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Environmental Analysis of Modern Speleothems from Sterkfontein Caves and its' Implications for Reconstructing Palaeoenvironments

MSc Thesis – List of Corrections

Claudia Venter 1259745

List of corrections

1. Examiner’s comment: Insert Candidate's Name

   Title page: My name was added.

2. Examiner’s comment: Generally accepted format after title page is: Declaration, Acknowledgments, Abstract, Table of contents.

   These are not part of the actual thesis text and should be number differently from the text e.g. i, ii...iv..x.

   General thesis: page numbers were adjusted accordingly.

3. Examiner’s comment: The breakdown of Chapter section and subsections should follow, for example:

   Chapter 1: Introduction

   1.1. Introduction

   1.2. Rationale and Research

   1.3. Significance of Research and Aims

   1.4. Dissertation Structure

   Chapter 2: Background

   2.1. Introduction

   2.2. Geology and Stratigraphy

      2.2.1 General Geology and Stratigraphy

      2.2.2 Dating of Cave Stratigraphy

      2.2.3 Speleothems

      2.2.4 Cave Formation

   General examiner’s comment: Where you are pointing the reader to a figure or Appendix in the thesis, avoid typing the word "see". For example (see Figure 2.1) should simply be (Figure 2.1).

General thesis corrections: the ‘see’ before figure numbers in text was removed throughout the thesis. Chapter, section and sub-section numbering was changed accordingly.

4. Examiner’s comment: Appendices are generally not referred as Chapters.

   Page III: Appendices were not listed as a separate chapter.

5. Examiner’s comment: The aim becomes confusing when the focus on variations in aridity and seasonality appear. It distracts from what is presented as the main aim which is to determine whether speleothems can be used as palaeoenvironmental proxies.

   Page 3: The aims with regards to variations in aridity and seasonality has been removed.

6. Examiner’s comment: Delete fossils, stone tools cannot be fossils.

   Page 7: ‘fossils’ was removed.

7. Examiner’s comment: in addition to other non-hominid fauna

   Page 10: ‘in addition to other non-hominid fauna’ was added.

8. Examiner’s comment: Kibii, 2000;

   Page 10: The reference Kibii (2000) was added.

9. Examiner’s comment: Kibii & Clarke 2003; Kibii, 2004; Kibii et al. 2011

   Page 10: The references ‘Kibii & Clarke 2003; Kibii, 2004; Kibii et al. 2011’ were added.

10. Examiner’s comment: Various cave systems are not dated, rather features within the caves have been dated.

    Page 13: Included a phrase stating that features within the cave systems were dated.

11. Examiner’s comment: along

    Page 15: ‘allow’ was changed to ‘along’.

12. Examiner’s comment: (Kibii, 2004; Reynolds & Kibii, 2011)

    Page 20: The references ‘Kibii, 2004; Reynolds & Kibii, 2011’ were added.

13. Examiner’s comment: Bobe & Behrensmeyer is 2004 not 2006

Page 27: Bobe & Behrensmeyer (2004) reference adjusted.

14. Examiner's comment: A large part of the literature review is taken from Pickering, 2004 – which is an unpublished MSc thesis. Therefore credit for the work cited is given to Pickering, not the original author – and this is unacceptable. The appropriate references need to be cited.

Chapter 2 in general: Pickering (2004) references changed, with appropriate original references added instead.

15. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page 34: 'Overall fractionation of oxygen isotopes in drip water may be related to mass differences of the respective isotopes, where heavier isotopes such as ^{18}O move and react much slower compared to ^{16}O, which has a lighter mass (Noah, 2010). This is referred to as isotopic equilibrium fractionation and generally occurs between two different phases of a particular compound, $CaCO_3$ (Harmon et al., 2004). In this regard, ^{18}O would be more enriched in speleothem carbonate than in drip water CO_2 (White, 2004). Oxygen isotopes are affected by two types of fractionation, namely equilibrium fractionation and kinetic fractionation.' removed from the Discussion section and added to Chapter 2 (Background), page 34.

Page 35: 'as cooling results in more negative, depleted oxygen isotope values and therefore lower temperatures' removed from Chapter 5 (Discussion), and add to Chapter 2 (Background), page 35.

Page 35-36: The temperature differences between the cave interior and exterior environment may result in corresponding pressure changes in the cave system, resulting in the movement of air from cave entrances to the cave roof (Noah, 2010). This movement of air may result in changes in the temperatures produced from $\delta^{18}O$ values of speleothems and drip water, and changes in humidity, which also affects the $\delta^{18}O$ values produced (Wigley & Brown, 1976).

