral [K_2Mg_6 ($Si_6Al_2O_{20}$)$(OH,F)_2$].
Boudin	From the French word meaning "sausage", Boudin is a sausage-like shape resulting from the stretching of a layer of rock.
Breccia	A rock consisting of angular fragments of other rocks connected together by finer material.
Calcareous Rock	Carbonate-rich sedimentary rock, characterized by the abundance of $[CO_3]^{2-}$ e.g. $CaCO_3$(calcite) or $MgCO_3$(dolomite).
Carbonate Rock	A calcium-rich rock like a limestone (Ca, Mg (CO_3)).
Cataclasis	Mechanical fracture or break up of a rock as opposed to plastic deformation. Associated with faulting.
Channel flow	Channel flow involves a viscous fluid-filled channel lying between two rigid sheets (of rock). This fluid is deformed through induced shear and pressure gradients within the fluid channel. In layman's terms, layers of plastic or molten rock are squeezed laterally (very much like toothpaste squeezed from a tube) due to a pressure gradient, mainly caused by gravity.
Cleavage	Numerous parallel planes of weakness in a rock which result in a tendency for rocks to break with ease along such parallel planes. Rock cleavage is designated as slaty, phyllitic, schistose or gneissic.

Compositional Zoning	Metamorphic minerals (e.g. garnet) may have a change in composition (e.g. Ca, Mg, Fe and Mn concentrations) from the core/centre of the mineral towards the rim. This is related to the changing stability of mineral compositions with increasing temperature (or metamorphic grade).
Conglomerate	A sedimentary rock consisting of large well-rounded fragments (e.g. pebbles transported large distances from their source) or sub-rounded fragments (e.g. flat shale or angular breccia transported a short distance from their source).
Cordierite	A mineral produced by contact or regional metamorphism of pelitic rocks, commonly occurring in granite and pegmatite and also with sillimanite and plagioclase feldspar.
Corona	A mineral reaction texture where one or more minerals grow around another mineral, forming a 'halo' or corona around the mineral.
Crust	The solid outer shell of the earth averaging 35 km in thickness on continents and 5 km in thickness below the oceans.
Cwm (pronounced koom)	The term comes from the Welsh meaning a "valley". It is a half-open, steep sided hollow in a mountain region that has been, or is being, glaciated. Its form is due to a combination of glacial scouring and glacial erosion by basal sapping.
D_1, D_2, etc.	Each distinguishable deformation event in a rock mass is named in the order in which it occurred. Thus the first deformation event in a particular rock would be D_1, the second would be D_2, etc.
Decompression	When rocks are brought to surface from deep within the crust, the pressure experienced by the rock decreases. If this happens very rapidly and at high temperatures, then evidence for this decompression can be preserved in mineral reaction textures.
Detachment	A major shallow-dipping fault in the earth's crust, accommodating extension.
Dyke	A sheet-like body of igneous rock that is discordant (cutting across strata at 90° and usually vertical).
Eclogite Facies	A high-pressure metamorphic facies, recording pressures in excess of 1.2 GPa (45 km depth) at >400–1000 °C and usually in excess of 600-650 °C. Eclogite itself is a basaltic-metamorphic rock and may contain garnet, kyanite, rutile, quartz, corundum, and many more minerals as well as, sometimes, diamonds.
Extrusion	The squeezing out of lava or molten rock between solid layers of rock.
Exhumation	The displacement of rocks with respect to the topographic surface (England and Molnar, 1990), which requires either removal of the overburden (e.g. by erosion, normal faulting, vertical lithospheric thinning) or transport of material through the overburden (e.g. by diapirism, buoyance-driven return flow in subduction zones).
Facies	A facies is the characteristic of a rock mass that reflects its depositional environment for a sedimentary rock or the pressure and temperature environment of origin for a metamorphic rock. Through these characteristics, it can be distinguished from other rock masses.
Fault	A break or fracture in rocks; a surface rock rupture along which there has been differential movement.

Feldspar	A milky white, grey or pink aluminium silicate mineral with chemical formula: $[(Na,K)AlSi_3O_8$ or $CaAl_2Si_2O_8]$.
Felsic	Light-coloured rock, aluminium rich, also referred to as leucocratic. A mnemonic derived from (fe) for feldspar, (l) for leucocratic and (s) for silica.
Fibrolite	A fibrous variety of sillimanite.
Flysch	A sequence of sedimentary rocks that is deposited in a deep marine facies in the foreland basin of a developing orogen. Flysch is typically deposited during an early stage of the orogenesis.
Fold	Bend flexure or wrinkle in rock produced when the rock deformed in a plastic state.
Folding	The formation of folds in rocks.
Forearc	The region between an oceanic trench and the associated volcanic arc, typically forms a basin filled with flat-lying sediments derived from the eroded volcanic arc. Forearc sediments lie unconformably on accretionary wedge material and are less deformed.
Fossil	The lithified remains of the cadaver of a previously living animal that acted as a mould and was subsequently silicified. Evidence of past life, such as dinosaur bones, ancient clam shells, footprint of a long extinct animal or impression of a leaf in rock.
Geology	The study of the earth's rocks. Organised body of knowledge about the earth.
Geosyncline	Major structural and sedimentary units in the crust of the earth, essentially elongated basins which become filled with great thicknesses of sediments.
Gneiss	A metamorphic rock preserving large-scale gneissic layering commonly formed by metamorphism of granite.
Granite	Coarse-grained igneous rock dominated by light-coloured minerals, including quartz, biotite and feldspar.
Granulite Facies	A high-temperate metamorphic facies. The granulite facies is determined by lower temperature boundary of 700 ± 50 °C and pressure range of 5–15 kbar.
Graptolite	These are coral-type fossils which were colonial organisms consisting of one or more branches.
Inverted metamorphic gradient	Typically, rocks get to higher metamorphic grades as one goes deeper in the earth's crust. Any instance where higher-grade rocks are found overlying lower-grade rocks is referred to as an inverted metamorphic gradient.
Igneous rock	Rock formed by the solidification of molten material that originated within the earth.
Isothermal	When metamorphic temperatures remain constant for an extended period of time. May be associated with a change in pressure at constant temperature (e.g. isothermal decompression).
K-feldspar	A potassium rich feldspar – see Feldspar for the chemical formula.
Kilo-bar (kbar)	1000 bars – the air pressure at sea level is one bar. One kbar is the equivalent of 3 km of depth in the earth's crust.

Leucogranite	Granite containing much quartz and feldspar, light in colour and aluminium-rich. Tourmaline is common.
Limestone	Any sedimentary rock consisting essentially of carbonates (CO_3 – bearing rocks).
M_1, M_2, etc.	As with deformation events, each distinguishable metamorphic event in a rock mass is named in the order in which it occurred. Thus the first metamorphic event in a particular rock would be M_1, the second would be M_2, etc.
Ma	Million years ago (Mega annum).
Mafic	A rock composed mainly of ferromagnesium minerals. It is generally dark in colour.
Magma	Naturally-occurring molten rock generated within the earth from which igneous rocks are derived.
Magnetic and Gravity Low	Geophysical techniques measure the intensity of the magnetic field in an area and a gravity techniques measure the pull of gravity in a certain area. These techniques provide useful information regarding the rock types that could exist beneath an area. A seismic survey is another geophysical technique that can detect liquid or plastic material as well as boundaries between rock types and faults.
Metamorphic isograds	Gradient lines that map the intensity of metamorphism.
Metamorphic rock	A rock derived from pre-existing rocks by changes in mineralogy, chemistry and structure as a result of changes in temperature and pressure.
Mica	A group of flat, platy minerals, usually sheet-like or flakey e.g. biotite with chemical formula: $[K(Mg, Fe)_3(AlSi_3O_{10})(OH)_2]$, and muscovite $[KAl_2(AlSi_3O_{10})(OH)_2]$.
Micrite	Micro-crystalline calcite.
Micritic Banding	Bands of micro-crystalline calcite.
Migmatite	A rock composed of inter-fingered magma and invaded rock which is metamorphic.
Molasse	Generally coarse-grained sedimentary rocks found in terrestrial or shallow marine deposits in front of rising mountain chains
Mylonite	A fine grained rock formed from intense shearing produced by extreme granulation during ductile deformation. From the Greek “mylos” meaning “to mill”.
Nappe structure	A large sheet of rocks moved along a fault plane for up to several kilometres from its original position.
Omphacite	The granular to foliated pyroxenic constituent of garnet rock called eclogite, often interlaminated with amphibole.
Ophiolite	A sequence of lavas and intrusions associated with infilling of geosynclines associated with the collision process.
Orogen	A belt of deformed rocks accompanied by metamorphic and igneous rocks. Orogens coincide with mountain belts on the earth’s surface.
Pegmatite	A coarse-grained igneous rock found as irregular dykes or veins within batholiths and intrusions.
Leucosome	The lightest-coloured parts of migmatite made up of quartz and feldspar.

Phyllite	A metamorphic rock which is coarser-grained, though less perfectly cleaved than slate, but which is finer-grained and better cleaved than mica schists.
Plate Tectonics	The motion of the large oceanic and continental plates (rigid crustal rocks) whose pattern of horizontal movement results in interaction at its boundaries.
Pluton	A body of igneous rock, usually coarse-grained, that formed beneath the surface by crystallization of magma.
Poikilitic	A rock texture in which numerous grains of various minerals are enclosed within a large crystal of different composition.
Prograde	Refers to metamorphic reactions/metamorphism occurring when a rock is heating up or being buried (i.e. before it reaches maximum temperatures or pressures).
Petrographic Microscope	A microscope used to view thin sections of the rock (less than 1mm in thickness and about 4 cm^2 in area. The section sample can be viewed in plane polarized light (pl) or cross polarized light (xp indicating crossed polars). In plane polarized light (pl) many of the grains can readily be identified, but crossing the polars (xp) allows further characteristics of minerals to appear, such as the parallel laminae showing the twinning of crystals in almost all plagioclase feldspar.
Proto mylonite	A rock in the process of becoming a mylonite.
P-T-D-t paths	Pressure, Temperature, Deformation, time path of a rock as it moves through the earth's crust over time as a result of tectonic processes.
Quartz	SiO_2 (silicon dioxide), a mineral.
Quartzite	Re-crystallized grains of quartz that develop an interlocking mosaic texture.
Recumbent Fold	A fold with near-horizontal to horizontal axial plane.
Retrograde	Refers to the metamorphic reactions/metamorphism occurring during the cooling or decompression of a rock from maximum temperatures or pressures.
Retrograde overprint	Metamorphic reactions which took place on the cooling path and eliminated earlier (prograde) minerals. Retrograde reactions may not have completely overprinted earlier formed minerals and evidence for earlier metamorphism is often preserved.
S_1, S_2, etc.	Alignment of planar minerals (such as micas) during deformation leads to the formation of a penetrative 'fabric' in a deformed rock. These fabrics are named according to the deformation event with which they are associated (S_1 is the fabric formed during D_1, S_2 is the fabric formed during D_2, etc.).
S-C fabrics	A metamorphic fabric formed by the intersection of shear surfaces within rocks affected by dynamic metamorphism; often indicative of the movement direction, as C-surfaces are parallel to the margin of the shear surface whilst S-surfaces are oblique to the surface and show the vergence direction.
Schist	A strongly foliated crystalline metamorphic rock that can easily be split into thin flakes due to well-developed parallelism of platy minerals in the rock.

Sedimentary rock	A rock created through accumulation of sediment consisting of rock fragments, remains of animals or plants, or products of chemical action or evaporation.
Seismic Survey	A seismic survey is r geophysical technique that can detect liquid or plastic material as well as boundaries between rock types and faults.
Shear force	A straining action where tangentially applied forces tend to produce a skewing type of deformation.
Sill	A concordant, sheet-like pluton that is substantially wider than it is thick, usually horizontal.
Sillimanite	An aluminium silicate with chemical formula Al_2SiO_5. It is often associated with kyanite and andalusite. These three minerals are used to determine PT conditions of the rock in which they occur.
Staurolite	A medium- to high-grade regional metamorphic mineral commonly occurring with biotite and sillimanite in gneiss and schist.
Stockwork	A complex system of structurally controlled or randomly oriented veins. Stockwork is common in many ore deposit types.
Stratigraphy	The science of rock strata. It is concerned with the original succession and age relations of rocks, their form, distribution, composition, fossil content and all characteristics and attributes of rocks as strata.
Stylolites	An irregular suture-like boundary in some limestone that is independent of the bedding planes. Mineral material has been removed by pressure dissolution and has a teeth-and-socket appearance.
Subduction	Plate interaction in plate tectonics in which one plate descends under another plate.
Suture zone	The area where two continental plates have joined together through continental collision. Younger suture zones may be marked by mountain ranges, e.g. the Himalayas or the Alps.
Symplectites	An intergrowth of two minerals formed as products during a metamorphic reaction.
Thrust	A low angle reverse fault.
Thin Section	Refers to a slide prepared for a petrographic microscope used for the identification of minerals present in a rock.
Vergence	The vergence of a fold is the direction in which the fold is inclined or overturned. In structural geology, the vergence of a fold is the direction in which an antiform or synform is inclined or overturned. The term vergence comes from the German “vergenz”, which means "overturn". Vergence refers to the general sense of shear involved in the development of asymmetric folds.
Xenolith	An inclusion of a pre-existing rock in an igneous rock

Source: Modified and added to from the Dictionary of Mining, Mineral & Related Terms and The Penguin Dictionary of Geology, Whitten, et al.

REPLACED BY: (on new pages 15 to 26)

Glossary of Geological, Mineral & Related Terms

In many parts of the text, geological terms are used which may not be familiar to the lay person and as such, a glossary has been included right up front which explains the technical terms used in the text.

Accretionary Wedge	Sediments that are scraped off the top of the downgoing oceanic crustal plate and are appended to the edge of the over-riding continental plate. These sediments accumulate and deform where oceanic and continental plates collide, in an accretionary wedge or accretionary prism.
Ammonite	Spiral fossil marine mollusc animals which were swimming bottom-dwellers in open seas which preyed on fish and other molluscs; squid-like, from the Devonian to the Cretaceous period.
Amorphous	A mineral or other substance that lacks crystalline structure, or whose internal arrangement is so irregular that there is no characteristic external form.
Anatexis	Melting of a pre-existing rock.
Andean-type arc	A volcanic arc found where oceanic crust is subducted below continental crust (as is the case in the Andes, along the western margin of South America).
Augen	In metamorphic rocks such as schists and gneisses, large lenticular mineral grains or mineral aggregates having the shape of an eye in cross section, in contrast to the shapes of other minerals in the rock. From the German word meaning 'eyes', Augen.
Axial plane	The plane formed by the extension of the axis of symmetry along the length of a fold. An axial surface that is planar.
Axial surface	A surface that connects the hinge lines of the strata in a fold. A hinge line is a line connecting the points of flexure or maximum curvature of the bedding planes in a fold.
Barrovian Metamorphism	In complexes of regional dynamothermal metamorphism, one of the belts of increasing metamorphic grade, based on the first appearance of the index minerals chlorite, biotite, almandine, staurolite, kyanite and sillimanite. This now classical sequence, representing the commonest type of regional metamorphism, is named after George Barrow who first described and mapped zones of progressive regional metamorphism in the Grampian Highlands of Scotland in 1893.
Batholith	A large, generally discordant plutonic mass that has more than 100 km^2 of surface exposure and no known floor.
Biotite	A widely distributed and important rock-forming mineral of the mica group. It is generally black, dark brown or dark green and forms a constituent of crystalline rocks (either as an original crystal in igneous rocks of all kinds, or a product of metamorphic origin in gneisses and schists) or a detrital constituent of sandstones and other sedimentary rocks.$[K_2Mg_6 (Si_6Al_2O_{20})(OH,F)_2]$.

Boudin	One of a series of elongate, sausage shaped segments occurring in boudinaged structure, either separate or joined by pinched connections, and having barrel shaped cross sections.
Breccia	A coarse grained clastic rock composed of angular broken rock fragments held together by a mineral cement or in a fine grained matrix; it differs from conglomerate in that the fragments have sharp edge sand unworn corners. Breccia may originate as a result of talus (rock fragments lying at the base of a cliff) accumulation, igneous processes, especially explosive, disturbance during sedimentation, collapse of rock material or tectonic processes.
Calcareous Rock	A calcium-rich rock like a limestone (Ca, Mg)(CO3). Carbonate-rich sedimentary rock, characterized by the abundance of $[CO_3]^{2-}$ e.g. $CaCO_3$ or calcite or $(CaMg)(CO_3)_2$ or dolomite.
Cataclasis	Rock deformation accompanied by fracture and rotation of mineral grains without chemical reconstitution. Associated with faulting.
Cephalopod	Any marine mollusc belonging to the class Cephalopoda, characterised by a definite head, with the mouth surrounded by part of the foot that is modified into lobelike processes with tentacles or armlike processes with hooklets or suckers or both.
Channel flow	A hypothesis proposed to explain the large-scale geology of the Himalaya whereby a 10 to 15km thick slab/layer (“channel”) of crust, exhibiting evidence of intense strain and high temperature history, appears to have been extruded between layers of lower temperature, less deformed crust. Channel flow involves a viscous fluid-filled channel lying between two rigid sheets (of rock). This fluid is deformed through induced shear and pressure gradients within the fluid channel. In layman’s terms, layers of plastic or molten rock are squeezed laterally (very much like toothpaste squeezed from a tube) owing to a pressure gradient, mainly caused by gravity.
Clastic Rock	A consolidated sedimentary rock composed principally of broken fragments that are derived from pre-existing rocks or formed during chemical weathering and which have been transported to their places of deposition e.g. sandstone, conglomerate, shale or limestone formed from particles from a pre-existing limestone.
Cleavage	In structural geology: The property or tendency of a rock to split along secondary, aligned fractures or other closely spaced planar structures or textures, produced by deformation or metamorphism. In a mineral: The breaking of a mineral along its crystallographic planes. Rock cleavage is designated as slaty, phyllitic, schistose or gneissic.

Compositional Zoning	A synonym for phase layering commonly used for with reference to metamorphic rocks. (Phase layering: The mineralogical layering of plutonic rocks caused by the generally sudden appearance and progressive disappearance of some mineral phase.) This is related to the changing stability of mineral compositions with changing temperature or pressure.
Conglomerate	A coarse grained clastic sedimentary rock, composed of rounded to subangular fragments larger than 2 mm in diameter (granules, pebbles, cobbles, boulders) set in a fine grained matrix of sand or silt, and commonly cemented by calcium carbonate, iron oxide, silica, or hardened clay; the consolidated equivalent of gravel both in size range and in the essential roundness and sorting of its constituent particles.
Cordierite	A light blue to dark blue or violet blue orthorhombic mineral $(Mg, Fe)_2Al_2Si_5O_{18}$. It exhibits strong pleochroism (showing many different colours when observed in polarised light in a microscope), is easily altered by exposure and is an accessory mineral in granites and a common constituent of metamorphic rocks formed under low pressure.
Corona	A zone of minerals, usually with radial arrangement, around another mineral. It is a general term that has been applied to reaction rims and originally crystallised minerals.
Crust	The outermost layer or shell of the Earth, defined according to various criteria, including seismic velocity, density and composition; that part of the Earth above the Mohorovicic discontinuity (the boundary surface that separates the Earth's Crust from the mantle). The solid outer shell of earth averages 35 km in thickness on continents and 5 km in thickness below the oceans.
Cwm (pronounced koom)	The term comes from the Welsh meaning a "valley". It is a half-open, steep sided hollow in a mountain region that has been, or is being, glaciated. Its form is due to a combination of glacial scouring and wearing down the rocks at the base of the glacier.
D_1, D_2, etc.	Deformation episode 1, 2, etc. Deformation is a general term for the process of faulting, folding, compression, shearing or extension of the rocks as a result of various Earth forces. Each distinguishable deformation event in a rock mass is named in the order in which it occurred. Thus the first deformation event in a particular rock would be D_1, the second would be D_2, etc.
Decompression	When rocks are brought to surface from deep within the crust, the pressure experienced by the rock decreases. If this happens relatively rapidly and at high temperatures, then evidence for this decompression can be preserved in mineral reaction textures.
Denudation	The sum of the processes that result in the wearing away of the Earth's surface by various natural agencies, which include weathering, erosion, mass wasting, and transportation; also the combined destructive effects of such processes.

Detachment	A major shallow-dipping fault in Earth's crust, accommodating extension.
Ductile	Said of a rock that is able to sustain, under a given set of conditions, 5-10% deformation before fracturing or faulting. Generally, rocks respond to stress in one of two ways: they break, or they bend. When a rock breaks, it is called **brittle** deformation. Any material that breaks into pieces exhibits brittle behaviour. When rocks bend or flow, like clay, it is called **ductile** deformation.
Dyke	A tabular igneous intrusion that cuts across the bedding or foliation (a planar arrangement of textural or structural features) of the country rock. Country Rock: the rock traversed or enclosing a mineral deposit. Originally a miner's term, it is less specific than Host Rock.
Eclogite Facies	The set of metamorphic mineral assemblages (facies) in which basic rocks are represented by omphacitic pyroxene and almandine-pyrope garnet. Also common is the association pyrope+olivine+diopside+enstatite. These associations indicate high pressure crystallisation, although a broad range of pressure-temperature conditions is possible. Pressures are in excess of 1.2 GPa (45 km depth) at >400–1000 °C, and usually in excess of 600-650 °C. Eclogite itself is a metamorphic rock of basaltic composition and may contain garnet, kyanite, rutile, quartz, corundum, and many more minerals as well as diamonds.
Erosion	The general process or the group of processes whereby the materials of the Earth's crust are loosened, dissolved, or worn away, and simultaneously moved from one place to another, by natural agencies, which include weathering, solution, corrosion, and transportation, but usually exclude mass wasting.
Exhumation	The uncovering or exposure by erosion of a pre-existing surface, landscape or feature that had been buried
Extensional movement	Movement along a fault in sedimentary rocks along which there has been bed-parallel elongation, giving rise to tectonic thinning. See Fault - Normal
Extinction (Optics in a microscope)	The more or less complete darkness obtained in a mineral at two positions during a complete rotation of a thin section between cross polarized light in a microscope used for examining thin sections of rock samples.
Extrusion	The squeezing out of molten or solid rock from between layers of rock.
Fabric	The complete special and geometrical configuration of all those components that make up a deformed rock. It covers such terms as texture, structure and preferred orientation and so is an all-encompassing term that describes the shapes and characters of individual parts of a rock mass and the manner in which these parts are distributed and oriented in space.
Facies	A facies is the characteristic of a rock mass that reflects its depositional environment for a sedimentary rock or the pressure and temperature environment of origin for a metamorphic rock. Through these characteristics, it can be distinguished from other rock masses.

Fault	A fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture. The two main types of fault are: 1. Normal (extensional) – see *Extensional Movement* where rock strata are pulled apart across the fault and 2. Reverse (compressional) – see *Reverse Fault* where rock strata are pushed over each other across the fault
Feldspar	A group of abundant rock forming minerals of general formula: $MAl(Al, Si)_2O_8$, where M = K, Na, Ca, Ba, Rb, Sr or Fe. Feldspars are the most widespread of any mineral group and constitute 60% of the Earth's crust. They occur as components of all kinds of rocks (crystalline schists, migmatites, gneisses, granites, most magmatic rocks) and as fissure minerals in clefts and druse minerals in cavities.
Felsic	A mnemonic adjective derived from *fe*ldspar + *l*enad (feldspathoid) + *si*lica + c, and applied to an igneous rock having abundant light-coloured minerals in its mode. Light-coloured rock, aluminium rich, also referred to as leucocratic. A mnemonic derived from FEL for feldspar and SI for silica.
Fibrolite	A fibrous variety of sillimanite.
Flysch	A deep marine sedimentary facies that is deposited in a foreland basin of a developing orogen, characterised by a thick sequence of poorly fossiliferous, thinly bedded deposits composed chiefly of marls and sandy and calcareous shales and muds, rhythmically interbedded with conglomerates, coarse sandstones and greywackes. Flysch is typically deposited during an early stage of the orogen or mountain building.
Fold	A curve or bend of a planar structure such as rock strata, bedding plans, foliation or cleavage.
Fold limb	The area of a fold between adjacent fold hinges.
Forearc	The region between a subduction related trench and a volcanic arc. Typically forms a basin, filled with flat-lying sediments derived from the eroded volcanic arc.
Fossil	Any remains trace or imprint of a plant or animal that has been preserved in the Earth's crust since some past geologic or prehistoric time. Loosely, any evidence of past life, such as dinosaur bones, ancient clam shells, footprint of a long extinct animal or impression of a leaf in rock.
Geology	The study of the planet earth, the materials of which it is made, the processes that act upon these materials, the products formed, and the history of the planet and its life forms since its origin. Geology considers the physical forces that act on the Earth, the chemistry of its constituent materials and the biology of its past inhabitants as revealed by fossils.

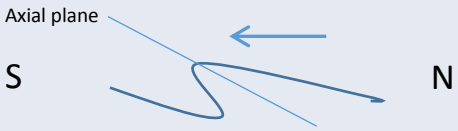
Geosyncline	A mobile down warping of the crust of the Earth, either elongate or basin like, measured in scores of kilometres, in which sedimentary and volcanic rocks accumulate to thicknesses of thousands of metres.
Gneiss	A foliated rock formed by regional metamorphism, in which bands of granular minerals alternate with bands in which minerals having a flakey or elongate prismatic habits predominate.
Granite	A plutonic (igneous) rock in which quartz constitutes 10 to 50 % of the felsic components and in which the alkali/total feldspar is general restricted to the range of 65% to 90%.
Granulite Facies	The set of metamorphic mineral assemblages (facies) in which the basic rocks (rocks with a low silica content) are represented by diopside + hypersthene + plagioclase. Almandine (a garnet) is characteristic of basic and pelitic rocks. Pelitic assemblages show the association of sillimanite and kyanite with feldspar and almandine garnet, often also with cordierite.
Graptolite	Any colonial marine organism belonging to the class Graptolithina , characterised by a cup– or tube– shaped highly resistant external skeleton arranged with other individuals along one or more branches to form a colony.
Hangingwall	The overlying side of an orebody, fault or mine working esp. the wall of rock above an inclined vein or fault. Also the rocks above a particular layer of rock under discussion.
Inverted metamorphic gradient	For example: a conversion of shale to slate would be low grade thermal metamorphism (greenschist facies) whereas its continued alteration to garnet sillimanite schist would be high grade metamorphism. Typically, rocks get to higher metamorphic grades as one goes deeper in the earth's crust. Any instance where higher-grade rocks are found overlying lower-grade rocks is referred to as an inverted metamorphic gradient.
Igneous rock	A rock that solidified from a molten or partly molten material i.e. from magma.
Isostasy	The condition of equilibrium, comparable to floating, of the units of the lithosphere above the asthenosphere (Figure 1). Crustal loading as by ice, water, sediments or volcanic flows leads to isostatic depression or down warping; removal of load to isostatic uplift or up warping.
Isothermal	Pertaining to the process of changing the thermodynamic state of a substance e.g. its pressure and volume, while maintaining a constant temperature.
K-feldspar	A potassium rich feldspar – see Feldspar for the chemical formula.
Kilo-bar (kbar)	1000 bars – the air pressure at sea level is one bar. One kbar is the equivalent of 3 km of depth in the earth's crust.
Leucogranite	Granite containing much quartz and feldspar, light in colour and aluminium-rich. Tourmaline is common.
Leucosome	The light coloured part of a migmatite, usually rich in quartz and feldspar

Limestone	A sedimentary rock consisting chiefly (more than 50% by weight or by areal percentages under the microscope) of calcium carbonate, primarily in the form of the mineral calcite and with or without magnesium carbonate. specif. A carbonate sedimentary rock containing more than 95% calcite and not more than 5% dolomite.
M_1, M_2, etc.	As with deformation events, each distinguishable metamorphic event in a rock mass is named in the order in which it occurred. Thus the first metamorphic event in a particular rock would be M_1, the second would be M_2, etc.
Ma	Millions of years before the present or Mega Annum.
Mafic	An igneous rock composed chiefly of one or more ferromagnesian (dark coloured) minerals.
Magma	Naturally occurring mobile rock material, generated within the Earth and capable of intrusion and extrusion, from which igneous rocks are thought to have been derived through solidification and related processes.
Magnetic and Gravity Low	Magnetic field intensity is a region in which magnetic forces would be exerted on any magnetised bodies or electric currents present. A low force would indicate a region of low magnetic intensity and vice versa. Gravitational field intensity is the measure of the gravitational force, expressed as a vector quantity, exerted on a unit mass at a particular point. A low force on a unit mass would be a low gravitational intensity and vice versa. Geophysical techniques measure the intensity of the magnetic field in an area and gravity techniques measure the pull of gravity in a certain area. These techniques provide useful information regarding the rock types that could exist beneath an area. A seismic survey is another geophysical technique that can detect liquid or plastic material as well as boundaries between rock types and faults – see *Seismic Survey*.
Mantle	The zone of the Earth below the Crust and above the Core, which is divided into the Upper Mantle and the Lower Mantle, with a transition zone between.
Metamorphic isograds	A line on a map joining points at which metamorphism proceeded at similar values of pressure and temperature as indicated by rocks belonging to the same metamorphic facies.
Metamorphic rock	Any rock derived from pre-existing rocks by mineralogical, chemical and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress and chemical environment, generally at depth in the Earth's Crust.
Mica	A group of minerals of general formula: $(K,Na,Ca)(Mg,Fe,Li,Al)_{2-3}(Al,Si)_4O_{10}(OH,F)_2$. They readily split into thin, tough, elastic laminae or plates with a splendent pearly lustre in colours of silvery white, pale brown, yellow, green, black or are colourless.

Micrite	A descriptive term used for the semi-opaque crystalline matrix of limestones, consisting of chemically precipitated carbonate mud with crystals less than 4 microns in diameter, and interpreted as a lithified ooze.
Micritic Banding	Bands of Micrite.
Migmatite	A rock composed of igneous or igneous appearing and/or metamorphic materials which are generally distinguishable megascopically. Specifically, a rock composed of inter-fingered magma and invaded rock which is metamorphic.
Molasse	A partly marine, partly continental or deltaic sedimentary facies consisting of a very thick sequence of soft, ungraded, cross-bedded, fossiliferous conglomerates, sandstones, shales, marls, characterised by primary sedimentary structures and sometimes by coal and carbonate deposits. It is generally coarse-grained and found in terrestrial or shallow marine deposits in front of rising mountain chains
Mylonite	A compact chert-like rock without cleavage, but with a streaky or banded structure, produced by the extreme granulation and shearing of rocks that have been pulverised and rolled during over-thrusting or intense dynamic metamorphism. More simply, a fine grained rock formed from sliding of rock masses against each other. From the Greek “mylos” meaning “to mill” referring to the fine-grained nature of these rocks.
Nappe structure	A sheet-like rock unit which has moved on a predominantly horizontal surface for several kilometres. It may have a recumbent fold at its terminus.
Omphacite	A grass-green to pale-green granular aluminous mineral variety of pyroxene with chemical formula $(Ca,Na)(Mg,Fe^{2+},Fe^{3+},Al)Si_2O_6$, found as a common constituent in the rock type called *eclogite.*
Ophiolite	A group of mafic and ultramafic igneous rocks, derived by later metamorphism, whose origin is associated with an early phase of the development of a geosyncline. More simply, a sequence of lavas and intrusions associated with infilling of geosynclines associated with the collision process.
Orogen	Literally the process of formation of mountains.
Partial melt	In rocks made up of several different minerals, some will melt at lower temperatures than others. Partial melting is an important consideration in geology with respect to the chemical differentiation of crustal rocks.
Pegmatite	An exceptionally coarse grained igneous rock, with interlocking crystals, usually found as irregular dykes, lenses or veins, especially at the margins of batholiths.
Pelite or pelitic rock	A sedimentary rock composed of the finest detritus, clay or mud-sized particles or a calcareous sediment composed of clay and minute particles of quartz..
Phyllite	A metamorphosed rock intermediate in grade between slate and mica schist.

Plate Tectonics	A plate is a rigid thin segment of the Earth's lithosphere, which may be assumed to move horizontally and adjoins other plates along zones of seismic activity. Tectonics is a branch of geology dealing with the broad architecture of the outer part of the Earth; the regional assembling of structural or deformational features, a study of their mutual relationships, origin and historical evolution.
Pluton	An igneous intrusion.
Poikilitic	A texture of an igneous rock in which small grains of one mineral are irregularly scattered without common orientation in a typically anhedral larger crystal of another mineral.
Prograde (metamorphism)	Metamorphic changes in response to a higher pressure or temperature than that to which the rock last adjusted itself.
Petrographic Microscope Polarising Microscope	A microscope that uses polarised light and a revolving stage for analysis of petrographic thin sections of rocks. The thin section sample can be viewed in plane polarized light (pl) or cross polarized light (xp indicating crossed polars). In plane polarized light (pl) many of the grains can readily be identified, but crossing the polars (xp) allows further characteristics of minerals to appear, such as the parallel laminae showing the twinning of crystals in almost all plagioclase feldspar.
Proto mylonite	A mylonitic rock produced from contact-metamorphosed rock, with granulation being due to over-thrusts following the contact surfaces between intrusion and country rock. Or: A coherent crush breccia whose characteristically lenticular, megascopic particles faintly retain primary structures.
P-T-D-t paths	Pressure-Temperature-Deformation-time path of a rock as it moves through the earth's crust over time as a result of tectonic processes.
Quartz	Crystalline silica, an important rock forming mineral: SiO_2
Quartzite (metamorphic)	A metamorphic rock consisting mainly of quartz and formed by recrystallization of sandstone or chert by regional or thermal metamorphism. More simply, re-crystallized grains of quartz that develop an interlocking mosaic texture.
Recumbent Fold	An overturned fold, the axial surface of which is horizontal or nearly so.
Retrograde (metamorphism)	A type of metamorphism by which metamorphic minerals of a lower grade are formed at the expense of minerals characteristic of a higher grade of metamorphism, a readjustment necessitated by a change in physical conditions e.g. lowering of temperature or pressure.

Retrograde overprint	The superposition of a new set of structural features on an older set. Metamorphic reactions which took place on the cooling path and formed minerals which eliminated earlier (prograde) minerals. Retrograde reactions may not have completely overprinted earlier formed minerals and evidence for earlier metamorphism is often preserved.
Reverse fault	A fault on which the hangingwall appears to have move upward relative to the footwall.
S_1, S_2, etc.	Alignment of planar minerals (such as micas) during deformation leads to the formation of a penetrative 'fabric' in a deformed rock. These fabrics are named according to the deformation event with which they are associated (S_1 is the fabric formed during D_1, S_2 is the fabric formed during D_2, etc.).
S-C fabrics	A metamorphic fabric formed by the intersection of shear surfaces within rocks affected by dynamic metamorphism; often indicative of the movement direction, as C-surfaces are parallel to the margin of the shear surface whilst S-surfaces are oblique to the surface and show the vergence direction.
Schist	A strongly foliated crystalline rock formed by dynamic metamorphism, that can be readily split into thin flakes by or slabs due to the well-developed parallelism of more than 50% of the minerals present.
Sedimentary rock	A rock resulting from the consolidation of loose sediment that has accumulated in layers e.g. a clastic rock such as a conglomerate or tillite, consisting of fragments of older rock transported from its source and deposited in water or from air or ice; or a chemical rock formed from precipitation from solution, such as gypsum or rock salt, or an organic rock such as limestones, consisting of the remains or secretions of plants and animals.
Seismic Survey	A term used to describe the use of artificially generated seismic waves (using a mechanical hammer or light explosive) in determining depths of bedrock or faults or bedding planes of rock strata which reflect these seismic waves and which are measured and collected with "listening equipment". Usually done in traverse lines; these traverse lines can be connected in 3-D to give a computer generated model of the structure of rock units to a several kilometres in depth. A seismic survey can also detect liquid or plastic material.
Shear force (stress)	The component of stress which acts tangentially to a plane through any given point in a body.
Sill	A tabular igneous intrusion that parallels the planar structure of the surrounding rock.
Sillimanite	A brown, pale-green or white orthorhombic mineral: Al_2SiO_5 Together with its polymorphs, kyanite and sillimanite, it can be used to determine PT conditions of the rock in which they occur.
Staurolite	A brown to black orthorhombic mineral: $(Fe,Mg)_2Al_9Si_4O_{23}(OH)$.
Stockwork	Said of a mineral deposit consisting of a three-dimensional network of planar to irregular veinlets closely spaced.

Stratigraphy	The science of rock strata concerned with all characters and attributes of rocks such as original succession, age, form, distribution, lithologic composition, fossil content, geophysical and geochemical properties.
Strain	Usually referred to as shear strain: A measure by which parallel lines have been sheared past one another by deformation.
Stylolites	A surface or contact occurring in carbonate rocks marked by irregular and interlocking penetrations of the two sides. The seam is characterised by a concentration of insoluble constituents of the rock e.g. carbon, clay, or iron oxides and is commonly parallel to the bedding or cleavage. Mineral material has been removed by pressure.
Subduction	The process of one lithospheric or crustal plate descending beneath another. See Plate Tectonics.
Suture zone	The area or zone where two continental plates have joined together through continental collision. Younger suture zones may be marked by mountain ranges, e.g. the Himalayas or the Alps.
Symplectites	A rock texture produced by the intimate intergrowth of two different minerals.
Terrane	A fault-bounded body of rock of regional extent, characterised by a geologic history different from that of contiguous terranes.
Thin Section	A fragment of rock or mineral mechanically ground to thickness of approx. 0.03mm and mounted between two glasses as a microscope slide. This reduction renders most rocks and minerals transparent or translucent, thus making it possible to study their optical properties.
Thrust	An overriding movement of one crustal unit over another, as in thrust faulting.
Vergence	The direction in which the upper component of a fold is rotated e.g. in the diagram below, the top of the fold is rotated to the south , hence a south verging fold. 
Vertebrates	Characterised by an internal skeleton of cartilage or bone, and by specialised anterior organisation of the animal; the front of the body is a head that bears organs of sight, smell, taste and hearing, and the front of the central nervous system is the brain.
Xenolith	A foreign inclusion in an igneous rock.

Source: Modified and added to from the Glossary of Geology (Bates and Jackson, 1987), and Penguin Dictionary of Geology, (Whitten and Brookes, 1972).

Geological tour in the Himalayas

Page 18: This has been replaced by the heading "**The Geology of the Himalayas"** on new page 28.

Between this heading and Stop 1, extensive re-arrangement has been done.

Pages 18 to 24 have been completely re-arranged.

Stop 1

Parts of pages 25 and 26 have also been moved to the introduction as suggested by the examiner.

1. Box 1.1 has been re-arranged and the paragraph starting with "The lower portion of Everest…" has been left in Stop 1, but the structure of the Earth and subduction diagrams inserted upfront on new pages 28 to 30 as suggested by the examiner.
2. Some of the contents of Box 1.1 has been moved to the introduction section titled The Geology of the Himalayas.
3. The following has been re-arranged and re-written:

   "Following the breakup of Gondwana around 180 million years ago, India was the last continental fragment to separate from Africa and began to move northwards (Figures 6 and 7). After more than 50 million years of northwards movement, the Indian continent collided with Asia around 50 million years ago (Figure 6A). As it approached the Asia plate, the denser oceanic crust of the Indian plate was subducted beneath the less dense Asian plate. Whilst this subduction occurred, a number of small micro continental fragments or terranes were accreted onto Asia (Van der Voo et al., 1999). India's speed northwards varied between ~15 to 17 cm/yr between 73 and 53 million years ago, the fastest of any of the post-Gondwana continents (Copley et al., 2010). It slowed down to ~9.5 cm/yr between 30 and 20 million years ago and slowed further from this rate since then (Aitchison et al., 2007). The collision forced the continental crust of India to follow its oceanic crust beneath the Asian continent and resulted in thickening of the crust to >45 km and the uplift of the Asian/Tibetan plateau to an average of 4000 m above sea level. Normally the continental crust is 30 to 35 km thick and the oceanic crust only about 15 km thick."
4. "the Proterozoic to Mesozoic (541 to 66 million years ago)" inserted
5. "were brought down" replaced with " descended"
6. "sediments" deleted and replaced with "rocks then reversed direction and"
7. Ductile defined in glossary as: "Generally, rocks respond to stress in one of two ways: they break, or they bend. When a rock breaks, it is called **brittle** deformation. Any material that breaks into pieces exhibits brittle behaviour. When rocks bend or flow, like clay, it is called **ductile** deformation."
8. "two" added
9. "Today these form" added
10. "are" replaced with "is"
11. The following (on old page 99, now on new page 35) was considered by the examiner as too complex for the layman and was modified and shortened as shown in Point No. 12 below:

    During the Palaeozoic and Mesozoic ages, Tibet was formed by the successive accretion of five continental fragments or terranes, each extending about 2500 km east-west and between 200 km and 500 km wide north-south. The fragments are separated by faults (Figure 9 A and B).

    The geological evolution of the Tibetan Plateau is a protracted one. A number of terranes (magmatic arcs and continental fragments) were accreted onto the North China Craton between the Permian and the Eocene ages (between 300 to 50 million years ago), prior to the continent-continent collision between India and Asia.

The northernmost of these, the Kunlun Terrane, is a composite batholith originating from two periods of magmatism. The initial period took place in the late Cambrian, 490 million years ago (Yuan, 1999), and is related to intra-oceanic subduction which formed a magmatic arc that was accreted to the North China Craton around 470 million years ago (Yuan, 1999). A second period of arc magmatism took place between 215 and 210 million years ago (Yuan, 1999), but the origins are still under debate. It may have originated from a northward subduction of the Songpan-Ganze ocean-floor under an arc (Zhang and Zheng, 1994) or southward subduction of the Kunlun under the arc (Burchfiel et al., 1995). The Kunlun thrust system, along which shortening of around 250 km is estimated, is still active today in northern Tibet.

The Songpan-Ganze Terrane is an accretionary complex that collided with the Kunlun Terrane in the late Permian (260 million years ago). It is associated with the Qiangtang Terrane (a continental fragment originating from the breakup of Gondwana) in that southward subduction of the Songpan-Ganze ocean basin formed a north-facing volcanic arc on the Qiangtang Terrane (Yin et al., 1999) during the Jurassic (200 – 145 million years ago). The Qiangtang Terrane collided with the Songpan-Ganze Terrane in the late Jurassic-early Triassic (around 200 million years ago; Dewey et al., 1988), becoming part of the Asian continent.

The southernmost terrane underlying the Tibetan plateau is the Lhasa Terrane. It is also a continental fragment derived from the breakup of Gondwana. It collided with the Qiangtang Terrane in the late Jurassic (Dewey et al., 1988), and was thus the last crustal fragment to accrete to the Asian continent prior to the collision of India with Asia.

These terranes are all characterized by intense deformation resulting in fold and thrust belts related to foreland basin development (Yin and Harrison, 2000). Regional east-west striking decollements assisted in the crustal thickening and total north-south shortening. Extensional collapse occurs after continent-continent collision as the thickened crust is spread out due to gravitational collapse often accompanied by the formation of very large extensional faults (e.g. The South Tibetan Detachment, the Qomolongma Detachment and the Lhotse Detachments), and basins (e.g. the Tibetan basin).

Much of Tibet is like a giant bowl, with mountain belts along its rim and active depositional basins in its centre. This is a result of extensional collapse of the plateau with active accretion along the margins. Hence, the Tibetan plateau is a high plateau and not a series of mountain belts. Figure 14.2 shows the margins of the Tibetan basin comprising mountain belts, whilst the centre of Tibet is a depositional basin with rivers draining into the basin and forming lakes. The plateau is elevated due to the erosion of the surrounding high mountains and deposition into the basin.

12. The above was modified to (new page 35):

The geological evolution of the Tibetan Plateau is a protracted one. A number of terranes were accreted onto the North China Craton. During the Palaeozoic and Mesozoic ages (541 to 66 million years ago), Tibet was formed by the successive accretion of five continental fragments or terranes, each extending about 2500 km east-west and between 200 km and 500 km wide north-south. The fragments are separated by faults (Figure 10 A and B).

The northernmost of these, the Kunlun Terrane, is a composite batholith originating from two periods of magmatism. The initial period took place in the late Cambrian, 490 million years ago (Yuan, 1999), and the second took place between 215 and 210 million years ago (Yuan, 1999)

The Songpan-Ganze Terrane collided with the Kunlun Terrane in the late Permian (260 million years ago). It is associated with the Qiangtang Terrane, which was a continental fragment originating from the breakup of Gondwana. In the southward subduction of the Songpan-Ganze terrane, the ocean basin of this terrane formed a volcanic arc on the Qiangtang Terrane (Yin et al., 1999) during the Jurassic (200 – 145 million years ago). Subsequently, the Qiangtang Terrane collided with the Songpan-Ganze Terrane in the late Jurassic-early Triassic (around 200 million years ago; Dewey et al., 1988), becoming part of the Asian continent.

The southernmost terrane underlying the Tibetan plateau is the Lhasa Terrane. It is also a continental fragment from the breakup of Gondwana. It collided with the Qiangtang Terrane in the late Jurassic (Dewey et al., 1988), and was thus the last crustal fragment to accrete to the Asian continent prior to the collision of India with Asia.

Much of Tibet is like a giant bowl, with mountain belts along its rim and active depositional basins in its centre. Figures 6B and 10B show the margins of the Tibetan basin comprising mountain belts, whilst the centre of Tibet is a depositional basin with rivers draining into the basin and forming lakes. The plateau is elevated due to the erosion of the surrounding high mountains and deposition into the basin.

13. "heated and then exhumed" deleted.
14. Partial melt defined in Glossary
15. Temperatures for low and high grade metamorphism added
16. "were" deleted and "are being" added
17. "(Figure 6)" deleted.
18. Reference to old Figure 1.2 A,B and C made in the text (New Figure 8 A,B,C and D.
19. "These are different from other sediments in the subduction zone as they were subjected to low grade metamorphism as opposed to sediments from the forearc basin and younger sediments from the erosion of the Himalayas." Inserted
20. "and abyssal sediments" inserted
21. "found in the Indus Suture Zone (D). " inserted
22. *Original text from Figure 1.2 : "As movement continued, so the Tethys Sea began to shrink. Sediments developed as the leading edges of the Asian and Indian plates were brought together. Once collision began, sediments were juxtaposed, and the Main Boundary Fault was formed along which much of the movement was taken up."*

    Replaced with: " *By 50 million years ago, the Tethys Sea oceanic crust had been dragged below Asia and continent-continent collision had commenced. This brought sediments from the edges of both continents together and caused the formation of the MBF, along which much of the subsequent movement has occurred. Starved of subducting crust, the volcanic arc died." In new Figure 8C, new page 34.*
23. Caption to Fig 1.2 C (new Figure 8C) re-written: "The mountains rise by being squeezed out of a wedge bounded by faults. Collision buried some of the Palaeozoic to Mesozoic sedimentary rocks to mid-crustal depths, where they were folded, deformed and heated to 600 to 850°C. These hot rocks then began to melt, and were extruded southwards out to surface along a channel between the Main Central Thrust and the South Tibetan Detachment."
24. "*The rocks of the Lesser Himalayas and the Higher Himalaya are of the same age and were originally deposited together on the Indian continent."* Deleted
25. "*granite intrusions north of the Himalayas"* inserted
26. *"**The granite intrusions north of the Himalayas resulted from subducted crust melting and are now called the Transhimalaya Batholith.***" moved to new Figure 8A
27. "**the approaching Indian Continent and the remains of the Tethys Sea to today's high Himalayan mountain range, bracketed by India and Tibet" deleted**
28. "***from 75 million years ago to today"*** inserted.
29. "(Figures 8D and 9)" inserted
30. Fault explanation in Glossary expanded as shown above.
31. "See Stops 11 and 14" inserted
32. Original text on old page 26: "The Khumbu Thrust, which is a more recently postulated fault (Searle, 1999a), and shown in Figure 1.3, is found in the upper portions of the Greater Himalayan Sequence and located at the base of a series of leucogranite intrusions between it and the Lhotse Detachment. These large scale faults are all east-west striking and dip northwards at shallow angles, sub-parallel to the northward dip of the strata of the Himalayas." Deleted.
33. "south" inserted
34. "(Lukla Granite Gneiss)" inserted

Page 27

1. "to Lhotse (Map 4)" inserted in (new) Box 1.1
2. https://upload.wikimedia.org/wikipedia/commons/7/77/Geologic_Clock_with_events_and_periods.svg inserted in Box 1.1
3. "The Greater Himalayan Sequence occurs south of Mount Everest, between the base of the mountain (south the town of Lukla) and the foothills of the Himalayas" re-written: "The Greater Himalayan Sequence extends from Mount Everest southwards the town of Lukla." In new Box 1.1
4. As I am introducing the stratigraphy, I feel that I needed to give some detail of all the formations. I think the layman will ask about this detail even at this early stage in the trek. I have separated the geologic model of the Himalayas from the stratigraphy in Box 1.1 and put the model near the beginning of the guidebook.

Page 28 (new page 43)

1. The source of Figure 1.3 is myself.
2. "Sillimanite gneiss" and "gneiss" difference needs explaining in Fig 1.3. The following has been added: *Near the top of the GHS, a sillimanite-rich gneiss located just below the augen gneiss and leucogranite differs from the gneisses closer to the base of the GHS and in the Siwaliks in that the latter have little or no sillimanite in them. Figure 1.8 (granite gneiss) and Figure 3.6 (sillimanite biotite schist and gneiss) explains the difference between the two rock types.*

Page 29 (new page 44)

1. KT" inserted on Fig 1.4
2. For Fig 1.4, K – K' is correct.
3. The Source is myself.
4. "is well" replaced by "lies 5km"
5. "A number of" replaced by " Several"
6. "is'" replaced by "are"
7. Comma added
8. "and folded" deleted
9. "is a walk across" replaced with "traverses"
10. "the others are the Indus Suture Zone, the South Tibetan Detachment and the Main Boundary Fault)." Added
11. "Searle et al. (1997) estimates that some 12 km of rock material has been removed from the Shisha Pangma (8027 m) granite in ~3 million years between 17 and 14 million years ago, resulting in an estimated 4 mm/year exhumation rate." Added in Box 1.2
12. Added the following: "As one walks through the streets of Lukla, one sees that most of the houses are built with hand-hewn bricks of granite gneiss typical of the Greater Himalayan Sequence (Figure 1.6). Examination of these bricks shows typical crystalline gneiss with distinct bands of lighter and darker minerals. The dark minerals (biotite) are aligned to form a planar fabric whilst the minerals quartz (clear), and K-feldspar (milky white) and plagioclase grains (white) form the lighter coloured parts of the rock. Quartz and the feldspars form poikilitic grains (i.e. grains of different minerals within a larger different mineral grain). Quartz-feldspar intergrowths are found, as well as numerous grains with irregular grain boundaries. These suggest that the rock may have partially melted during high-grade metamorphism. Large poikilitic grains may be up to 5 mm in size, whilst other minerals are less than 1 mm in size. Both strained and unstrained quartz found in the rock, indicate that the rock has experienced deformation. Strained quartz has a wavy, irregular pattern of extinction under the microscope, whilst unstrained quartz grains show regular extinction.

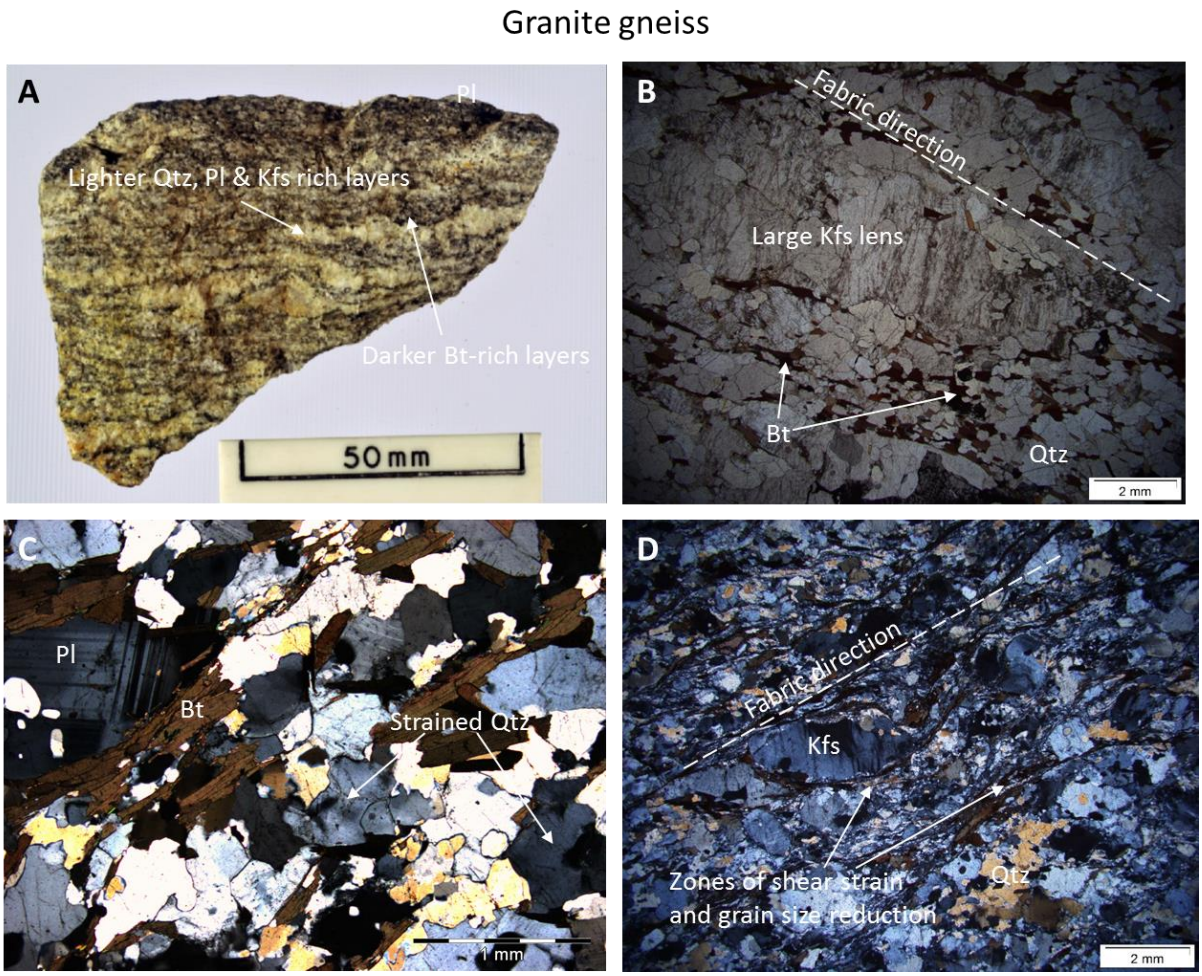
Page 30 (new pages 45 and 46)

1. “Intense folding and partial melting during this process resulted in the folded fabrics and migmatitic textures that can be seen in the gneissic rocks around Lukla” deleted
2. “around” replaced with “at”
13. “and migmatitic” deleted.
14. Added the following: “Examination of the granite gneiss (new Figure 1.8) shows zones of lighter and darker minerals with a strong directional orientation. The white and glassy minerals are feldspar and quartz; the darker grey/black mineral is biotite.”
15. “Microscopic examination of the granite gneiss (Figure 1.8) shows zones of lighter and darker minerals with a strong directional orientation. “ deleted

Page 31 (new page 48)

1. Deleted old Figure 1.7

   And replaced with:



2. Caption changed to: *Figure 1.8: The main rock type along the route between Lukla and Phakding is granite gneiss. A – hand sample of granite gneiss collected near Lukla. Note the banding of darker minerals (typically biotite) and lighter minerals (quartz and feldspar) – this is known as gneissic banding is characteristic of a gneiss. B – photomicrograph (plane light) of granite gneiss. Note the large grain of K-feldspar (Kfs) which forms a lens surrounded by the fabric, defined by aligned biotite (Bt) grains. C – photomicrograph of granitic gneiss) showing evidence for strain – strained quartz (Qtz) which is the result of deformation of the crystal structure of the quartz caused by strain. D – photomicrograph showing an intensely strained and sheared gneiss . Note the strong fabric*

surrounding a lens of K-feldspar (Kfs), surrounded by the fabric. Unlike image B, the fabric is more intense, with grain size reduction and a strong alignment of minerals caused by intense strain in zones of shear.

Stop 2

Page 32 (new page 49)

1. All small maps at the start of each stop deleted
2. "The" and " A" deleted
3. Distance to next stop added to each Stop.
4. "One feels a little out of breath, but it is great to be on the trail at last." Deleted
5. "above" replaced with " west of ".
6. "Complex for the layman" noted
7. "ed" deleted

Page 33 (new page 50)

1. "and have subsequently been exhumed during the uplift of the Himalayas" replaced with: "and have been exhumed (Figure 8C)"
2. "for the GHS" added to "burial to >45 km"
3. Source of Fig. 2.1: drawn by myself with the help of Dr L Longridge
4. "Schematic" added

Page 34 (new page 51)

1. "and" replaced by "with" signs of partial melting
2. Amphibole does occur in the GHS (Searle 2003) and in the leucogranites (Searle 1999)
3. "folds" deleted, replaced with "textures" re folds are ductile, not brittle.

Page 35 (new page 52)

1. Deleted original text: "In the southern parts of the Greater Himalayan Sequence, the effects of southwards-verging thrusting are still apparent. This thrusting (mainly along the Main Central Thrust (MCT)) brings high-grade ductile rocks such as those shown in the photographs above, over lower-grade rocks to the south. Although this thrusting was largely along the MCT, some related D_2 deformation is found in the rocks of the Greater Himalayan Sequence in this area. "
2. Although Fig 2.3 looks like the dip of the fault is S, the caption has been rephrased as follows: "Figure 2.3: In this boulder, which has rotated clockwise by an estimated 25° (faults generally dip between 5° and 15° north in the GHS and Everest Series)," as shown in point 4, below.

3. Deleted original photo:



4. And replaced it with this one:

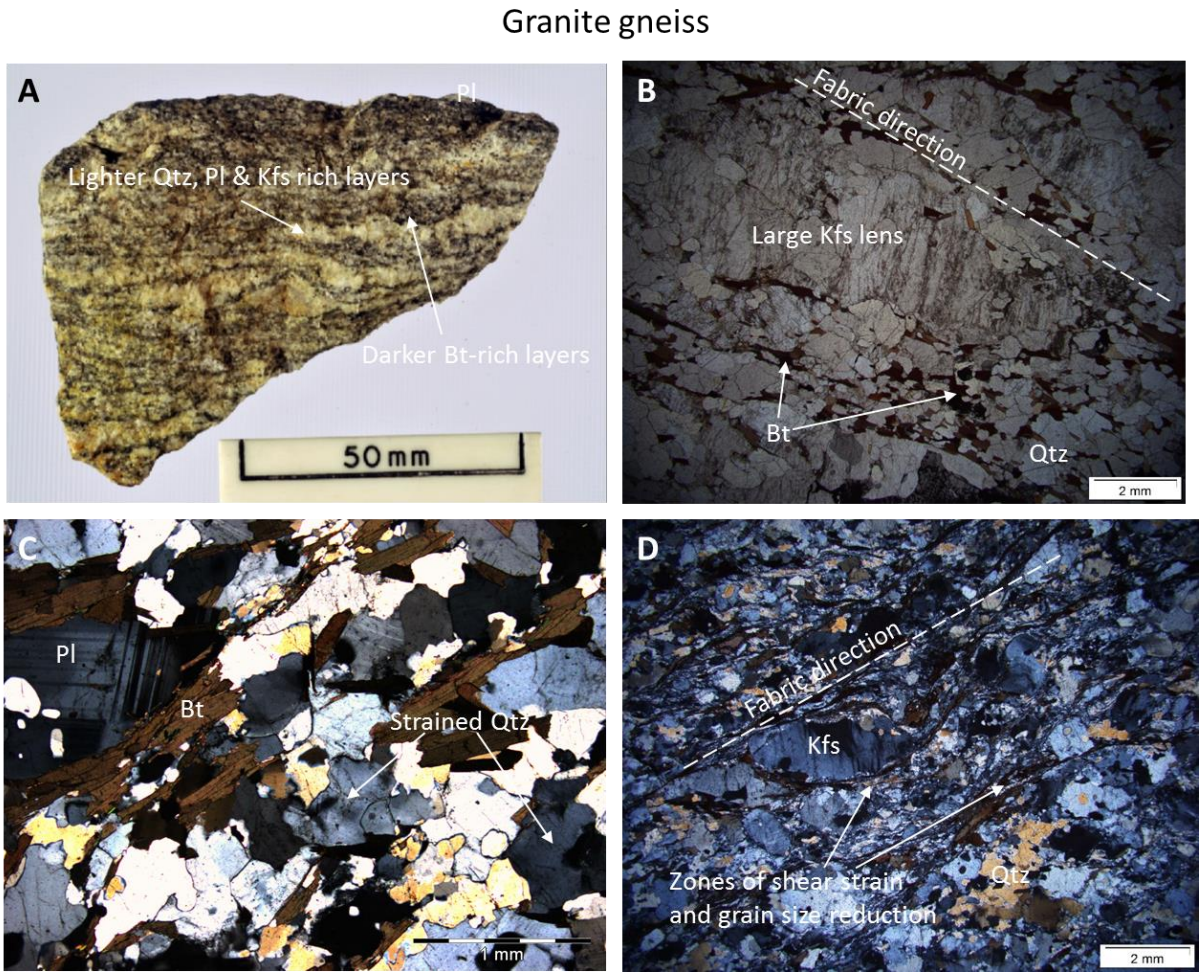


Quality is better and the caption was changed to: *Figure 2.3: In this boulder, which has rotated*

clockwise by an estimated 25° (faults generally dip between 5° and 15° north in the GHS and Everest Series), a recumbent fold occurs in quartz-feldspar-biotite gneiss south of Phakding. A thrust plane visible at its base shows vergence of the fold to the south. This folding and faulting is part of the D_2 deformation event in the Greater Himalayan Sequence which is related to exhumation of the Greater Himalayan Sequence along the Main Central Thrust. GPS co-ordinates 27°42'57.27"N, 86°42'46.51"E.

Page 36 (no new page, Figure 1.8 is on new page 48)

1. Removed original Figure 2.4:
2. Replaced this with:



This being new Figure 1.8 with new caption:

Figure 1.8: The main rock type along the route between Lukla and Phakding is granite gneiss. A – hand sample of granite gneiss collected near Lukla. Note the banding of darker minerals (typically biotite) and lighter minerals (quartz and feldspar) – this is known as gneissic banding is characteristic of gneiss. B – photomicrograph (plane light) of granite gneiss. Note the large grain of K-feldspar (Kfs) which forms a lens surrounded by the fabric, defined by aligned biotite (Bt) grains. C – photomicrograph of granitic gneiss) showing evidence for strain – strained quartz (Qtz) which is the result of deformation of the crystal structure of the quartz caused by strain. D – photomicrograph showing an intensely strained and sheared gneiss. Strained quartz has a wavy, irregular pattern of extinction under the microscope, whilst unstrained quartz grains show regular extinction. Note the strong fabric surrounding a lens of K-feldspar (Kfs), surrounded by the fabric. Unlike image B, the fabric is more intense, with grain size reduction and a strong alignment of minerals caused by intense strain in zones of shear..

Stop 3

Page 37 (new page 53)

1. ", panorama unequalled" deleted "the Everest massif" added
2. "**giants" replaced with " peaks"**
3. "Namche Bazaar has some great bakeries and a hot chocolate drinks, making for welcome relief after a strenuous climb." Deleted
4. "(Khunde 3750 m)" and "composed of limestone (Everest) and leucogranite (Ama Dablam)" added
5. "Across" replaced with "On"
6. "**composed of limestone (Ev) and leucogranite (AD) added**
7. Comma added
8. "In general, the rocks consist of gneiss and granite with varying textures and differing amounts of biotite (a dark brown mineral) and feldspar/quartz (white/glassy minerals)." Added
9. "Box 3.1 explains how different minerals grow in response to a change in pressure and temperature and the path they follow on a pressure-temperature diagram. " re-written for a layman.

Page 38 (new page 54)

1. "geological" replaced with "metamorphic"
2. "rocks are put under very high pressure)" replaced with : "when there is differential stress on the rock under ductile conditions"
3. "'clockwise'" deleted

Page 39 (new page 55)

1. "highly" added
2. Source: "**(after Lombardo & Rolfo, 2000; Jessup et al. 2008)" added**

Page 40 (new pages 55 and 56)

1. Cross section line extended K to K' to K''
2. There is no thrust fault at the migmatite horizon
3. No, the vertical scale is the same
4. The N and S labels are the same, though a different colour
5. Source: the section was drawn by me
6. "from left (south) to right (north)" deleted.
7. "and these form the lower planes along which the Greater Himalayan Sequence "channel" has been exhumed" deleted.
8. "D_1" added

Page 41 (new pages 57 and 58)

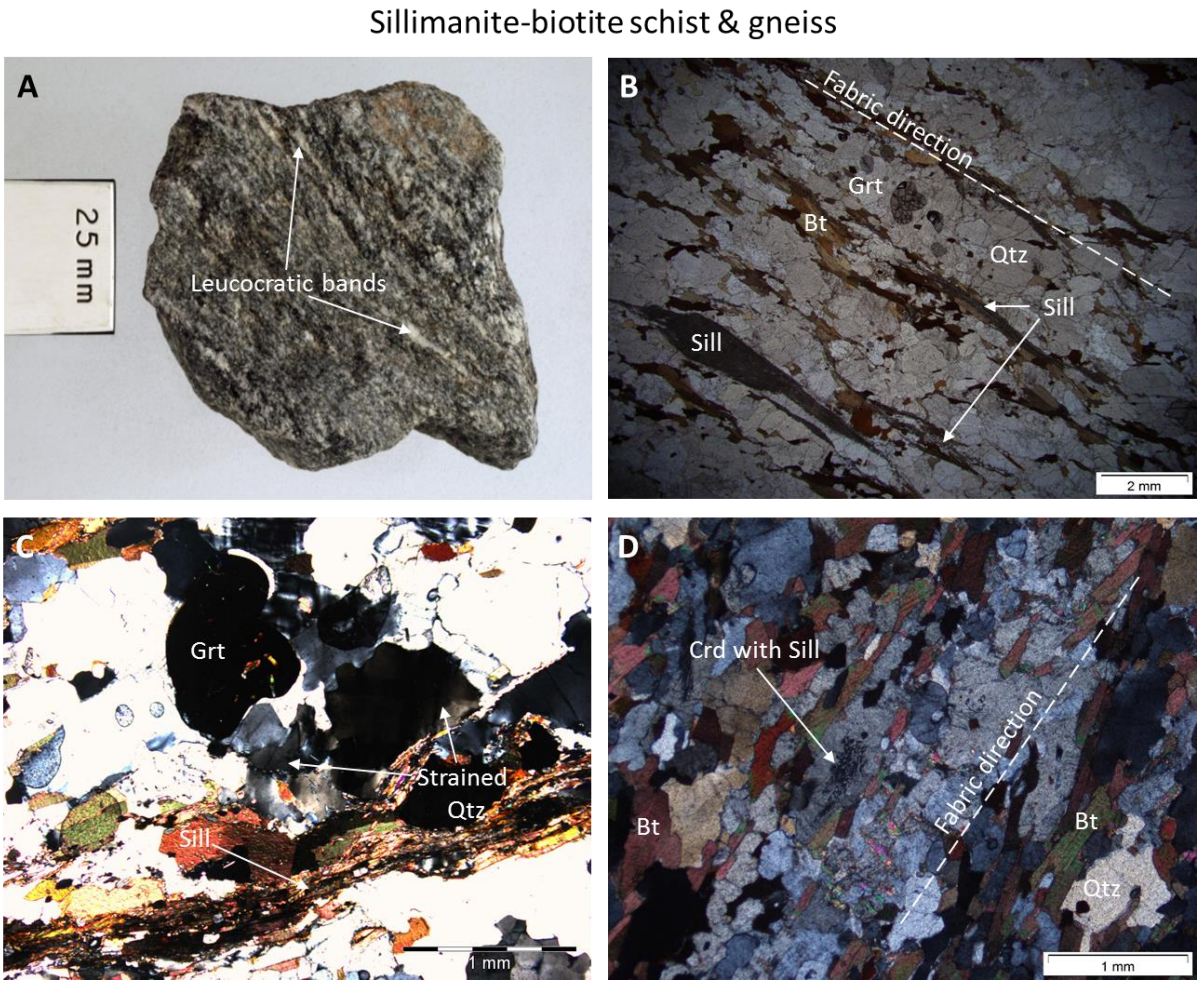
1. "One of the greatest panoramas in the world can be seen from just above" deleted.
2. "View from Namche Bazaar towards Everest" added to Fig 3.5
3. Image improved
4. "which were buried to much greater depths and underwent M_1 metamorphism to much higher grades (granulite facies) than the Everest Series rocks." Deleted.
5. Inserted in the place of point No. 4: "The Yellow Band is near the summit of Everest. The rocks below the Nuptse Ridge are composed of metamorphosed calcareous rocks of the Everest Series. These have been intruded by leucogranites of the Greater Himalayan Series. The location of the Lhotse and Qomolongma Detachments is shown. Brown rocks along the sides of the valley are biotite-sillimanite gneiss of the Greater Himalayan Sequence. The summit of Ama Dablam (to the left of the photograph,

not in view) is made up of Higher Himalayan Leucogranite which formed from the anatexis (melting) of the Greater Himalayan Sequence rocks."

6. Fig 3.5 labels added

Page 42 (new page 59)

1. This figure (original Figure 3.6) deleted.
2. Replaced by:



3. With new caption:

Figure 3.6: The main rock type along the route from Namche Bazaar to Everest Base Camp is biotite sillimanite schist and gneiss. A – hand sample of biotite-sillimanite gneiss, the dark shade being due to the mineral biotite, which makes up much of the rock. Note the lighter leucocratic bands, made up of quartz and feldspar, and which distinguish the gneiss from schist (which has a more uniform, unbanded texture). B – photomicrograph of biotite-sillimanite gneiss). Note the fabric, made up of alignment of biotite crystals and fine-grained patches of grey sillimanite. A small garnet grain is also found. C – photomicrograph of garnet, sillimanite and strained quartz. Garnet is a metamorphic mineral commonly found in medium- to high-grade metamorphic rocks. D – photomicrograph showing a grain of cordierite with inclusions of sillimanite. Cordierite typically grows from a reaction between biotite and sillimanite during metamorphism (Searle et al. 2003).

Stop 4

Page 43 (new page 60)

1. “all the way until just before” replace with “to”
2. “dark” deleted
3. “behind” deleted
4. “gneisses west of” added

Page 44 (new page 61)

1. “dark” added” light-coloured” replaced by “ pale”
2. “(Figure 4.3)” added
3. Old Box 4.1 moved to the beginning of the Guidebook.
4. “or orogens” deleted
5. “Hence” deleted
6. “Thrusting results from two layers of rock moving in opposite directions separated by a thrust plane.” Deleted and replaced by “as the subducting layer passes by underneath the Asian plate. The zone between the two crustal layers is called a thrust plane.”
7. “processes assisted by faults and channel flow where a sub-horizontal layer is extruded to surface at a shallow angle” deleted
8. “but also thrust rates and e.g. channel flow.” Added
9. “of the hangingwall above the thrust takes place.” Added

Page 45 (new page 62)

1. “lateral spreading would occur and higher mountains would result.” Added
2. “, where deeper-level rocks are progressively thrust over shallower level rocks during underplating” deleted
3. This is why I mention that “northwards-dipping planes (which) are observed in the Greater Himalayan Sequence” “may have” resulted from a wedge stacking process. Agreed they can also be layering or normal faults
4. “in the faces near the summits of e.g. Ama Dablam and Taboche, (Figures 4.2 and 5.4)”
5. “This granite is different from the migmatitic rocks in that it is medium to fine grained and light grey in colour compared with the coarse grained, pegmatitic banded migmatites.“ added’
6. " Evidence of high rates of erosion, and the resulting high rate of exhumation of subducted layers of rock, are the high mountains rapidly being eroded – clearly evidenced by the steep-sided valleys and large amounts of loose rubble and boulders in the valleys and the lower slopes of the mountains all along the route. The large amounts of debris and boulders along the trail and in the rivers along the route, in fact, make outcrops of the Greater Himalayan Sequence rocks quite rare.” Moved to the start of the “Geology along the way” section

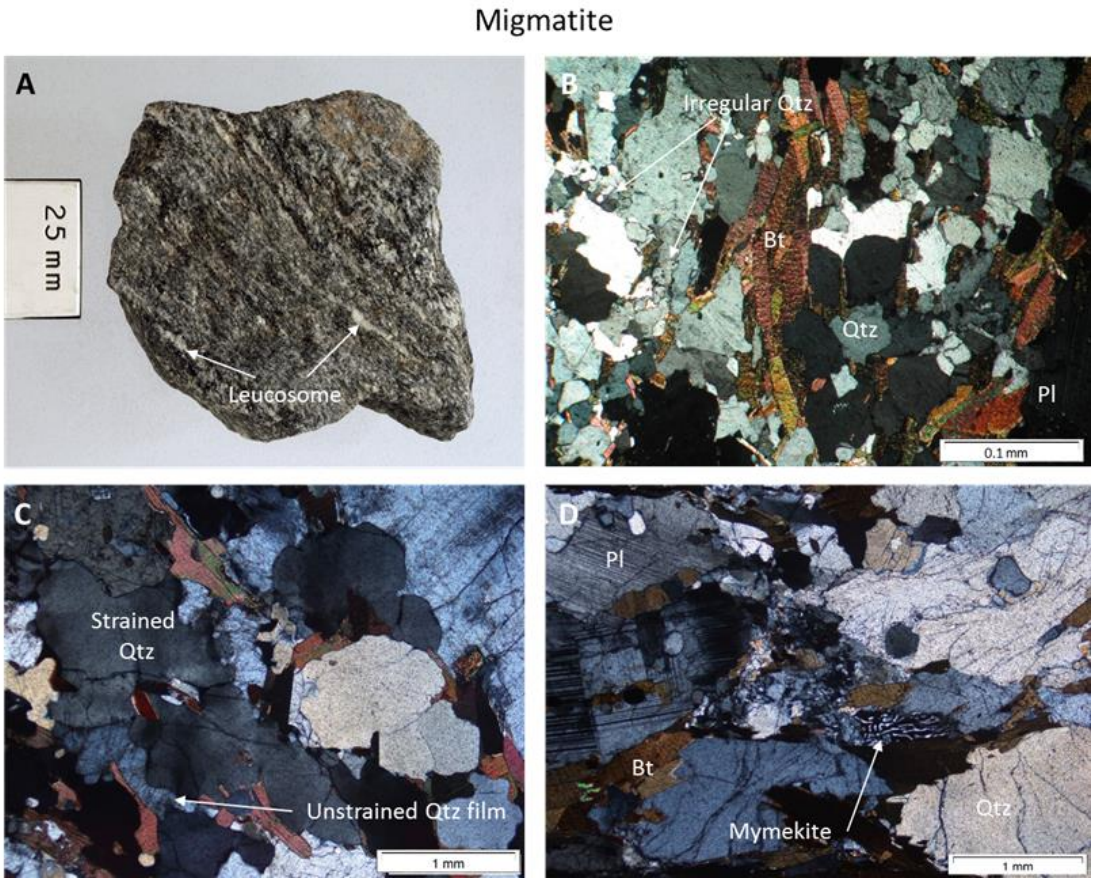
Page 46 and 47 (New page 63)

1. The LD goes through the lower parts of Lhotse and would come out just above the Nuptse ridge as shown
2. “View from Tengboche” added to Fig 4.4
3. “just before” replaced with “the approach to”
4. “below” deleted and sentence adjusted with “this photograph”
5. “until the” replaced with “ up to”
6. Ref “(Searle 1999)” added

7. “The Everest pelites above the Lhotse Detachment have acted as a cap to any further upwards intrusion of the leucogranite.” Deleted

8. Added the following text on new page 63, last paragraph: “Leucogranites form when migmatites begin to partially melt and the melt rises upwards through zones of weakness such as faults and shear zones. A large migmatite zone occurs above Namche Bazaar (Figure 4.5). Numerous examples of migmatite outcrops are encountered along the route from Namche Bazaar through Tengboche to Pangboche. Box 4.1 explains how leucogranites form with a study done by Searle et al. 1997 on the Shisha Pangma (8027 m) leucogranite, approximately 100 km west northwest of Everest.”

9. New photomicrograph of migmatite added:



10. With caption:

Figure 4.4: Migmatite examples. Migmatite is a term for a rock that shows evidence for partial melting (also known as anatexis). A: Typically, migmatites have lighter layers or zones known as leucosomes that are relicts of melt, and are made up of quartz and feldspar. In this example, a sample of biotite-sillimanite gneiss (sample RH02) has a number of leucosomes. B-D: Microscopic evidence of relict melt including irregular quartz grains that have not yet annealed (B), thin films of unstrained quartz between grains of strain quartz (C) - the unstrained quartz is crystallized melt and myrmekites (D), which are intergrowths of quartz and feldspar that form during crystallisation of trapped leucosome.

Page 47 (new page 64)

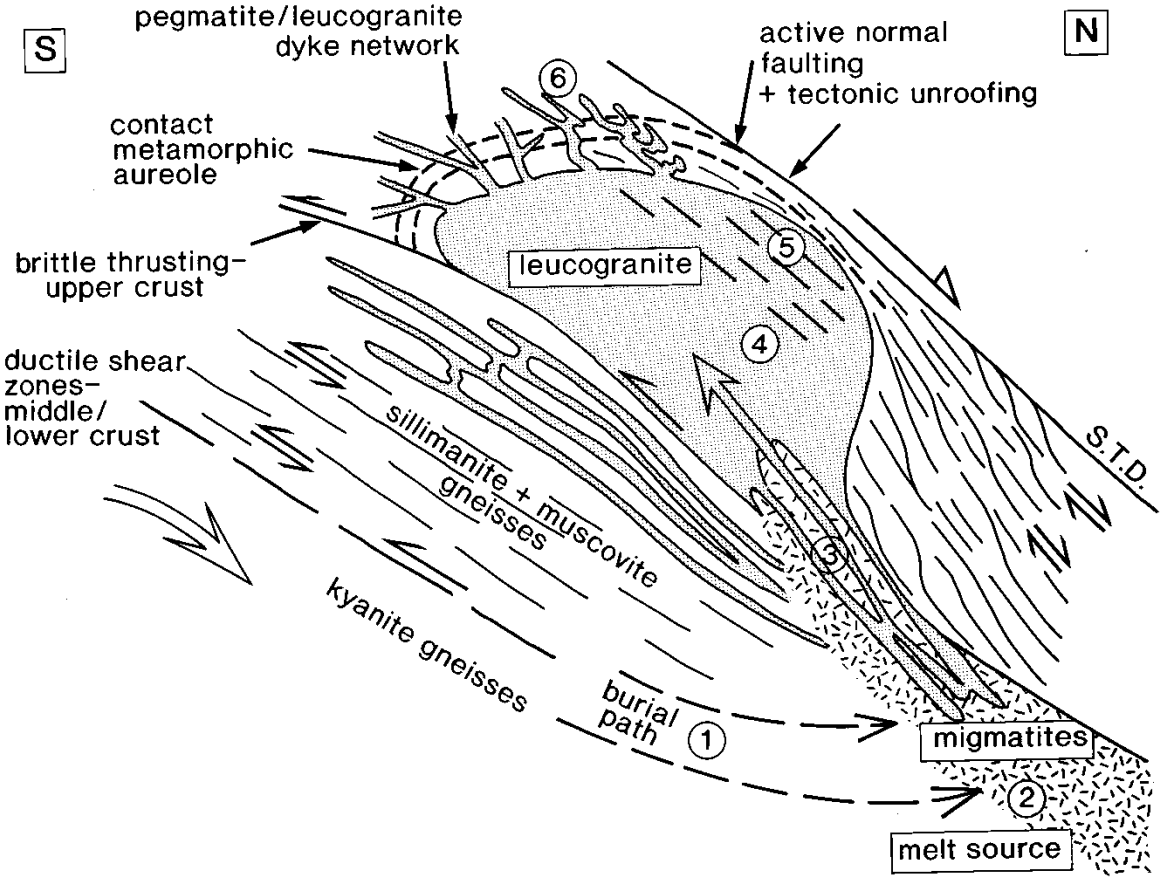
1. “above” replaced by “overlooking”
2. “magma” replaced with “ melt”
3. “B” replaced with “b” in Boudins
4. “darker coloured rock” replaced with “sillimanite-biotite schist”.
5. I do not recall any red garnets though the photo where the examiner indicates such looks quite likely as containing garnets.

Stop 5

Page 48 (new pages 65, 66 and 67)

1. "which continue to draw the eye relentlessly" deleted
2. "in one's sights" replaced with "visible"
3. "(e.g. Highland Sherpa Lodge has magnificent views)" deleted.

4. Deleted original text: "through the accumulation of melt in the leucosomes in migmatites which rise upwards to just below the colder rocks above the South Tibetan Detachment and which are then extruded through a mechanism known as channel flow."
5. Added Searle et al. (1997) diagram in new Box 5.1 to explain rise of melts from migmatites to form leucogranites.



Page 49 (new pages 66 and 67)

1. "amazingly" deleted
2. "The eroded remnants of this granite sheet form the Higher Himalayan leucogranites." Deleted.
3. "Mapping and correlation of the structure and stratigraphy of the Higher Himalayas has shown that these leucogranites form a distinct horizon near the top of the Greater Himalayan Sequence (Figure 5.1)." added
4. "rather than being discrete plutons (Searle et al. 1997)." Added
5. "magma" replaced with "melt"
6. "under buoyancy" added
7. "and why it may eventually reach the surface to form volcanoes" added
8. "(circa 23 to 17 million years ago (Searle et al. 1997), when the gneiss of the Greater Himalayan Sequence was partially melting to form migmatite. Rapid cooling of the Everest leucogranite occurred between 19 and 17 million years ago." Added

Page 50 (new pages 67 and 68)

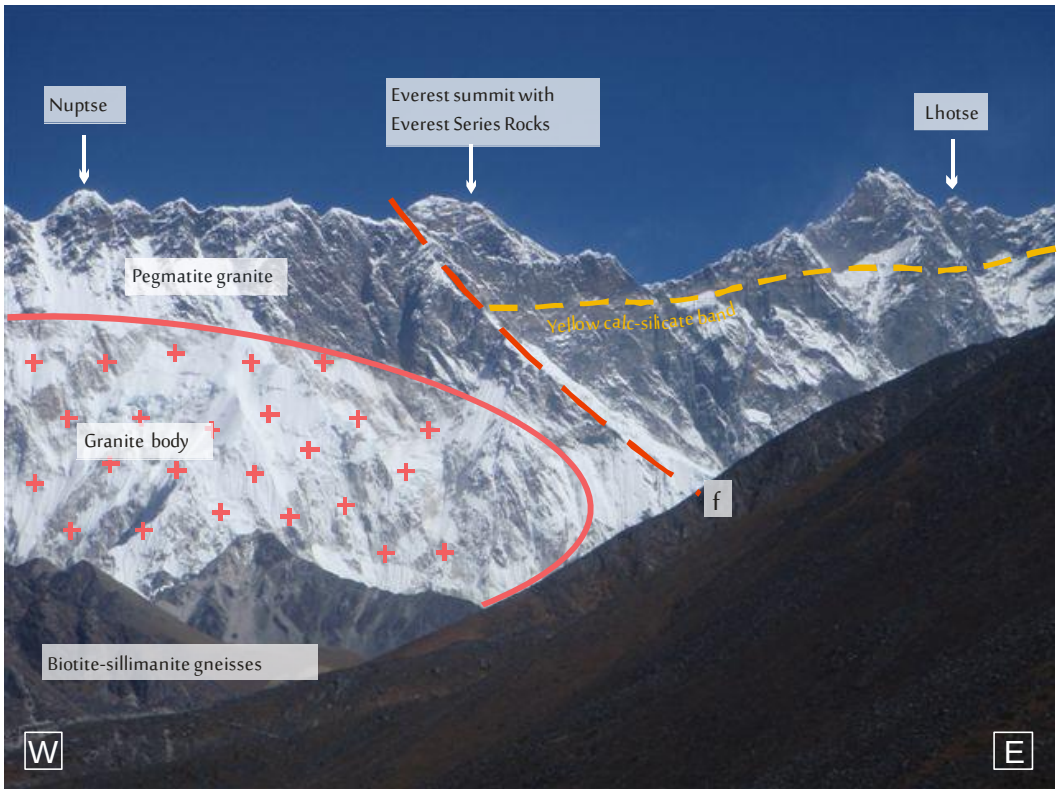
1. Cross section ref: Searle (2003)
2. Repetition deleted and replaced with:" Searle et al. (1997) estimates that some 12 km of rock material has been removed from the Shisha Pangma (8027 m) granite in ~3 million years between 17 and 14 million years ago, resulting in an estimated 4 mm/year exhumation rate."
3. Labels added regarding white bands and large boudin in sillimanite-biotite schist in Fig 5.3
4. "A hanging glacier on the summit of Ama Dablam is possibly the source of the mountains name in Sherpa: "mother's necklace"." Added

Page 51 (new page 69)

1. "subduction" deleted and "underplating" added
2. Comma inserted
3. Fairly certain of the location of the KT on Fig 5.4
4. Searle's maps (2003 and 2007) show that there are also dykes below the leucogranite, implying that when they were intruded, dykes were formed all around the plutons as shown in Searle's diagram in the corrections Pg46, point 9 above.

Page 52 (new page 70)

1. Caption to Fig 5.5 re-written as follows:" Figure 5.5: View looking at the Nuptse–Lhotse massif from the northern slopes of Taboche. In the foreground are the sillimanite biotite gneisses situated in the valley behind the ridges. The lower slopes of Nuptse show a large granite intrusion (See Figure 8.2 for geological interpretation). In the centre background is Everest. The Lhotse ridge shows yellowish calc-silicate bands above the Lhotse Detachment (LD), dipping into the ridge to the north at ~10˚. These calc-silicate bands are truncated by the LD running diagonally across the ridge. This same calc-silicate band can be observed later along the route in the Western Cwm, at Stop 11 Figure 11.1)."
2. Also, a better quality photo replaced it, with this one:



Page 53 (no new page)

1. Figure 5.3 deleted as a sillimanite-biotite schist sample has been inserted as Figure 3.6.

Stop 6

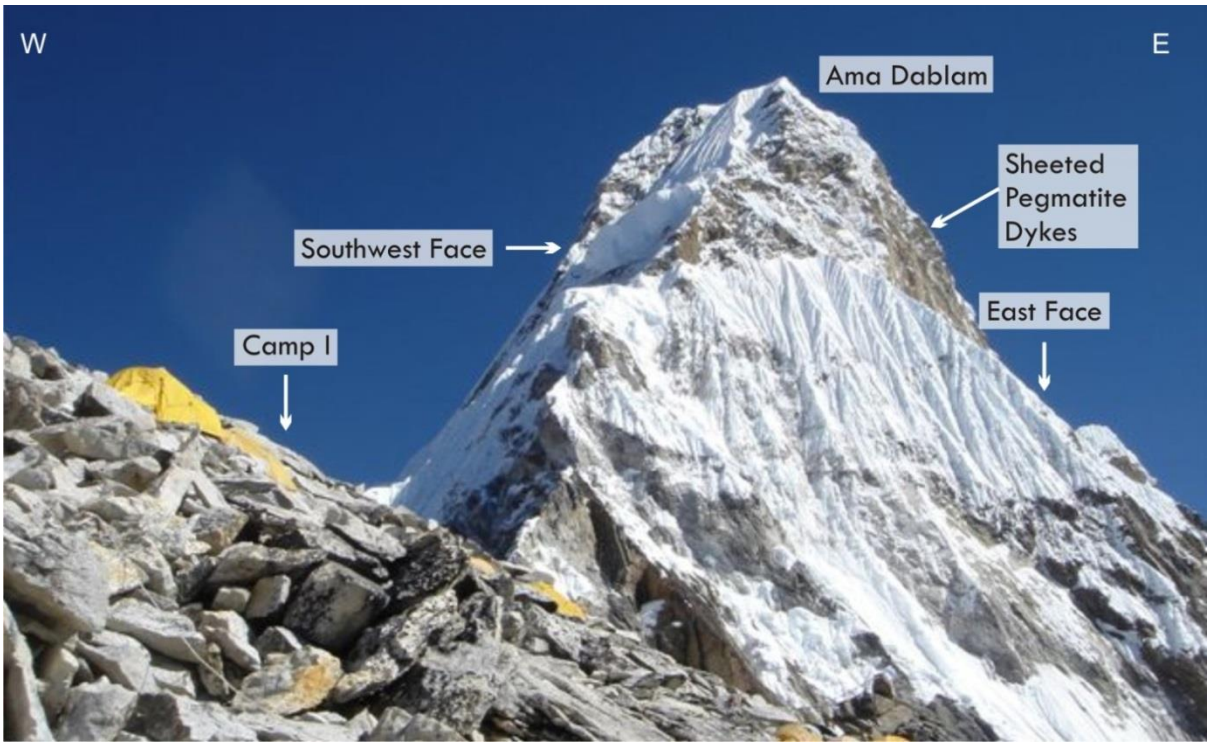
Page 54 (new page 71)

1. Small maps all deleted
2. Deleted original text: “The summit ridge of Ama Dablam is in a realm of its own. The exposure is extreme and most of the rocks are loose scree. One is laden with climbing gear, all movement is on fixed ropes and each movement causes breathlessness.”
3. All annotated changes made in Paragraph 1
4. “form” replaced with “ accumulate in”
5. “accumulate” replaced with “ coalesce”
6. “which are major components of quartz and feldspar” added
7. “(and will thus accumulate in the melt during partial melting).” Deleted
8. “low degrees” replaced with “limited amounts”

Page 55 (new pages 72 and 73)

1. “pegmatite sheeted sills” added; “dykes” deleted
2. The cross-section is drawn by me from Searle’s Map
3. New text added: “The tourmaline-granites found on Ama Dablam are one of two types of granite making up the Higher Himalayan Leucogranites, the other being the two-mica granites. Although both granites are likely to have originated from the partial melting of the underlying GHS, with the melt segregating and subsequently ascending to be emplaced as plutons and sheets at the top of the GHS, they were formed by different processes. The tourmaline granites were locally derived, having not travelled far from their source, and were produced by muscovite dehydration melting in a muscovite rich metapelites at lower temperatures than the two-mica granites (Le Fort et al. 1987). The tourmaline content of these granites is usually > 2.2% (Le Fort et al. 1987). The two-mica granites (tourmaline content < 2.6%), were generated by melting at higher temperatures in biotite-rich gneiss, resulting in hotter magmas. These intruded upwards by a network of dykes and sills, and solidified below the cooler rocks of the STD (Visona and Lombardo, 2002).”
4. Original Figure 6.2 replaced:

5. With this better quality Figure 6.2:



6. With caption: "*Figure 6.2: The Ama Dablam south-east ridge is a mass of broken rocks composed of tourmaline-bearing leucogranite which is shown in the foreground. The summit and the north face are composed of sheeted sills of leucogranite and pegmatite-intruding sillimanite-biotite gneiss, calc-silicate and amphibolite."*
7. Also more text added: "The granites are made up of mostly quartz, plagioclase feldspar, and K-feldspar, are generally coarse-grained (>0.5 mm) and do not contain a strong fabric. Very minor amounts of biotite are found but large amounts of pale muscovite mica and dark tourmaline occur. Both muscovite and tourmaline are common in granites generated by the melting of metasedimentary rocks such as the sillimanite-biotite gneiss near the base of Ama Dablam. Tourmaline is a boron (B) mineral and is indicative of the enrichment of the leucogranites in the incompatible elements."

Page 56 (new page 74)

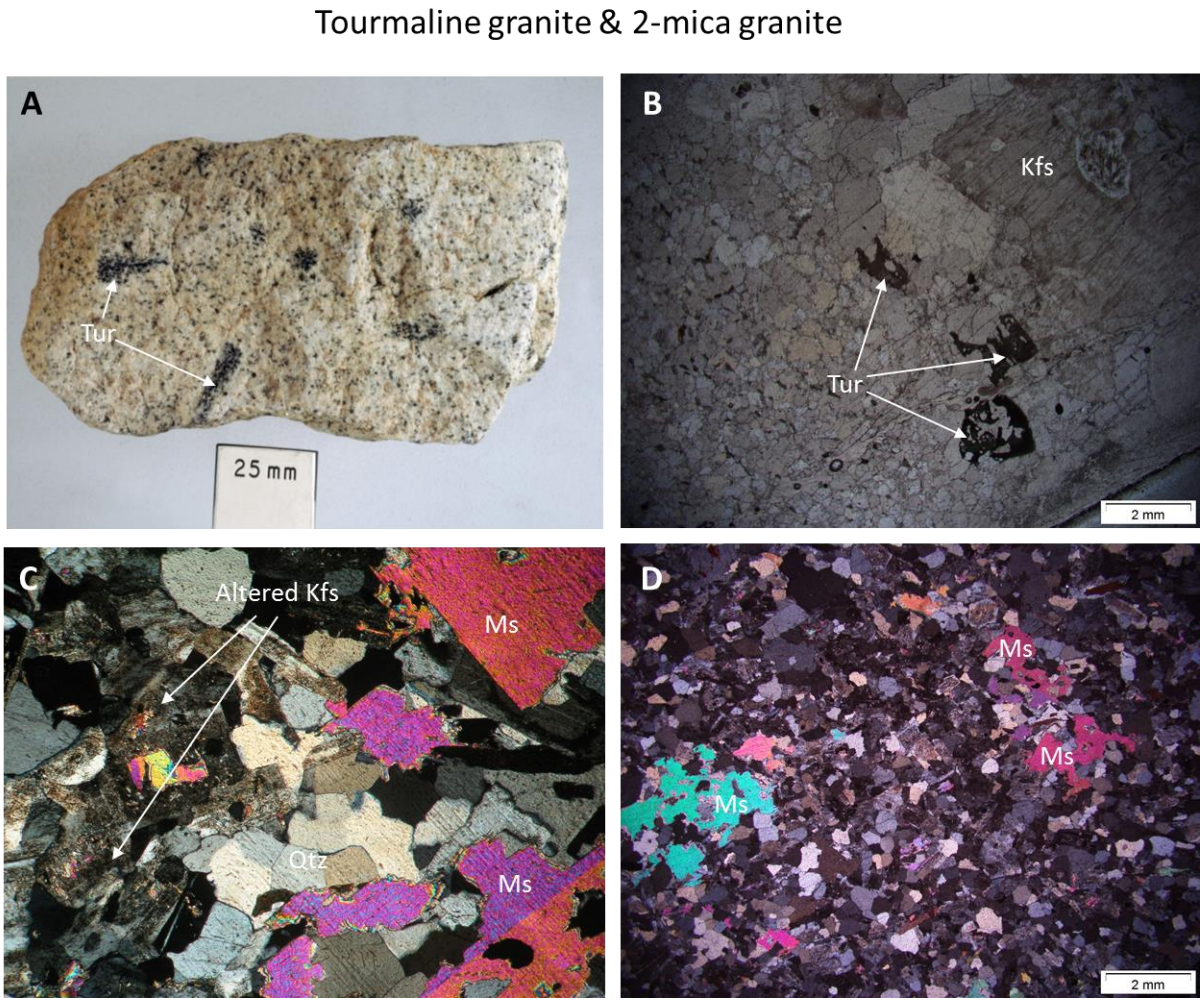
1. "ripped up" replaced with " detached
2. "The south-east ridge is composed mainly of tourmaline-bearing leucogranite' has been re-written.
3. "eroded" deleted and replaced by "detached"
4. Original text in caption of Figure 6.3 deleted: " *The south-east ridge contains numerous xenoliths of biotite-sillimanite gneiss (the dark rock in the photo on the next page). These were likely to have been eroded from the base of the channel on extrusion of the leucogranite layer. GPS co-ordinates 27°51'24.35"N, 86°51'17.23"E."*

   Replaced by: "*The south-east ridge is composed mainly of tourmaline-bearing leucogranite and contains numerous xenoliths of sillimanite-biotite gneiss (the black rock). These were likely to have been detached from in-situ wall rocks isolated by sill-dyke intrusion and expansion of the pluton/sill. Photograph taken at GPS co-ordinates 27°51'24.35"N, 86°51'17.23"E.*"

Page 57 (new page 75)

1. Added: "Most of the dark material in the hand specimen is tourmaline."
2. "sillimanite-biotite" reversed

3. Figures 6.4 and 6.5 (old pages 57 and 58) deleted and replaced by:



4. With expanded caption as follows:
"*Figure 6.4: The main rock type along the south-east ridge of Ama Dablam is a tourmaline-bearing leucogranite*, with *large crystals of black tourmaline up to 5 cm in length in places. Elsewhere, two-mica granites with only minor amounts of tourmaline are found. Both of these granite types were generated by the melting of the gneisses lower down in the Greater Himalayan Sequence. A – hand sample photo, showing large, distinctive tourmaline (Tur) crystals in an otherwise pale rock. B – photomicrograph showing tourmaline under the microscope, as well as a large K-feldspar (Kfs) crystal. C –K-feldspar from a two-mica granite from closer to Everest has been heavily altered to sericite by late-magmatic fluids. D – photomicrograph of a two-mica granite, showing large muscovite crystals typical of this granite."*

Page 58 (no new page)

1. Figure 6.5 deleted – replaced by new Figure 6.4.

Stop 7

Page 59 (new page 76)

1. Small map deleted
2. "was observed" inserted
3. Serac in glossary

Page 60 (new page 77)

1. “Global warming saw the Khumbu glacier retreat almost to Base Camp in 2013 from just south of Laboche in 2006. The valley floor is covered in moraine 1 to 5m thick, dumped by the retreating glacier. “ deleted
2. “(Cross section drawn from Searle’s Maps, 2003, 2007)” added
3. Labels added on Figure 7.1

Stop 8

Page 61 (new page 78)

1. “which extends ESE to WNW” deleted
2. “front” deleted and “ face” added

Page 62 (new page 79)

No changes required

Page 63 (new page 80)

1. “walk” deleted and “route” added
2. Added: “In the foreground is sillimanite-biotite gneiss. The roof of the pluton is criss-crossed by a network of dykes and sills that intrude the sillimanite-biotite gneiss.” to Fig 8.2.
3. Fig 8.4 correlated to Fig 8.2
4. “fractures” deleted and replaced with “ planes of weakness”
5. “sheet” added in 2 places

Page 64 (new page 81)

1. “Along” deleted and “T” inserted
2. “, one is walking” deleted and “traverses” added
3. “Figures 8.1 and 8.2 correspond to the west side of the section.” Added
4. Deleted: “, in combination with exhumation,”

Page 65 (new page 92)

1. “and” added

Stop 9

Page 66 (new page 83)

1. “Everest Base Camp is in sight at last (Maps 2 and 4).” Deleted.
2. “as are the other beautiful mountains all around one” deleted.
3. “together with the surrounding peaks (Map 4)” added
4. “and” replaced with “that”
5. “elongate” added
6. “in” deleted
7. “one is now physically standing” deleted and replaced with “is located”
8. “. Keep a look out for evidence of” deleted.
9. “as evidenced by” added

10. “in which” replaced by “which describes”
11. “can be” replaced with “as”

Page 67 (new page 83)

1. Caption of Fig 9.1 changed from “View of Changtse with detailed geology superimposed” to “: View of Changtse from the summit of Kala Pattar showing the Everest Series on Changtse.”

Page 68 (new pages 84 and 85)

“Everest leucogranite intrusions are encountered, containing black tourmaline crystals. From here, the summit leucogranite of Pumori can be seen (Figure 9.3).

1. “replaced with “Everest leucogranite containing black tourmaline crystals intrusions are encountered in the sillimanite-biotite gneiss.”
2. Labels added on Fig 9.3 and GPS co-ords added.
3. “are just” replaced with lie”
4. Comma added
5. Added the following text (this text is now on page 84 of the new Part 2): “These samples (such as the sample from near Camp 2 – Figure 9.4), have experienced low-grade metamorphism and may show evidence of D_2 deformation in the Everest Series (see Figure 3.2D). These schists are made up of biotite, muscovite and quartz. No high-grade minerals such as sillimanite, or leucosomes containing coarse feldspar (common in the GHS) are found in these rocks, which are either fine-grained (<0.1 mm) slate ore slightly coarse (~0.25mm) schist that is strongly foliated – this foliation formed by aligned biotite and muscovite crystals is typical of the S_1 fabric found throughout the Everest Series, and was formed during prograde metamorphism. The S_1 fabric was subsequently folded into asymmetrical kink-folds during exhumation, and these so-called kink-bands are typical of D_2 deformation in the Everest Series. (See Figure 3.2)”.
6. Added: “An example of low-grade schist from the Everest Series is shown in Figure 9.4”

Page 69 (new page 86)

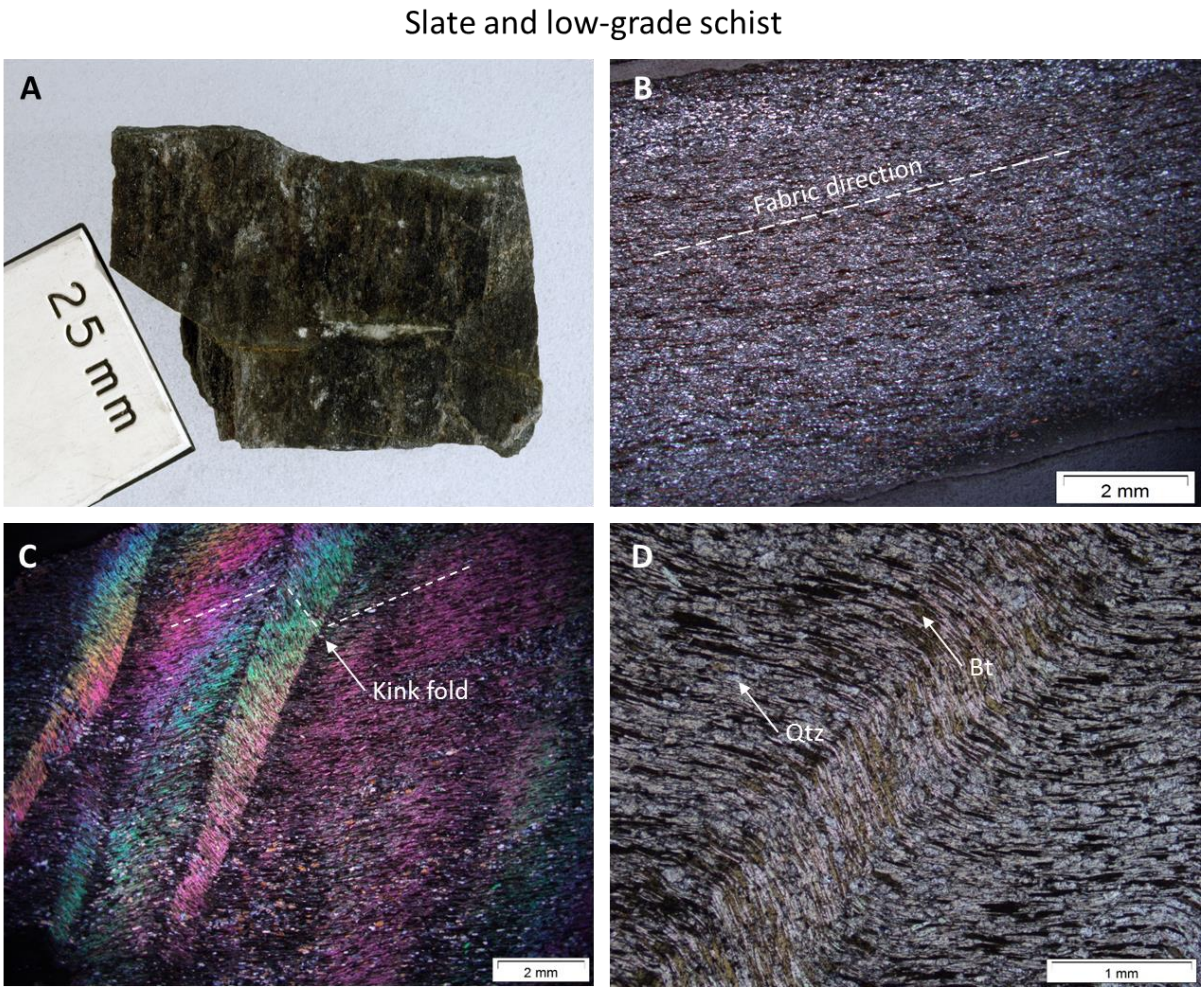
1. “The thickness of the KT fault zone is estimated to be 100m.” added in Fig 9.4
2. Fig 9.4 “A” and “B” parts of the figure labelled
3. Added: “View from GPS co-ordinates: 27°59’45”N, 86°49’42”E.”

Page 70 (new page 87)

1. “with a stockwork of dykes and sills” added
2. “Above the fold, there is a stockwork of leucogranite sills and dykes.” Deleted

Page 71 (new page 88)

1. Figure 9.6 “Sillimanite Biotite Gneiss” rock description replaced by:



2. And Caption added:
“*Figure 9.4: Everest series low grade schist and slate. Samples of low-grade slat and quartz-biotite schist from the Everest Series. A: Hand sample photograph of slate, a fine-grained, dark rock. B: photomicrograph (XPL) of slate, showing alignment of very fine-grained biotite and quartz to form a fabric. C: Photomicrograph (XPL) of low-grade quartz-biotite schist. This schist is slightly higher-grade than the slate, and shows coarser biotite and quartz that are aligned to form the schistose fabric. The fabric has been deformed (likely during exhumation – the late stages of D_2 deformation) into kink folds. D: photomicrograph (PPL) showing a closer view of a kink fold in the quartz-biotite schist.”*
3. Deleted: “simultaneous deformation and high-grade metamorphism leading to melting. This deformation and melting is most likely the result of exhumation of the Greater Himalayan Sequence.”
4. “of sillimanite and” added
5. “high grade metamorphic conditions. The right hand side of the microscope thin section shows a re-crystallised melt texture.” Added
6. “near Gorak Shep” added in caption of Fig 5.7

Stop 10

Page 72 (new page 89)

1. Spaces deleted
2. “Base Camp is a good location to explain the channel flow theory as the Pumori-Lingtren ridge is an example of this mechanism (see Figure 10.1 in combination with Figure 10.3).” deleted
3. “although locally, steep dips indicate folding of the rocks in many places” added

Page 73 (new pages 89 and 90)

1. ““Himalayan wedge” (the Greater Himalayan Sequence)” added to Box10.1
2. Comma deleted
3. “due to” replaced with “ owing”
4. “this” added
5. “on” replaced with “at”
6. Denudation defined
7. Focused surface denudation “through snow, rain and ice erosion” added
8. “if temperature is too low, channel will underthrust” deleted

Pages 74 and 75 (new page 91)

1. The channel flow concept with the Pumori and Lingtren ridge as an example of an extruding channel **has been deleted in total**, and **has been replaced with the following**:

“The geology of the Pumori-Lingtren ridge (as seen from base camp, looking west) is shown in Figure 10.3. Sillimanite-biotite gneiss underlies the leucogranite of Pumori and Lingtren and dips gently to the north. The dip of the layering is sub-parallel to the dip of the major structures along which exhumation has taken place.

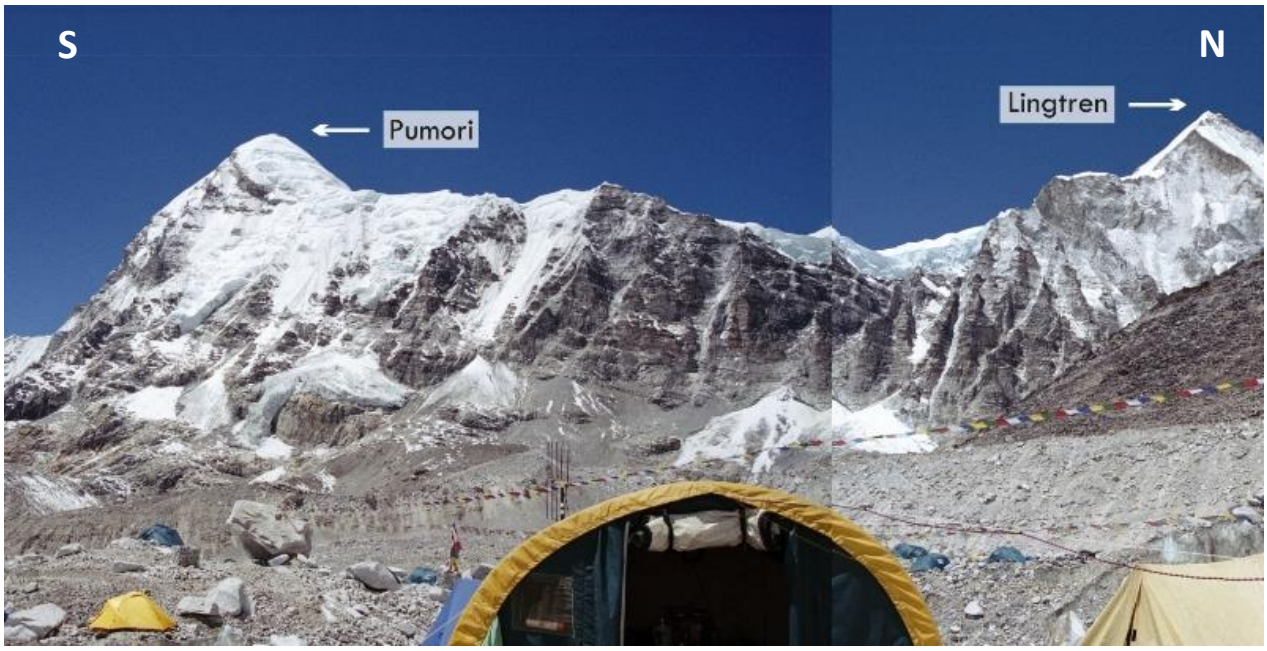


Figure 10.3: The east faces of Pumori and Lingtren above the Khumbu glacier showing exhumed leucogranite intruding sillimanite-biotite gneiss.

A closer look at the east face of Lingtren and Lingtren II, as seen from Base Camp, shows it is composed almost entirely of leucogranite (Figure 10.4). The isotherm, above which partial melting occurred, would have been on the gneiss–granite contact clearly seen near the base of Lingtren (Figure 10.4 point 11) allowing extrusion of the weak crustal channel (Figure 10.1 point 5).



Figure 10.4: The east face of Lingtren above the Khumbu Icefall showing a xenolith of sillimanite-biotite gneiss which indicates that the lower thrust zone (Khumbu Thrust) of the extruding block (11) was within the sillimanite-biotite gneiss and pieces of this gneiss were incorporated into the weak crustal channel (Figures 10.1 and 10.3, point 5).

Leucogranite can be examined in an outcrop just east of Base Camp on the other side of the Khumbu icefall. There is evidence of a number of intrusive episodes of granite with fine grained granite intruding into coarse-grained rocks. There is also evidence of younger granite intruding amphibole and pre-existing granite, with numerous xenoliths (Figure 10.5). This can be linked to channel flow: as the molten channel edges cooled and solidified, so new liquid granitic material was injected into the cooled rocks which included both granite and amphibolite.

The ridge is interpreted as an intrusion of leucogranite between the sillimanite-biotite gneiss and the Lhotse Detachment (Searle et al. 2003). Restoration of the Pumori Lingtren Everest profile (Figure 10.5) shows that melting of the leucogranite occurred at around 20km depth (P=7 kb) and, depending on the dip of the LD samples taken from Kala Pattar show that these rocks have been displaced southwards for a distance of between 90 to 216km (Searle et al. 2003). The Pumori – Lingtren ridge is therefore the top part of a channel extruded between the STD (of which the LD and the QD for part of) and the MCT.

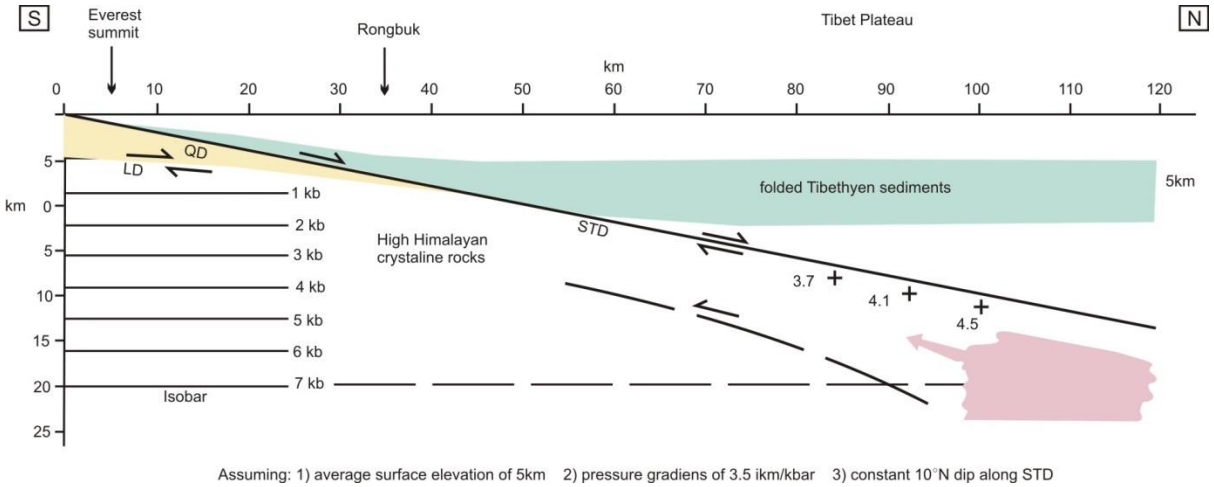


Figure 10.5: Restored Pumori – Everest profile before emplacement of the leucogranite. Crosses mark samples from Kala Pattar, 12km west of Everest (Map 4) which record pressures of 3.7, 4.1 and 4.5kb. at a true dip of 3° to 5°N measured on the N face of Everest, relative displacement is would be 180-216km (After Searle et al., 2003)."

Page 76 (new page 94)

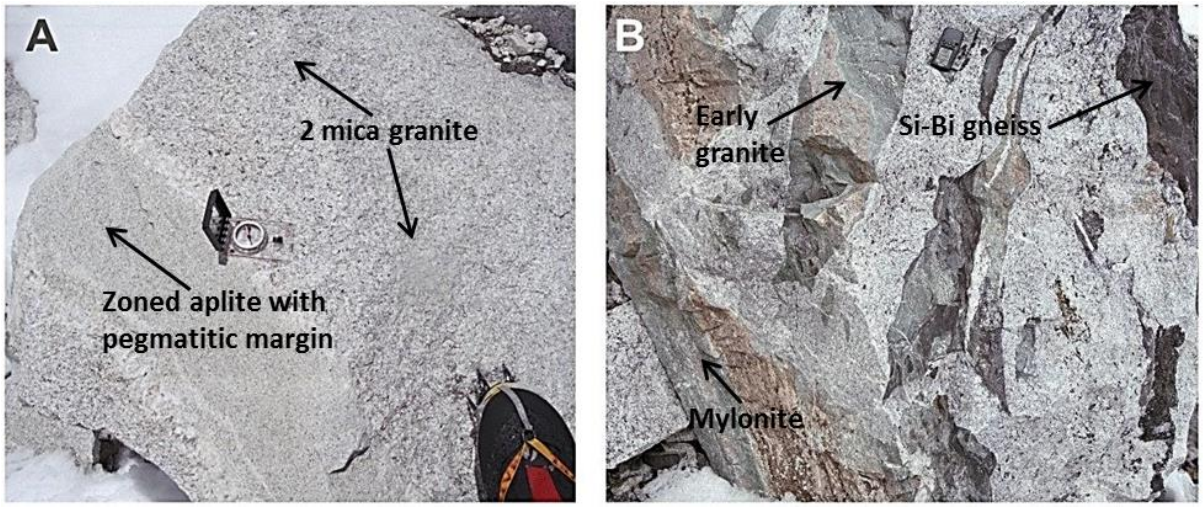
1. “the summit of” Nuptse inserted in new Figure 10.6

Page 77 (new page 94)

1. “through channel flow” deleted as speculative

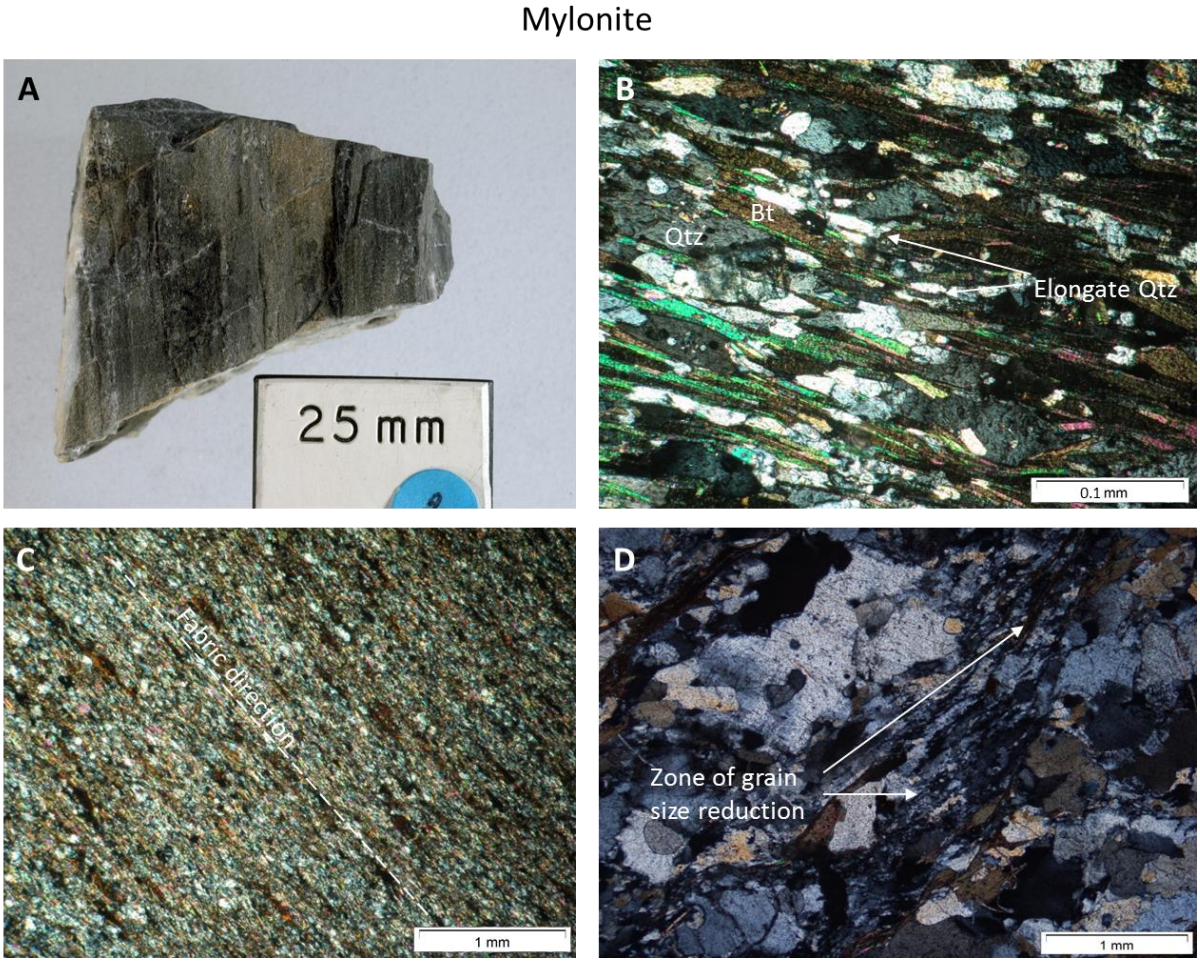
Page 78 (new page 94)

1. Added: “related to the Lhotse Detachment., one of the major detachments (a normal fault) found on the slopes below Everest.”
2. Labels added in new Figure 10.4 (old Figure 3.14) as follows:



3. Text added on new page 97: “Microscopic examination of a mylonite sample from near Base Camp (GPS co-ordinates 28°0’42.75”N, 86°51’24.57”E) is given in Figure 10.9. Mylonite is fairly abundant both at Base Camp and above it, likely owing to the proximity to the KT, a major zone of deformation, or possibly one of the major detachments found on the slopes of Everest, along which large amounts of movement have taken place. Mylonite is formed as a result of dynamic grain-size reduction caused by straining the rock in shear zones. Whilst the mineralogy of mylonites can be variable, they are fine-grained to extremely fine grained, with small (<0.1 mm) as intense deformation has led to grain size reduction.”

4. Original Figure 10.7 replaced with:



5. And new Caption:

"*Figure 10.9: Mylonite is a fairly common occurrence from Base Camp to the South Col of Everest. It has formed as a result of movement along major faults such as the Khumbu Thrust, Lhotse Detachment and Qomolongma Detachment. A: hand sample photograph of fine-grained mylonite. B: photomicrograph (XPL) showing the elongate nature of quartz grains and the alignment of quartz and biotite to form the fabric in a mylonite. C: Photomicrograph (XPL) showing the fine grained nature of the mylonite sample. D: Photomicrograph (XPL) of a proto-mylonite. This sample has not yet undergone wholesale grain size reduction, but zones in the sample show incipient grain-size reduction through crystallisation.*"

Stop 11

Page 79 (new page 99)

1. Original text deleted: "The Icefall is never-ending; 14 ladder-crossings and eight hours of climbing to reach Camp I; another four hours to reach Camp II (Maps 2 and 4). After arriving at Camp I, an avalanche off the West Shoulder came racing towards our tents. It lost power and we escaped with a good dusting of snow. It was also three days after three Sherpas were killed by a serac collapse on 21st April, 2006, just below Camp I. In total 11 climbers died on Everest in 2006, one of the worst years ever for Everest."

   And also deleted: "Camp I is located in the zone of leucogranites at the top of the Greater Himalayan Sequence, with numerous sills and dykes of granite in the area. Leaving Camp I at 5 a.m., the temperature is around minus 30 °C, the wind is howling and crevasse after crevasse still need to be

negotiated. Icicles are hanging from my nose and my beard is sticking to my balaclava. After what seems an age, suddenly Sean, our climbing leader, says “There’s Camp II in the rocks!” At 9 a.m. the sun hits us and suddenly we are boiling; we strip down to T-shirts and all my energy is gone. Our Camp II cook, Kajie Sherpa, brings me a cup of hot orange juice. Bliss!”

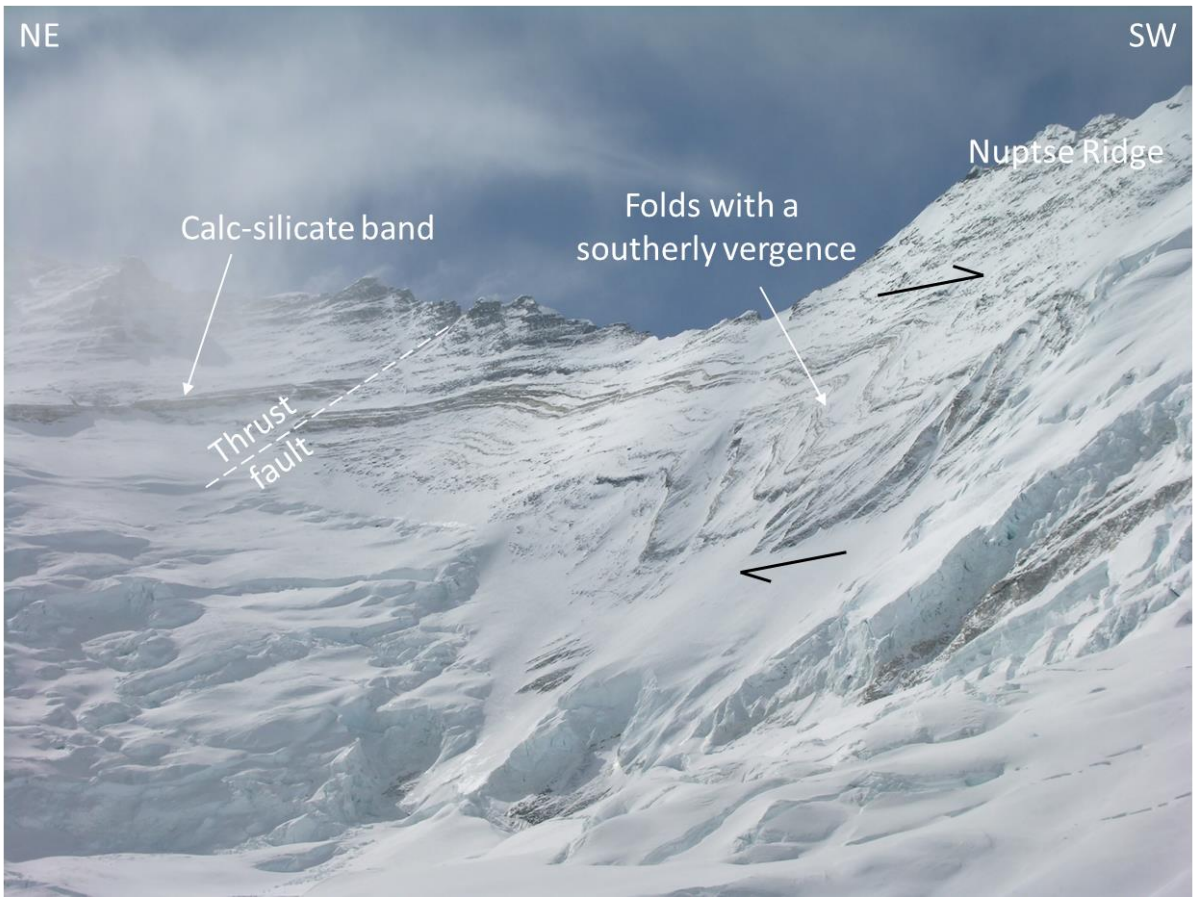
Replaced by:

“The Icefall has 14 ladder-crossings and it takes around eight hours of climbing to reach Camp I and a further four hours to reach Camp II (Maps 4). Avalanches are common. Both are powerful agents of erosion. Camp I is located in the zone of leucogranites at the top of the Greater Himalayan Sequence, with numerous sills and dykes of granite. Temperatures range from -30 to -40°C, to well into the +20°s adding another force to erosion as expansion and contraction of rocks can breaks them. High winds, sometimes in excess of 60 km/hr, can dislodge rocks leading to rockfalls and further assist erosion. These are the conditions that are normally experienced on Everest.”

2. “towards the south” added

Page 80 (new page 100)

1. Nappe structure renamed a recumbent fold in Fig 11.1 and in text
2. Fig 11.1 deleted and replaced with:



3. And caption changed to: *Figure 11.1: The Western Cwm fold seen looking eastwards from Camp II. A thrust (reverse) fault can be seen high up on the Lhotse face. The limbs of the fold appear to be buckled (B). Fold axial planes dip to the north at a low angle (estimated at 5° to 15°), and are likely to be related to extensional deformation (normal faulting) along the Lhotse Detachment (Searle, 1999).*

Page 81 (no new page as contents were deleted – no longer necessary)

1. Deleted Box 11.1 as the fold in the western Cwm is too small to be a nappe”

2. Deleted the following:

Box 11.1: What is a nappe?

A nappe is a large, thick sheet-like rock layer that has been thrust over itself along a fracture that itself was caused by its deformation and which has moved some kilometres along that thrust fault. Nappes usually form in a continental collision zone where compressional forces or thrust faulting dominates. The deformed rock layers are forced over each other so intensely that they break along a thrust plane and are pushed along this plane for large distances (Twiss and Moores, 1992).

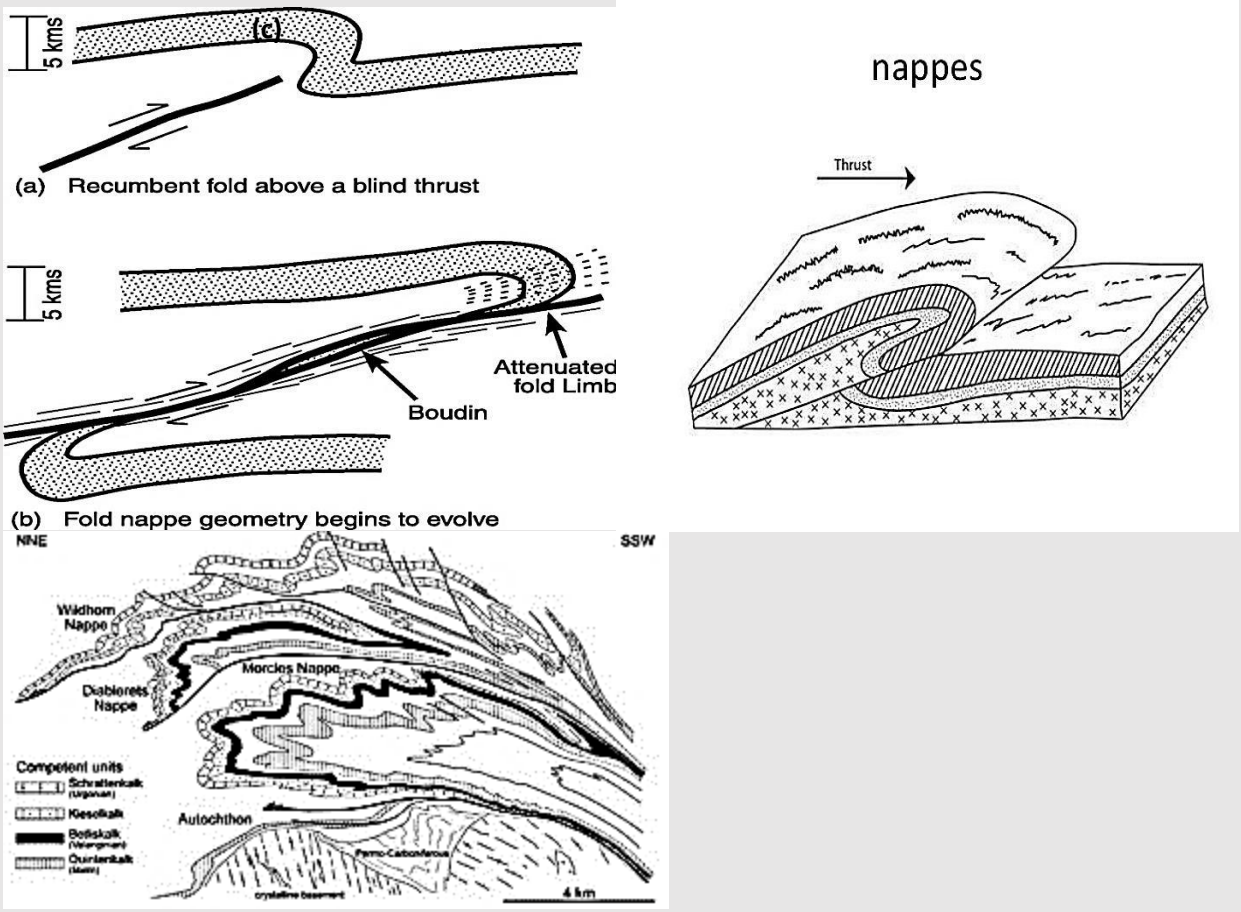


Figure 11.2: Schematic representation of the formation of a nappe, showing how a layer of rock reacts to a set of forces when a thick layer is compressed (after Marko and Jacko, 1999). Invariably, the folding is so intense (a) that a break occurs, which becomes a thrust fault (b). Movement can occur along the thrust fault for tens of kilometres Under certain circumstances, buckling of the folds occurs, as can be seen from the Morcles nappe in the Western Swiss Alps, (C) above (after Ramsay, 1981), similar to the buckling of the limbs of the recumbent fold in the western Cwm.

Page 82 (new page 101)

1. Modified to : "However, it may also be that it is an intrusion of leucogranite. "
2. "Z fault" changed to "thrust fault" – see new Figure 11.1.

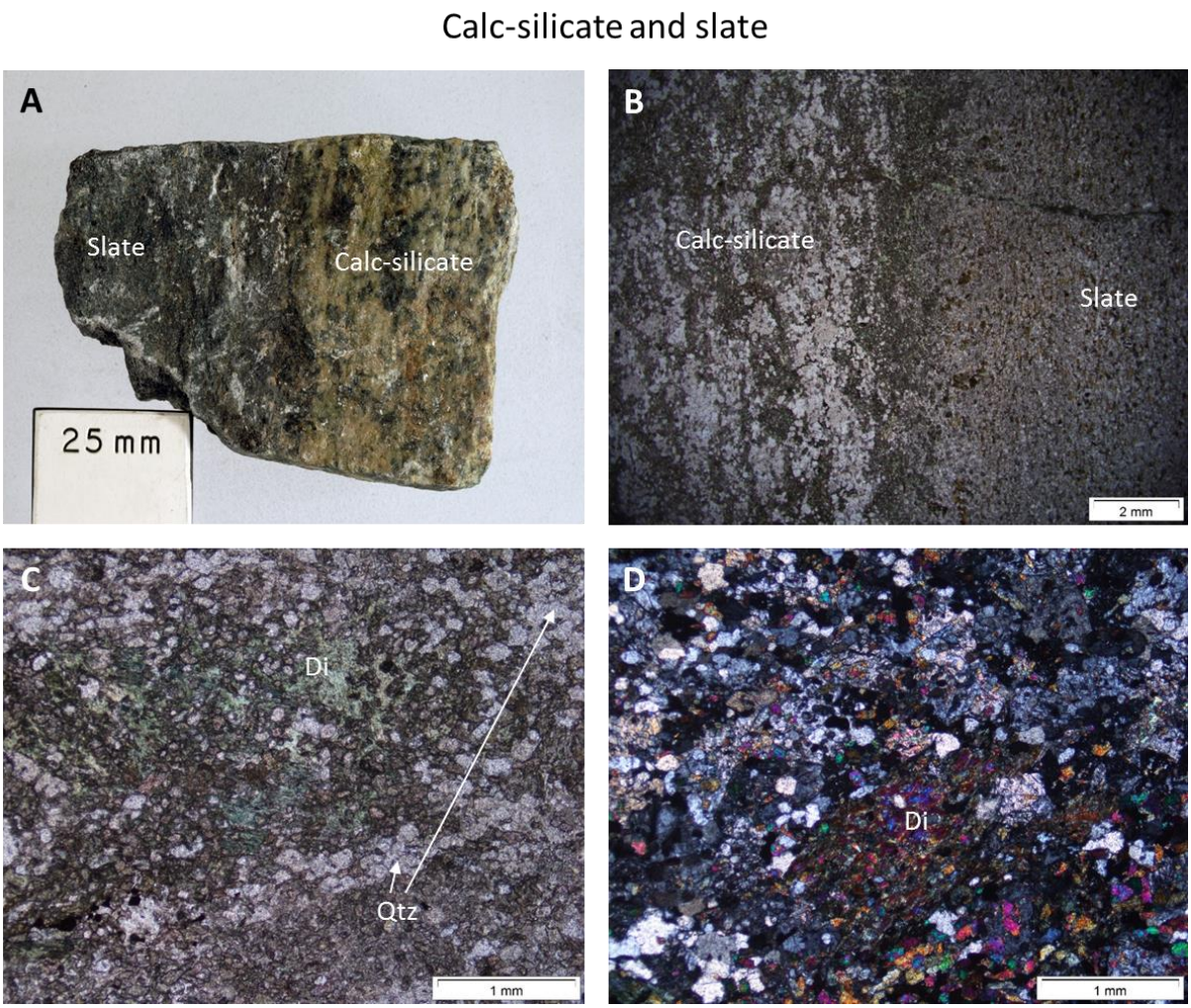
"This folding is a good example of the deformational event which accompanied channel flow and the exhumation of a channel of partially melted granitic material. Further evidence of this deformation is to be found in the mountains around Everest such as the slump structure on the south face of Changtse." deleted.

Page 83 (new page 102)

1. LD label added in Fig 11.3
2. “trek” replaced with “ route”
3. “migmatite” replaced with “mylonite”

Page 84 (new page 104)

1. Original Figure 11.4 deleted:
2. And replaced with:



3. With caption :

“ *Figure 11.4: Sample with slate in contact with calc-silicate. A – hand sample, showing dark, fine-grained slate on the left, and yellow and green calc-silicate on the right. B: Photomicrograph (PPL) showing the contact between calc-silicate (left) and slate (right). C: Photomicrograph (PPL) of calc-silicate, showing green diopside (calcium pyroxene) and quartz. D: Photomicrograph (XPL) of brightly coloured, highly birefringent diopside in the calc-silicate.”*

Stop 12

Page 85 (new page 104)

1. “has” replaced with “exposes”
2. Ref added (Gansser 1964)

2. Original Text: “The early history of the Himalayas was based on fossils.”

   Replaced by: “The early history stratigraphic subdivisions of the Himalayas were based on fossils.”

Page 86 (new pages 104 and 105)

1. “Fossils” added
2. “these rocks were first buried, then” added
3. “(Figures 1.2 and 1.3 in B0x 1.1)” added
4. Definition of Ammonite in the Glossary changed to: ”Spiral fossil marine mollusc animals which were swimming bottom-dwellers in open seas which preyed on fish and other molluscs; squid-like, from the Devonian to the Cretaceous period.”
5. “present day forms” replaced by “modern equivalents”
6. Bar scales added in Fig 12.1
7. “PPL” added in Fig 12.1

Page 87 (new pages 106 and 107)

1. “zone between” deleted and replaced with “faults called” the LD and the QD
2. “, of which the Yellow Band is part,” added to text
3. “(Figure 13.3)” added in the text – second line, new page 106.
4. “indicates a temperature range of between 150°C and 250°C (Searle et al 2003).” Added to text.
5. “Further down the stratigraphy, below the LD, the Rongbuk Formation indicates a temperature range of 600 °C to 650°C and burial depths of between 10 km and 20 km (Jessup et al., 2008). Here, fossils are likely to have been obliterated by the high temperatures and pressures.” Added to text

Page 88 (new page 108)

1. “and is repeated here” deleted
2. The purpose of the profile of Everest, etc. is that the formations and lithologies are roughly where they are found on the mountains.
3. “Most, if not all” replaced with “Many”
6. “a zone of” deleted

Page 89 (new page 108)

1. Fig 12.4 deleted and not replaced as there is already a description and new Figure 10.10 on mylonite:

Stop 13

Page 91 (new page 109)

1. “famous” deleted
2. “his” replaced by “ their
3. Comma inserted
4. The paragraph on Mallory was added, suggested by my supervisor, to compare Hillary (south side ascent) and Mallory (north side ascent) for the layman who would no doubt be interested in a comparison of who made it to the top first.
5. “due” deleted
6. Metamorphic Box 13.1 modified

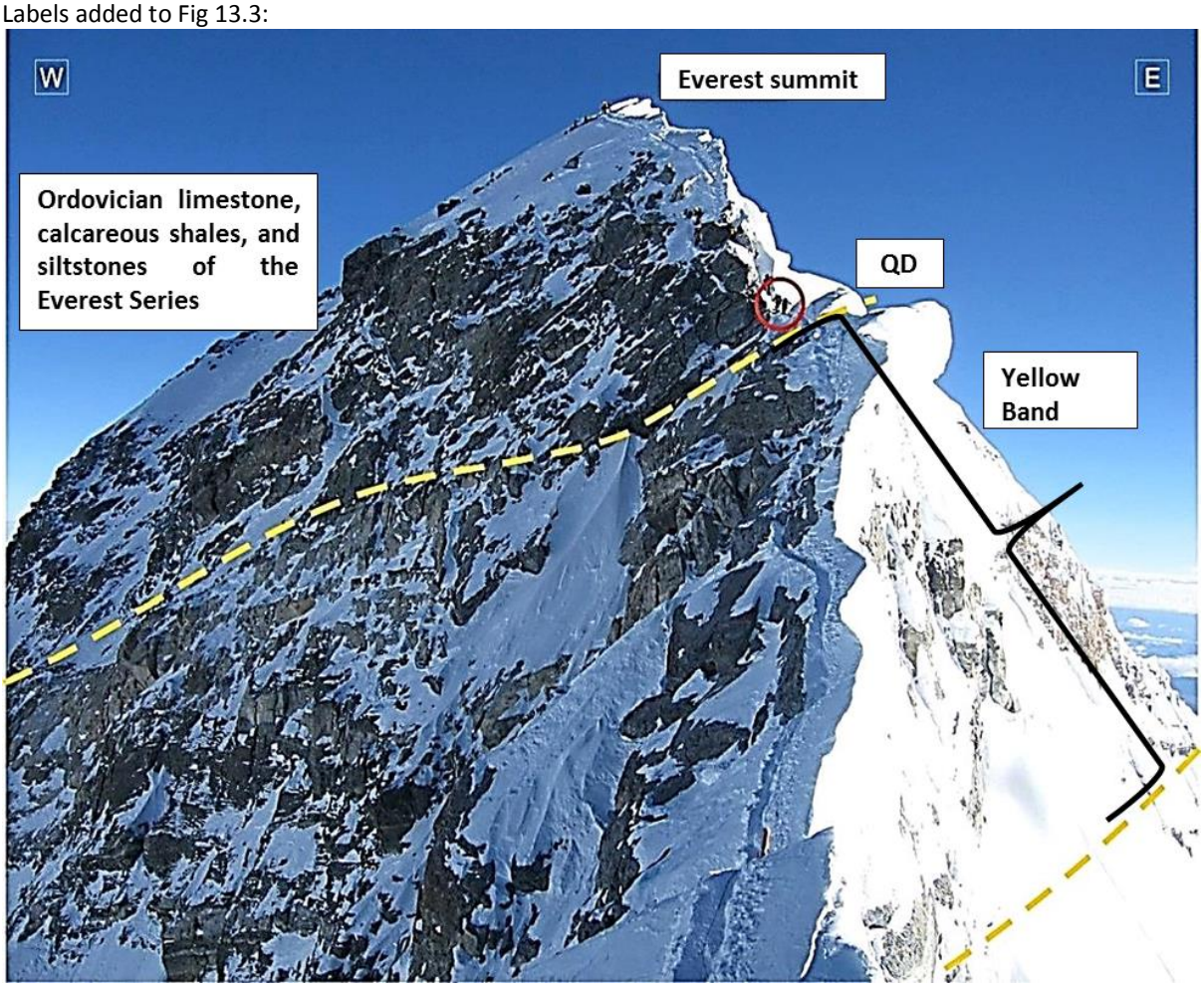
Page 92 and 93 (new pages 111 and 112)

1. Fig 13.2 is referred to as to the Lhotse ridge extending southwards from Everest, not Fig 13.1.
2. Original text: “pelite”

   Replaced with “ calcareous shale”
3. “and below the Lhotse Detachment, in the Greater Himalayan Sequence,” added
4. “but is less common” added
5. “rapidly” deleted

Page 94 (new page 113)

1. “These rocks contain retrograde-reaction textures indicating burial to over 20 km and decompression to about 10 km” moved from Fig 13.2 caption to text and is the last line on new page 111.
2. Fig 13.4 deleted and replaced with Figure 14.3
3. “The two figures circled in red are at the base of the Hillary Step (above the top dotted line).” Added to caption in Fig 13.3
4. “which” changed to “that”
5. Labels added to Fig 13.3:



Pages 95 and 96 deleted as Figure 13.4 has been replaced with Figure 14.4 and Figure 13.5 was out of place at this Stop.

Stop 14

Page 97 (new page 114)

1. Deleted original text: “In Box 14.1, the enormous lateral continuity of the Himalaya and the Tibetan geological terranes, which can be seen from the summit of Everest, are discussed.”
2. Fig 14.1 labelled extensively

Pages 98 and 99 (new page 115)

1. These pages moved to near the beginning of the guidebook (new pages 30 and 37)
2. Inserted views from the summit in a new Box 14.1:

Box 14.1: View from the summit



. View wast showing Nuptse, Everest west shoulder and Cho Oyu. Source: everestspeakersbureau.com



View east shows Lhotse and Makalu. Source: mountainworld.photoshelter.com

3. Added text: “The distinctive Yellow Band is a marble and is composed almost entirely of sparry calcite with a number of large calcite crystals showing twinning. Minor amounts of quartz and black carbonaceous material are found. Fossils can make up 5% by volume of the Yellow Band, although

none can be seen in the sample collected, likely owing to its sheared nature (Figure 14.3). Although the deformation in this sample may have destroyed fossil evidence, the wavy black carbonaceous material visible at the bottom of both photos could have originated from fossiliferous material. Samples from above the yellow band lack the distinctive yellow colour, but are also marbles, although they may be very fine-grained (Figure 14.3) and show evidence of high-strain (Figure 14.3). The numerous shears cutting through the samples often give the rock a strong fabric, and calcite grains form elongate lenses between the shear planes and meandering veins of black carbonaceous (organic) material (called stylolites). It is likely that these samples were sheared during D_2 deformation. In some samples, opaque pyrite forms euhedral to subhreral cubes, All samples are from the Qomolongma Formation, and have experienced low-grade metamorphism typical of the Everest Series."

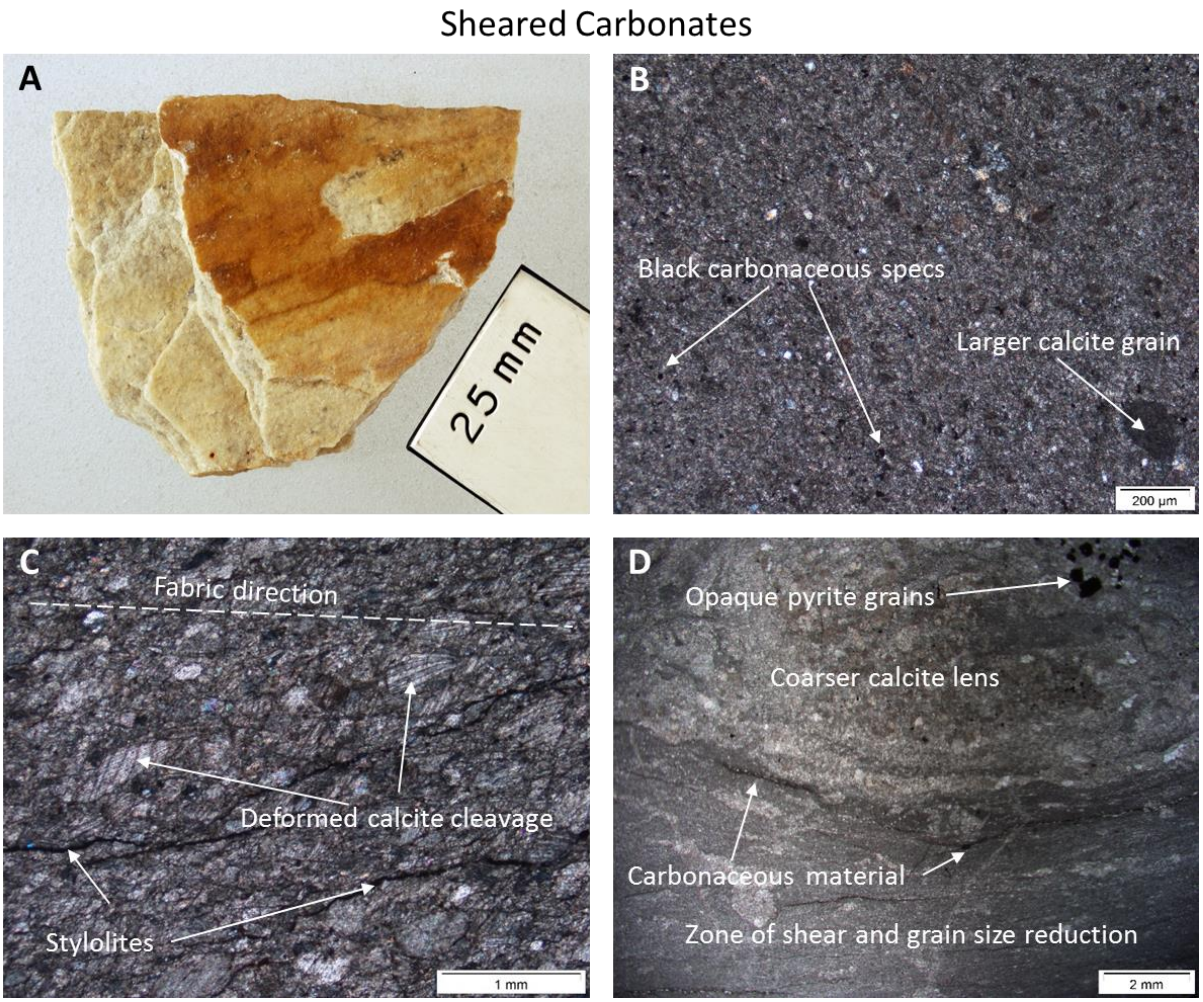
Page 100 (new page 116)

1. "Map 1" inserted in second paragraph in text
2. "and frigid summit rocks were formed in a warm sea." added
3. "relatively modern" deleted
4. "highest density levels of life" added
5. "Peak just catching the sun" deleted
6. Not called a nappe anymore – renamed recumbent fold
7. In Fig 14.4 also change name of the western Cwm Nappe to recumbent fold.
8. "and" added
9. "just above " deleted and " beyond" inserted in its place

Pages 101 and 102 (new page 117)

1. "Hillary Step" cut and "summit of Everest" added
2. Figures 14.5 and 14.6 deleted.

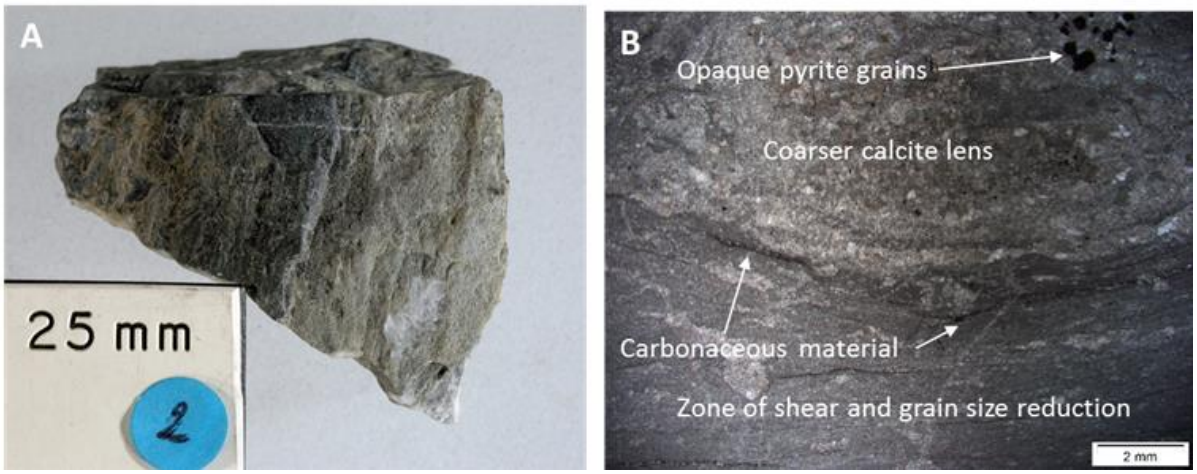
3. Replaced with:



4. And caption changed to:
" *Figure 14.3: Description of the calcareous rocks of the Everest Series from the Hillary Step. A – Hand sample of sheared marble from the Yellow Band. B – Photomicrograph (XPL) of fine-grained marble from the Hilary Step. This sample has experienced intense deformation leading to grain size reduction, with only few larger calcite grains remaining. A number of small carbon-rich grains are visible. C: Photomicrograph (XPL) of sheared marble from the Yellow Band, showing elongate shear planes and meandering veins of black carbonaceous (organic) material (stylolites). Bent cleavage planes in some calcite crystals are further evidence of deformation. D: Photomicrograph (XPL) of marble from the summit of Everest (one of the highest geological samples on the planet). This shows a coarse lens of calcite surrounded by finer carbonate and carbonaceous bands (stylolites) indicating that minor shear zones (related to movement on the STD and associated detachments) are present even at the summit of Everest".*

5. And added text: A sample of the summit rocks of Mount Everest is described in Figure 14.4.

6. And also replaced Figure 14.6 with:



With caption:

"*Fig. 14.4: A sample of sheared limestone from the summit of Everest, one of the highest geological samples on the planet. A - hand sample of fine-grained grey limestone. B - photomicrograph (XPL) of marble from the summit of Everest. This shows a coarse lens of calcite surrounded by finer carbonate and carbonaceous bands (stylolites) indicating that minor shear zones (related to movement on the STD and associated detachments) are present even at the summit of Everest. Sample collected at GPS co-ordinates* 27°59'17"N, 86°55'31"E."

Page 103 (new page 119)

1. "giant" deleted and replaced with " summits"
2. The paragraph on the "one more thing" and the hum in the Khumbu Valley and on Everest deleted in its entirety – agreed, not appropriate.

END OF CORRECTIONS

Further changes suggested by my supervisors

Part 1

Abstract

1. In the Abstract: "High-temperature metamorphism of the GHS has resulted in partial melting and melt segregation and ascent to form the High Himalayan Leucogranites, a number of granitic bodies that have accumulated near the top of the GHS." has been added and "resulting in the sillimanite-biotite gneiss adjacent to the leucogranite plutons of the GHS" has been deleted.
2. Section 1.4: "of India with Asia" added
3. Caption to Fig 1.3 re-written as: "*Figure 1.3: One of Tapponnier's plasticine experiments using a flat indenter in an apparatus called the Prandl cell. This rigid indenter, when pressed into layered plasticine as shown in this figure, closely approximates the strike-slip faulting that we see in Tibet and China today. The left hand (western) side of plasticine had resistance kept in place to approximate the Eurasian continent. The right hand (eastern) side had no resistance placed on it to approximate the low resistance that a subduction zone would offer. Hence, the resulting approximation of crustal flow was strikingly similar to the geology of the Tibetan terrane and that of southern China as shown in Figures 1.2, 2.1, 3.29 and 4.4 (after Tapponnier and Peltzer, 1988)*"
4. Caption to Fig 1.4 re-written as: "*Figure 1.4: Convergence of India and Asia was accommodated by crustal flow eastwards (indicated by the arrows) into the Pacific subduction zones, which offered less resistance owing to the thinner crust and pre-existing crustal weakness compared to the thick, stable crust of the Eurasian Craton to the west (after Clark and Royden, 2000). Strike-slip faulting is a consequence of this crustal flow owing to differential flow rates between crustal blocks. The orange area is annotated as being a zone of deep fluids upflow.*"
5. Section 2.2 Tectonic Boundaries re-written as: "they are considered to be a part of a large-scale zone accommodating the strain caused by the collision of India and Asia to form the Himalayas (Searle, et al. 2006)"
6. New page 12: The part in red added to expand on heat sources which are responsible for elevated temperatures during metamorphism as suggested by the examiner in his comments referring to the original page 13 of Part 1. "What this means is that crust from the Indian Plate, which has been forced below the Asian Plate, has been heated to temperatures sufficiently high to cause the plate to melt. The heating of rocks that have been forced to great depths in collisional zones is a common phenomenon (Allegre, et al. 1984). This occurs primarily because of radioactive decay of small amounts of uranium, thorium and potassium within rocks that causes them to heat up. Because rocks have low thermal conductivities, this radiogenic heat escapes more slowly than it is generated when crustal thickening occurs, causing rocks to heat up. The temperature increase that occurs is related to the degree of crustal thickening, the conductivity of the rock, the amount of radioactive material present in the rock, and the time before exhumation occurs (England & Thompson, 1984). Other heat sources may play a role (e.g. magmatic heating, heat from the mantle, shear heating, etc. – Harley, 1989) and the conduction of heat may be enhanced by fluid movement (England & Thompson, 1984), but radiogenic heating of thickened crust remains the primary source of elevated temperatures and regional metamorphism in collisional orogens. Rocks will initially begin to melt above 650 °C, but significant partial melting does not really occur until at least 750-800 °C, depending on the rock type (Vielzeuf and Montel, 1994). The molten material formed at these high temperatures segregates and accumulates to form granites; consequently, granites are common products of collision zones. (Searle et al. 2003)."
7. New page 17: the part in red added to show the relative timing difference of metamorphism in the Siwaliks and the GHS. "They differ both in terms of P-T path, degree of metamorphism (high T, low P in the GHS but low T and high P in the Siwaliks) and timing of the metamorphism (older in the GHS, at 20-24 Ma, and younger in the Siwaliks, at 6-18 Ma – Goscombe et al., 2006). They are bounded to the north by the MCT, and to the south they are thrust over the Sub-Himalayas along the Main Basal Thrust or Main Frontal Thrust (Jessup et al. 2008)."

8. On new page no. 19:The word “brown” added to the term “dark (brown) sillimanite gneisses”
9. All captions have been italicised.
10. On new page no. 19: “with the hangingwall of the STD moving down towards the north at the same time as the hanging walls of the MCT and KT were being thrust to the south (Figure 2.3). This means that although extension is evident in the STD, no net extension occurred across the Himalayan Mountain belt as the environment was purely compressive, and any extension across the STD was less than contractional thrusting across the MCT, MBT and KT. This implies the channel-flow-type mechanism that allowed for the extrusion of rocks between the STD and the MCT.” added to paragraph 2.

11. Figure 2.2 caption re-written as: “*Figure 2.2: The location of the three main faults in Nepal, Bhutan and China. A zone about 30 km wide, bounded by the South Tibetan Detachment (STD) in the north and the Main Central Thrust (MCT) in the south, is referred to as the Greater Himalayan Sequence or High Himalaya. Further to the south from the MCT are the foothills of the Himalayas, the so-called Siwaliks or Lesser Himalaya, which are separated from the Indian lowlands by the Main Frontal Thrust (MFT) and Main Basal Thrust (MBT). The Khumbu Thrust (KT) is located very close to the STD and is not shown in this image, but is shown in Figure 2.3. The base map is an image taken from Google™ Maps.”*

*12. Page 21 last paragraph re-written as: “*The northern limits of the Greater Himalayan Sequence occur immediately south of Mt Everest and the GHS extends to the south past the town of Lukla towards the foothills of the Himalayas (Figure 2.3). It comprises a 10 km thick sequence of crystalline orthogneiss (the Namche migmatites) and sillimanite-biotite gneiss (Jessup et al. 2008). Large- and small-scale recumbent folds (with subhorizontal to shallow northwards-dipping fold axial planes) were observed along the route.”

13. Figure 2.3 caption re-written to: “*Figure 2.3: Geological cross section of the Everest massif, Tibet-Nepal showing the main faults and the detail of the STD which consists of the Qomolongma Detachment (QD) and the Lhotse Detachment (LD) with the Khumbu Thrust (KT) immediately below the LD. (modified after Jessup et al. 2008).*

14. “, lower than those of the GHS, which exceed 700 °C (Searle et al. 2003). Pressure estimates for the Everest Series are more variable,” added to paragraph 1 on page 28.

15. “early collisional thrusting and” added to paragraph 3 on page 28

16. New page 29, third paragraph re-written as: “The P-T path thus involved a prograde pressure and temperature increase followed by a peak-to-retrograde pressure decrease (at or near peak temperatures), and is consistent with a continuously evolving history from burial to exhumation. The D_2 features are related to shearing on the LD/QD, which has been linked to exhumation (Jessup et al. 2008). The switch from D_1 to D_2 is likely the point at which channel flow starts. The P-T-t-D path discussion in Jessup et al 2008 suggests that the M_1 and M_2 (coincident with D_1 and D_2) are related to burial via thrusting and decompression/exhumation, respectively.”

17. New Page 32 second paragraph: “It is likely that the S1 fabric formed during burial or at high pressures, however this has not been confirmed.” Added

18. New Page 32, 4th paragraph: “or a lack of retrograde fluids owing to the high-temperatures reached in the Greater Himalayan Sequence.” Added at the end of the paragraph.

19. New Page 34, first paragraph: “A general model for orogens would place the highest-grade rocks centrally in the orogen on the basis that the greatest thickening led to highest grades of metamorphism at depth, and the greatest subsequent exhumation (REFERENCE). In the Himalayas, however, although the grade varies laterally (from low-grade in the Siwaliks, to high-grade in the GHS, and back to lower grades in the Everest Series, the orientation of structures and the relationships

between these high-grade zones means that the metamorphic grade also varies considerably vertically, with temperatures decreasing both upwards and downwards from the higher-grade GHS. This unique vertical zonation in metamorphic grade is one of the key geological factors that has given rise to the Channel Flow model." re-written.

20. New page 35: "i.e. the contrasting shear direction, top-to-north, normal dip-slip faulting in the north (juxtaposing the GHS and the Everest Series) vs. top-to-south thrusting in the south (juxtaposing the GHS and Siwaliks) and the nature of the shearing (extension in the north vs. thrusting in the south)." Re-written.

21. New page 35: "(Figures 2.3 and 2.7)," added.

22. New page 41, paragraph 2: "where it was trapped and prevented from further upward migration by the South Tibetan Detachment (STD)" added.

23. New page 43: abbreviations to muscovite, quartz, biotite, K-feldspar, plagioclase, tourmaline have been written out in full. And also source referenced: "*the orogenic front (modified after Searle et al., 1997)."*

24. New page 43, paragraph 2: "Field relations, geochemistry and isotopic studies show that the leucogranites are sourced from the high-grade metasedimentary gneisses of the GHS, and occurred during the latest stages of metamorphism (Searle et al., 1997). From here the melt moved upwards along structurally weak zones, forming the plutons found in many parts of the Himalaya. Deformed leucogranites containing sillimanite along shear fabrics confirm that the leucogranites were emplaced syn-tectonically during D2, and were likely emplaced into sillimanite-grade rocks already at high temperature, and were emplaced before final movement along the STD, as no leucogranites have been intruded along the STD (Searle et al., 1997)." Added and re-written.

25. New page 45: "Early estimates of the age of leucogranites of the Everest region suggested it is early to middle Miocene, 20 to 10 Ma (Heim and Gansser, 1939, Gansser 1964), which has been confirmed by recent studies of granites that show that earlier biotite granites were emplaced at ~20Ma, and that younger tourmaline-muscovite granite formed at 17 Ma (Searle et al., 1997)." Re-written.

26. New page 45: "Over the years several different models for the extrusion of high-grade gneisses and leucogranites from the mid-crust to the surface have been put forward. These include: The channel flow model (Nelson et al. 1996)," re-written.

27. New page 45: "the Channel Flow model has been widely accepted as explaining the principal geological features across the Himalayas, and the other models are not discussed in detail here, although they may be locally applicable." Added.

28. New page 49: 'Associated microstructures indicate that flow occurred at close to peak metamorphic conditions (Jessup et al. 2006)." Added

29. New page 51: "The state of equilibrium of the Earth's crust (known as isostasy) elevates landmasses and balances them with gravitational force that commonly depresses landmasses. Once crustal thickening and uplift have taken place, isostatic equilibrium is re-established through erosion (and exhumation of the mid-crust). The difference between uplift and exhumation is that uplift is the result of gravitational balance, whereas exhumation is associated with tectonic processes (in this case, channel flow), often assisted by erosion. Exhumation can also occur through tectonic processes such as thinning of the crust along extensional faults, or even by ductile flow." Re-written.

30. New page 52, paragraph 3: 'Exhumation is often assisted by erosion, and" added.

31. New page 56: 'and the lateral extent of the India-Asia collision zone." Added.

32. New pages 61, 62 and 64: added in to captions of Figures 3.1, 3.2 and 3.3: “Length of walking pole handle quoted as being 14 cm in length.”

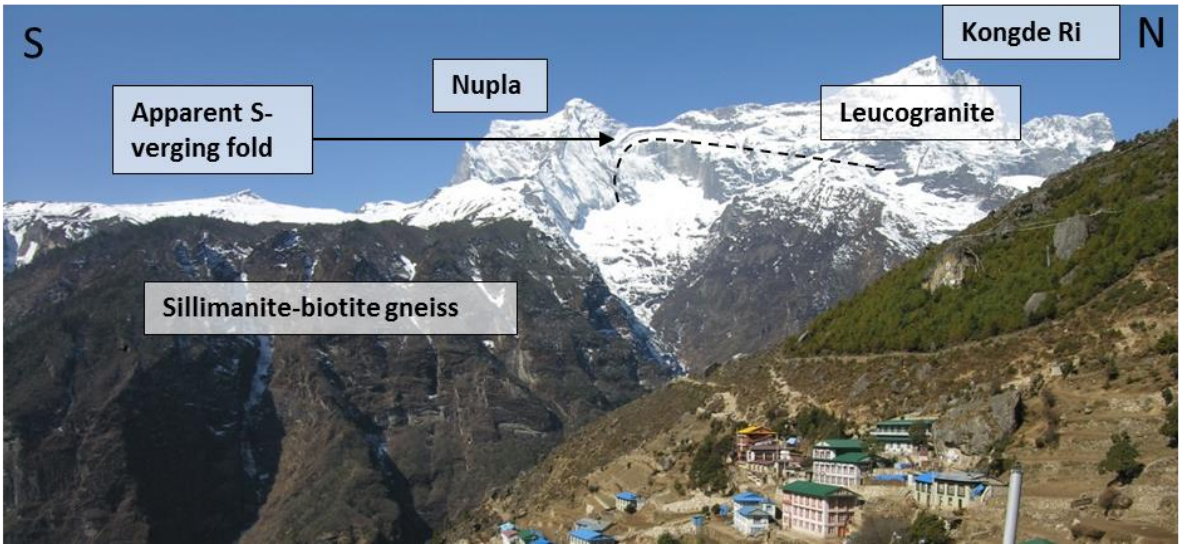
33. New page 62: “Migmatites are folded by F2 folds (Figure 3.2), and in places, display a stromatic nature, suggesting that D2 deformation continued whilst migmatisation was taking place.” Added and moved.

34. New page 63: “It has been suggested that the thick zone of partial melting in the Namche migmatites could have produced enough volume of magma to generate the large 2000 m to 3000 m thick plutons found near the top of the GHS (Searle et al. 2003).” Added.

35. New page 63, end of paragraph 2: “The emplacement of this granite into plutons on the west shoulder of Everest and the top of the Nuptse is seen in later stops.” Added.

36. New page 64: “Here, a south-verging recumbent fold lies on a thrust plane, which could be the southwards extension of the Khumbu Thrust, exposed near Everest. This fold may be the result of a fold-thrust association. The Namche migmatites occur throughout the granite gneiss, as well as in the sillimanite gneiss, which is capped by the KT and the leucogranite layer.” Re-written.

37. Found original photograph (on new page 65) and replaced the old (poor quality) one with new labels:”



38. New page 67: “The counter clockwise P-T-D-t history of the GHS (see Figure 2.8), of which the sillimanite-bearing gneiss is part shows that this rock has experienced burial of the original pelitic rocks, and heating to granulite facies. Decompression (exhumation) to upper amphibolite facies then saw the growth of cordierite and sillimanite in the surrounding gneiss. The fabric evident in the sample in Figure 3.5 is that resulting from D_2 deformation during exhumation. It is possible that the initial burial reached depths of >45 km or 14 kbar, i.e. reaching eclogite facies (Lombardo & Rolfo, 2000). Decompression and metamorphism then occurred with the growth of Hbl, Opx, Pl, and Bt coronas on Grt, with Cpx and Pl symplectites replacing Omph. Further decompression (exhumation) to upper amphibolite facies then saw the growth of cordierite and sillimanite in the surrounding gneiss (Figure 3.6).” added and modified.

39. Also on new page 67: Some plagioclase feldspar, k-feldspar and muscovite is also present. Sillimanite, a light fibrous mineral in polarized light (xp), is characteristic of high metamorphic grades above 500 °C (Yardley, 1989).

40. New page 70: "The summit of Ama Dablam is composed of sheeted dykes of pegmatite, above the thick leucogranite sheet that makes up the Ama Dablam massif, suggesting that hydraulic fracturing and emplacement of granites along a network of sills and dykes was followed by later emplacement of voluminous to form the larger the granite plutons and sheets of the Higher Himalayan Leucogranites (Searle et al. 1997). The two granites differ in terms of both grain size and mineralogy, with later intrusions observed in outcrops on Ama Dablam and at Base Camp having tourmaline suggesting that these pegmatites could represent late-stage incompatible-rich fractionates." Re-written.

41. Also on new page 70: relative proportions added. The rock is made up mostly of quartz (~20%), plagioclase (~25%) feldspar, and k-feldspar (~20%). Very minor amounts of biotite (~1%) are found, but large amounts of pale muscovite mica (~30%) and dark tourmaline (~5%) occur in the hand specimen of the sample in Figure 3.8.

42. New page 71: Added reference: "late-stage incompatible-rich fractionates (Searle et al. 1997, Searle et al. 2003)."

43. New page 76: "The west shoulder of Everest, similarly, comprises a large pluton of leucogranite and pegmatite, overlain by a network of leucogranite and pegmatite sills and dykes." Added.

44. New page 77: "this likely represents a dyke of tourmaline granite migrating upwards from the migmatites of the GHS to the zone of leucogranite plutons found near the top of the GHS. " added.

45. New page 78, first paragraph: "which appears to have been slightly folded (Searle, 1999). This may give the impression that leucogranite sills themselves have been folded. The folding of the layering (and possibly the leucogranite sills) is suggested to be related to shearing on the KT, which crops out near the base of Nuptse (Searle, 1999)." Added.

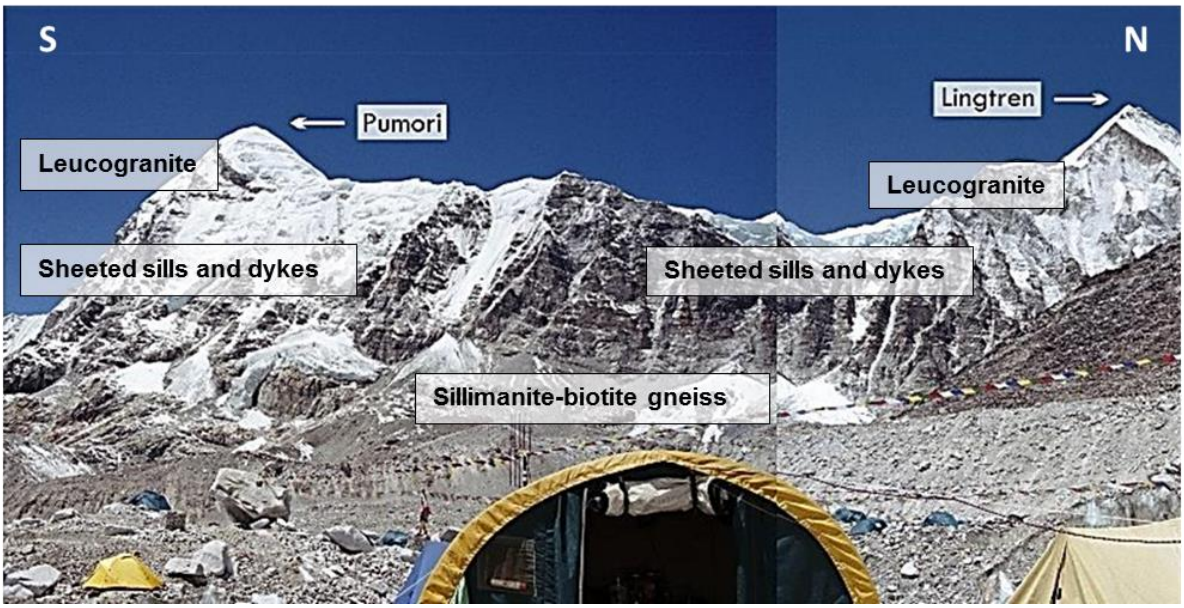
46. New page 79, second paragraph: ", with differing grain sizes and textures" added to first line.

47. Caption to Figure 3.14. Page 79: "*Figure 3.14: (**A**) Fine-grained aplite dyke intruding a two-mica granite. (**B**) Granite intruding sillimanite-biotite gneiss and an earlier generation of granite in moraine rock from Base Camp. Note the mylonitic zone seen near the bottom left of the photograph, indicating that granites have experienced shearing post-emplacement. GPS co-ordinates 28°0'6.58"N, 86°51'49.03"E" re-written.*

48. New page 81, first paragraph, modal proportions of the sample of protomylonite added, viz: "The rock is very pale white and contains few mafic minerals (such as biotite). It is composed of quartz (~30%), K-feldspar (~30%) and plagioclase feldspar (~30%), with minor muscovite mica. The muscovite micas in this fine- to medium-grained rock are aligned to form fabric (Figure 3.16)."

49. New page 82, second line in paragraph 2: added "with numerous leucogranite sills underlies the thick leucogranite pluton"

50. Also on new page 82, labels added to photograph:



51. New page 85: “Partial melting (migmatisation) of the GHS took place between 25 and 22 Ma (Viskupic & Hodges (2001), and these melts segregated from the migmatites and ascended to the top of the GHS to form the leucogranites that we see on surface today.” Re-written.

52. New page 87: An event that caused a disturbance, like a rock falling, a serac collapse or an avalanche was measured by the author to be on average about six seconds apart. This was done by listening and counting the seconds between events whilst lying in my tent at base camp mainly in the evenings after supper.

53. New page 94: “QD (samples of glacial moraine examined by Jessup et al. 2008” added to paragraph 1 line 9.

54. New Page 104: “The Namche migmatites are the product of deep burial and melting of muscovite and biotite-bearing rocks, at temperatures of up to 837 ± 59 °C and pressures of 6.7±1.0 kbar (Goscombe & Hand 2000 Searle et al. 2003),” has been re-written with Goscombe & Hand Ref added.

55. New Page 105: “Temperatures in the GHS during migmatisation are estimated to be above 700 C, and although there is a zoning of temperatures across the GHS (Goscombe et al. 2006), temperatures remain roughly isothermal between 620 and 730 °C across about 50 km horizontal distance from the top of the MCT zone to the STD, with pressures varying between 4 and 8 kbar (Searle et al., 2003). Temperatures of up to have been recorded in the GHS (Goscombe & Hand 2000). In contrast, Everest Series rocks just above the STD experienced” added

56. Also on new page 105: “and other granite plutons” deleted.

57. New Page 106: “The geological processes described in Section 1, involving the extrusion/exhumation of a mid-crustal channel, reach their uppermost limit in features seen around Base Camp. The leucogranite massif of Lingtren/Pumori, and the Nuptse granite and other granite plutons, together with their stockwork of sheeted dykes and sills, are the result of a magma intrusion originating from accumulated leucosomes which were generated in the underlying migmatites.” Added.

58. New page 106: “South-verging folds are clearly visibly on the face of Lhotse in the Western Cwm (Figure 3.19). Although their proximity to the LD suggest that they may be associated with the movement along the LD, their vergence is consistent with top-to-the-north movement the LD. A south–verging recumbent fold in leucogranites on the south face of Nuptse (Fig. 4.2) has been linked to thrusting on the KT (Searle 1999a). It may be that folds in the Rongbuk Formation are also related

to movement on the KT, or these could be an earlier generation of folds related to crustal thickening north of the STD, but south of the Indus suture zone (Searle 1999a)" re-written.

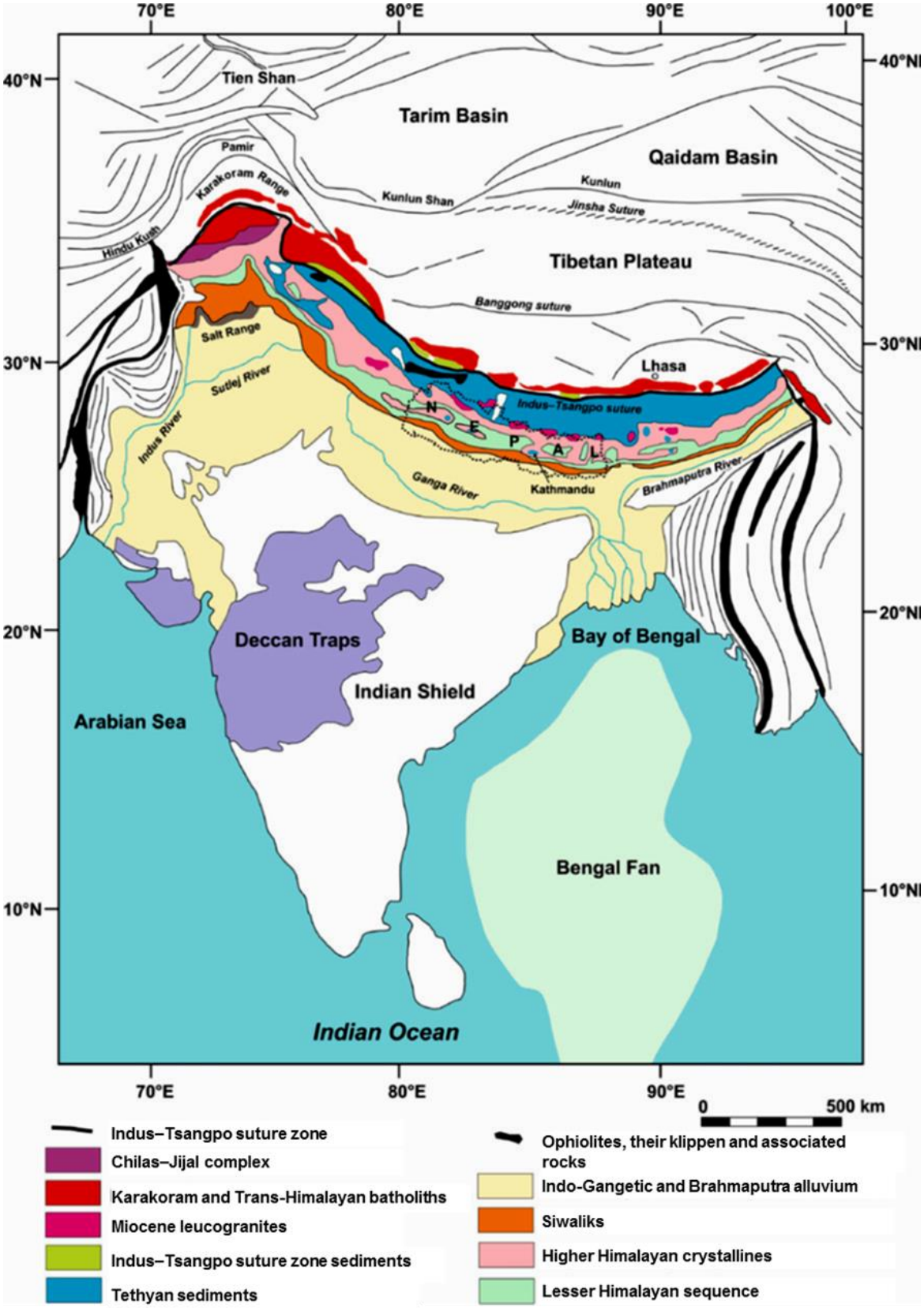
59. Labels added on Figures 3.17 and 3.18

60. New page 77: "The location of where this sample was taken is in the foreground of the photograph shown in Figure 3.12. " added on new page 78

61. Reworded the following: "4.1 Higher Himalayan Granite Gneiss, and the Namche migmatites. The granite gneiss of the Greater Himalayan Sequence (GHS), observed in the early part of the traverse from Lukla towards Everest, represents a granitic protolith that was subducted below the Asian continent during collision, and subsequently exhumed through crustal flow from below Tibet to its present position (Klemperer, 2006). Peak burial metamorphism occurred at c. 32 Ma during the Oligocene, for a period of 14 million years, until c. 17 Ma(Simpson et al. 2000, During this time, sillimanite ± cordierite metamorphism was occurring across the Greater Himalayan Slab at pressures of 4-5 kbar and depths of 13 – 17 km (Simpson et al. 2000). The High Himalayan crystalline granite gneiss also shows numerous south-verging recumbent folds, often bound by abundant mylonite (implying faults) above and below the folds (personal observation). The vergence of these folds (to the south) indicates that they are linked to channel flow type extrusion and exhumation with associated southwards thrusting. "

62. Corrected spelling mistakes (highlighted in yellow) in the caption of Dhital's Figure 3.32 as shown below.

63. New page 111: Referenced authors for channel flow: " (Beaumont et al. 2006; Brown and Gibson, 2006; Godin et al. 2006; Grujic, 2006; Hodges 2006; Jessup et al. 2006; Law et al. 2006; Scaillet and Searle, 2006; Searle et al. 2006). "


70°E
80°E
90°E
100°E
40°N
30°N
20°N
10°N
Tien Shan
Tarim Basin
Qaidam Basin
Pamir
Karakoram Range
Kunlun Shan
Kunlun
Jinsha Suture
Hindu Kush
Tibetan Plateau
Banggong suture
Salt Range
Sutlej River
Lhasa
Indus–Tsangpo suture
Indus River
N
E
P
A
L
Ganga River
Kathmandu
Brahmaputra River
Deccan Traps
Bay of Bengal
Indian Shield
Arabian Sea
Bengal Fan
Indian Ocean
0
500 km
Indus–Tsangpo suture zone
Chilas–Jijal complex
Karakoram and Trans-Himalayan batholiths
Miocene leucogranites
Indus–Tsangpo suture zone sediments
Tethyan sediments
Ophiolites, their klippen and associated rocks
Indo-Gangetic and Brahmaputra alluvium
Siwaliks
Higher Himalayan crystallines
Lesser Himalayan sequence

Part 2 Additions

As suggested by my supervisors

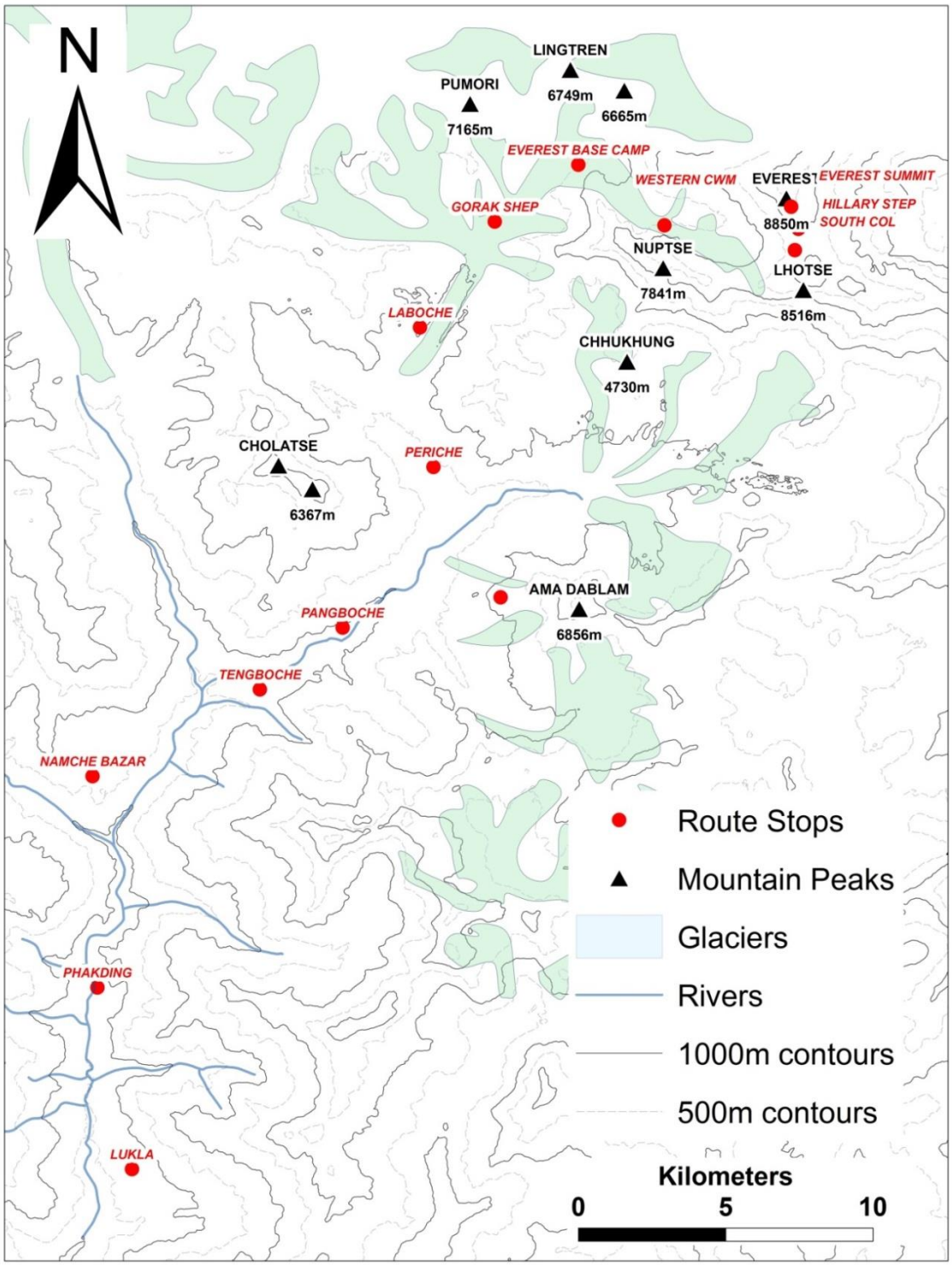
1. The Maps, the photomicrographs and the Figures and photos changed in Part 1 were also changed in Part2.
2. New page 9: Bold part in Table 1: Theme changed to non-bold.
3. New page 26: South Verging "fault" changed to "Fold" in Glossary.
4. New page 36: Start of each point capitalised.
5. New page 51 and 52: Figures 2.2 and 2.3: Added in to caption: Length of walking pole handle quoted as being 14 cm in length.
6. New page 61: Figure 4.2: Added in to caption: Length of walking pole handle quoted as being 14 cm in length.
7. New page 96: Pink blob explained in caption: "*Figure 10.8: Earthquake epicentres and their magnitude between 1900 and 2014. The pink area is a zone where most aftershocks occur. This is the zone where the South Tibetan Detachment (STD) and the Main Frontal Thrust (MFT) are closest together, and hence the area of most seismic activity. "*
8. New page 97: Caption re-written as follows: "*Figure 10.9: Map showing lift and drop associated with the earthquake of 25th April, 2015 with epicentre west-north-west of Kathmandu"*
10. New page 119: Original text: "I hope the reader has enjoyed this guidebook and that it has increased his/her understanding of the processes involved in the formation of the Himalayas, the highest mountains on Earth."

    Replaced with: "This guidebook has been produced with the aim of assisting the reader's understanding of the processes involved in the formation of the Himalayas, the highest mountains on Earth."

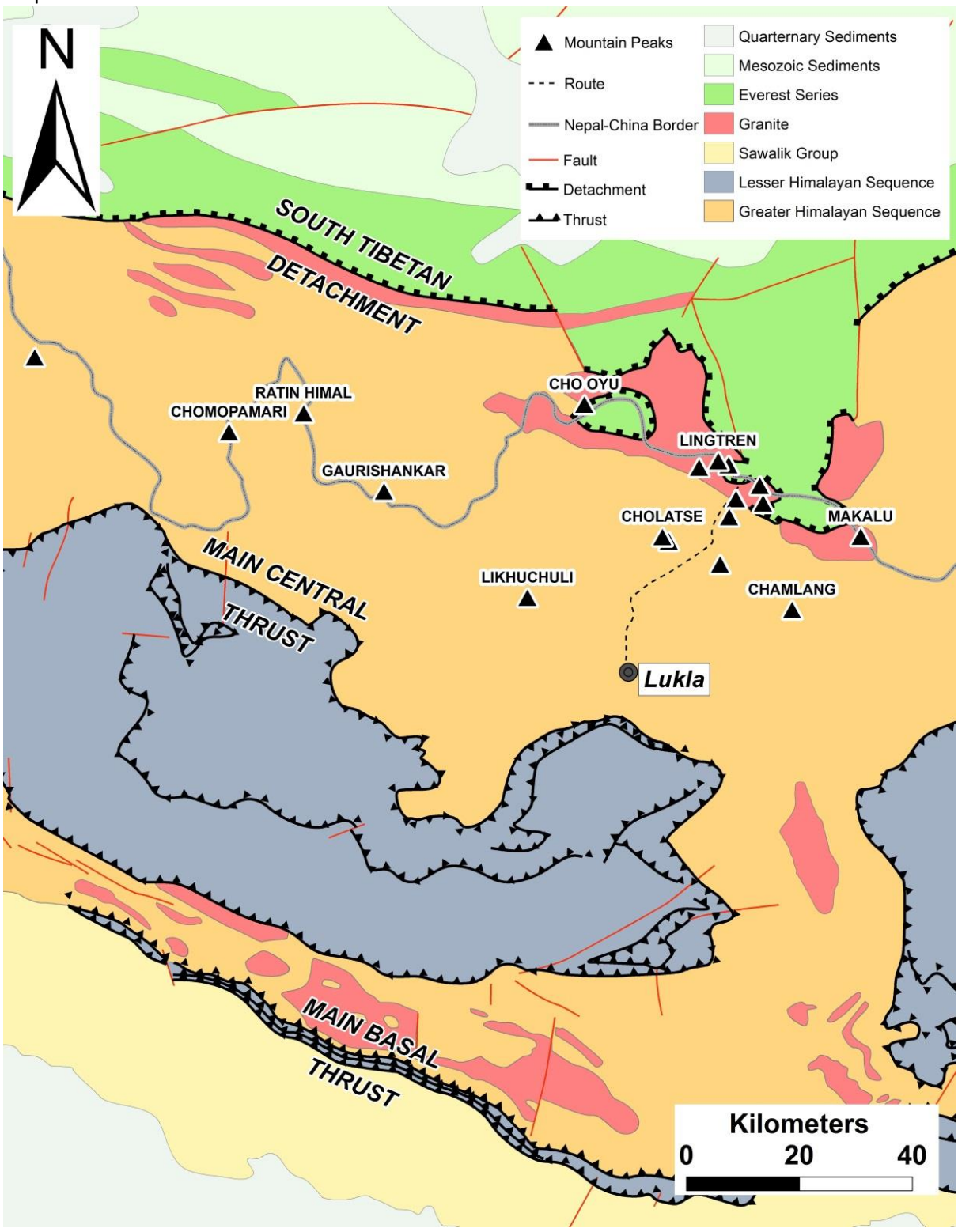
Re-draughting of Maps

Maps 1 to 4 re-drawn

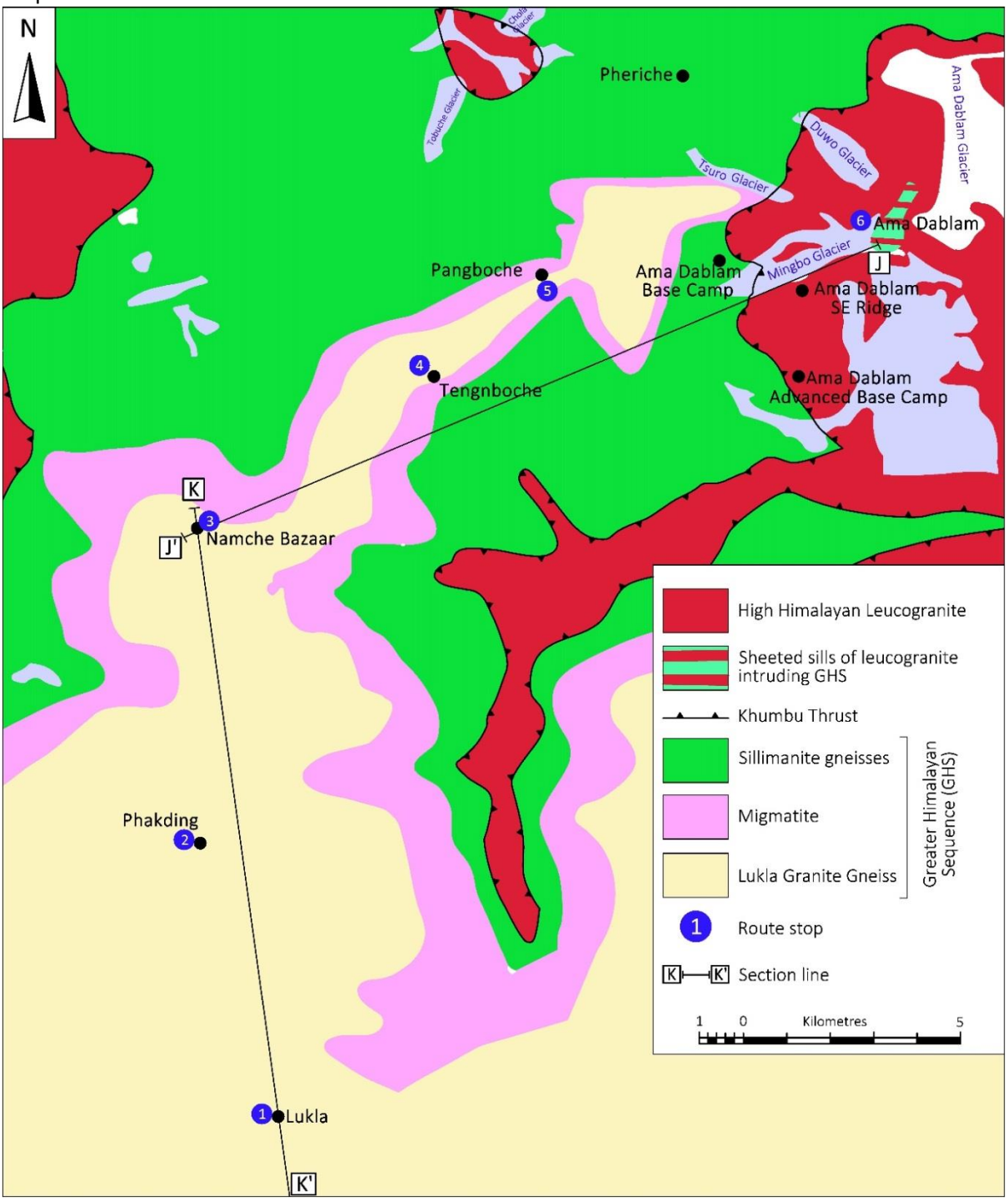
Map 1



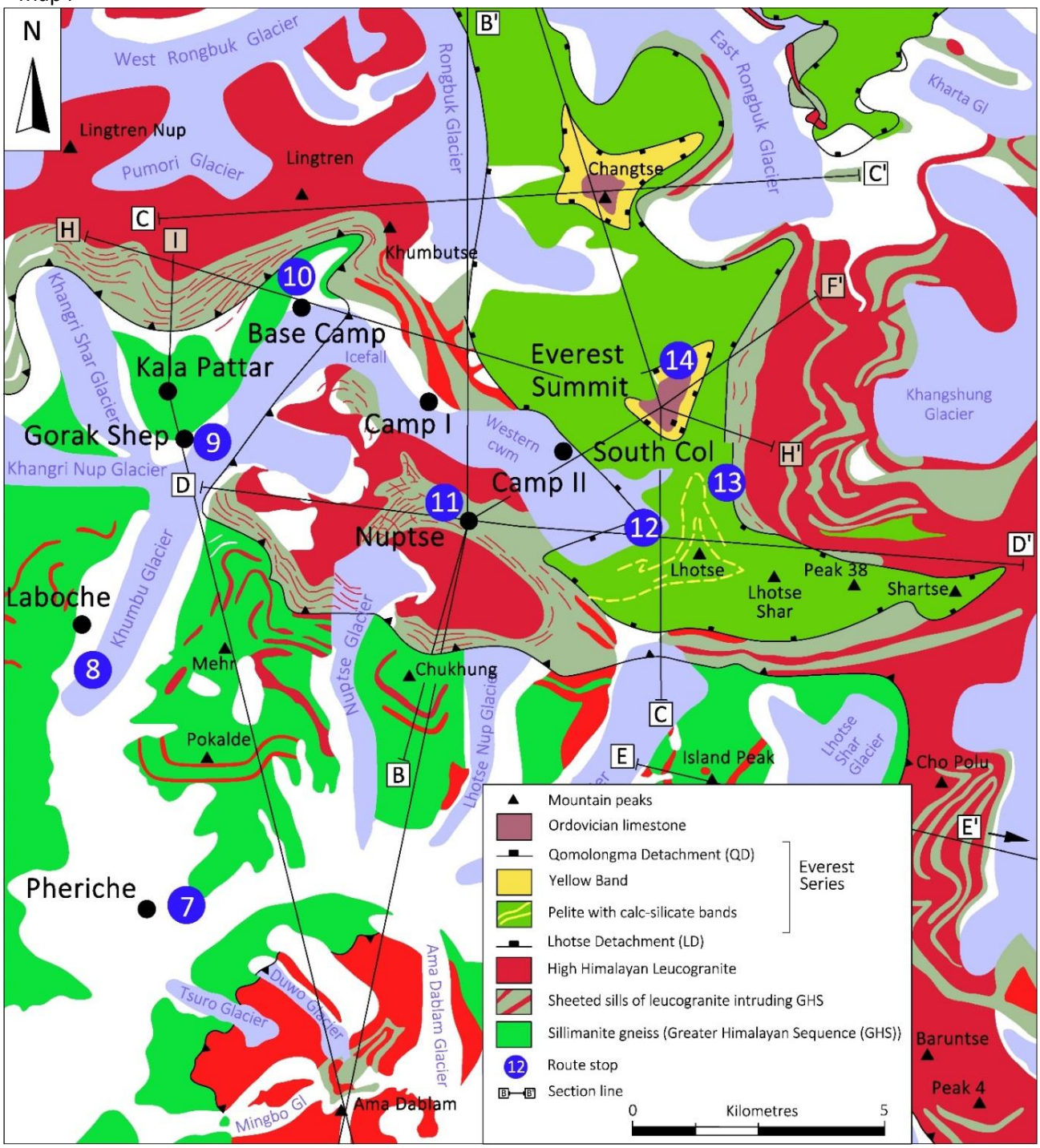
Map 2


N
Mountain Peaks
Route
Nepal-China Border
Fault
Detachment
Thrust
Quarternary Sediments
Mesozoic Sediments
Everest Series
Granite
Sawalik Group
Lesser Himalayan Sequence
Greater Himalayan Sequence
SOUTH TIBETAN DETACHMENT
RATIN HIMAL
CHOMOPAMARI
GAURISHANKAR
CHO OYU
LINGTREN
CHOLATSE
MAKALU
LIKHUCHULI
CHAMLANG
MAIN CENTRAL THRUST
Lukla
MAIN BASAL THRUST
Kilometers
0
20
40

Map3


N
Pheriche
Tobuche Glacier
Cholatse Glacier
Ama Dablam Glacier
Duwo Glacier
Tsuro Glacier
Mingbo Glacier
6 Ama Dablam
J
Ama Dablam Base Camp
Ama Dablam SE Ridge
Pangboche
5
4 Tengnboche
Ama Dablam Advanced Base Camp
K
3 Namche Bazaar
J'
Phakding
2
1 Lukla
K'
High Himalayan Leucogranite
Sheeted sills of leucogranite intruding GHS
Khumbu Thrust
Sillimanite gneisses
Migmatite
Lukla Granite Gneiss
Greater Himalayan Sequence (GHS)
1 Route stop
K K' Section line
1 0 Kilometres 5

Map4


N
West Rongbuk Glacier
Rongbuk Glacier
East Rongbuk Glacier
Kharta Gl
Lingtren Nup
Pumori Glacier
Lingtren
Changtse
Khumbutse
Base Camp
Icefall
Kala Pattar
Everest Summit
Khangri Shar Glacier
Gorak Shep
Camp I
Western cwm
South Col
Khangshung Glacier
Khangri Nup Glacier
Camp II
Nuptse
Lhotse
Peak 38
Lhotse Shar
Shartse
Laboche
Khumbu Glacier
Nuptse Glacier
Chukhung
Mehr
Pokalde
Lhotse Nup Glacier
Island Peak
Lhotse Shar Glacier
Cho Polu
Pheriche
Tsuro Glacier
Duwo Glacier
Ama Dablam Glacier
Ama Dablam
Mingbo Gl
Baruntse
Peak 4
Mountain peaks
Ordovician limestone
Qomolongma Detachment (QD)
Yellow Band
Pelite with calc-silicate bands
Everest Series
Lhotse Detachment (LD)
High Himalayan Leucogranite
Sheeted sills of leucogranite intruding GHS
Sillimanite gneiss (Greater Himalayan Sequence (GHS))
Route stop
Section line
0
Kilometres
5

END OF ADDITIONS AND RE-WRITTEN TEXT AS SUGGESTED BY MY SUPERVISORS