The amount of precipitation (Gascoyne 1992; Sundqvist et al., 2007) and the atmospheric air temperatures (van Beynen & Febbroriello, 2006; Sundqvist et al., 2007) also contribute to fractionation effects with regards to $\delta^{18}O$ signatures, and are related to Rayleigh distillation, which takes place during the course of the hydrological cycle, and within the cave system (Noah, 2010). With regards to the cave system, Rayleigh distillation may be responsible for kinetic fractionation of oxygen isotopes, which takes place during the removal of CO_2 and calcite of varying isotopic signatures from the drip water solution (Wynn et al., 2005). The removal of gaseous CO_2 from the drip water solution usually takes place at a constant rate in order to preserve calcite supersaturation; however this results in the enrichment of ^{18}O in the drip water solution (Hendy, 1971; Noah, 2010). This may therefore result in abnormally enriched $\delta^{18}O$ values within drip water solutions. With regards to the hydrological cycle, fractionation caused by Rayleigh distillation usually occurs during the evaporation or condensation of water (Fairchild et al., 2006), and the effects thereof are usually determined by the amount of precipitation, leading to a gradual depletion of ^{18}O isotopes during heavy rainfall events (White, 2004; Noah, 2010).' Removed from Chapter 5 (Discussion) and added to Chapter 2 (Background), pages 35-36.

16. Examiner's comment: delete "hand"

    Page 44: 'hand' was deleted from 'hand sample'.

17. Examiner's comment: areas and the...

    Page 45: added 'and the'.

18. Examiner's comment: deleted 'hand' and 'fresh'

    Page 46: deleted 'hand' and 'fresh'.

19. Examiner's comment: What is the difference between 'clean C' and 'fresh C'? And is the elevation above sea level?

    Page 48: Fresh calcite refers to newly precipitated speleothems/calcite. Clean calcite refers to calcite without any dirt/impurities. Metres changed to masl (metres above sea level).

20. Examiner's comment: What is the relevance of these dates? Were the samples collected each day?

    Page 49: The relevance of the dates and months listed was explained.

21. Examiner's comment: It is not clear how measuring the humidity etc. would establish the conditions under which the speleothems and drip water formed? This needs to be explained fully.

    Page 49: I feel this concept is explained in paragraph 2 of page 49 – 'In order for palaeoenvironmental analyses to be accurate with regards to both drip water and speleothem stable light isotope proxies, the conditions under which the speleothem originally formed must be determined (Hendy, 1971; Ouelette, 2013)…….. These conditions are usually met in environments like the back of very deep caves, where humidity values are high and air flow is reduced (Pickering, 2004). Measuring the humidity, air temperature, air pressure and dew point temperature for both the drip water and speleothem samples would allow for the conditions under which the speleothems and drip water formed to be established.'

22. Examiner's comment: In the methodology, it should then be indicated whether the drip samples were collected when there were tourists or if any control samples were taken during and off tourist visits.
    Page 49: A brief description of the location of the cave chambers with respect to the tourist path, and the potential effects thereof were added.

23. Examiner's comment: replace measured with "recorded".

    Page 50: 'recorded' was added.

24. Examiner's comment: delete 'speleothem sample'

    Page 50: 'speleothem sample' deleted.

25. Examiner's comment: The vegetation survey is very brief and confusing – this needs to be rewritten.

    Page 51: The description of the vegetation survey was amended – 'This was completed by noting down the different plant species and whether they were C_3 or C_4 or CAM plants, as well as the percentage coverage of this vegetation over the environment above the cave system.'

26. Examiner's comment: add 'into'. Replace 'weighed twice' with 'divided in two'.

    Page 51: 'into' and 'divided in two' were added.

27. Examiner's comment: Some photographs or sketch diagrams of the preparation for speleothem analyses would be useful, as the technical details are hard to follow without some visual guide.

    Page 52: A figure (Figure 3.2) was added showing the sample vial and double needle set up.

28. Examiner's comment: Explain why flushing the sample vials with helium was necessary.

    Page 52: Flushing with helium was explained.

29. Examiner's comment: any reason why the first run did not reproduce well?

    Page 52: no reason was given for needing to run the measurements twice.

30. Examiner's comment: Craig (1965) is not in the reference list.

    Page 55: Added Craig (1965) to the reference list.

31. Examiner's comment: delete 'is'

    Page 58: 'is' was removed.

32. Examiner's comment: Hammer et al. (2006) is not in the reference list.

    Page 58-59: Hammer et al. (2006) was supposed to be Hammer et al. (2001) – this was changed.

33. Examiner's comment: The equations are presented without an adequate explanation of each of the variables.

    Page 60: An explanation of the equation variables is included.

34. Examiner's comment: Last paragraph makes no sense. The atmosphere in the cave can, by the nature of cave environments, be different to the atmosphere outside the cave. You have to make the argument that they are comparable.

    Page 61: Further argument with regard to the comparison between the atmosphere in the cave and outside the cave system was added - 'The temperature data produced

was compared to the measured atmospheric temperatures in order to determine the correlation of variations between the two data sets. This allowed for the variations between the two data sets to be accounted for, as temperatures calculated from the $\delta^{18}O$ values of the drip water include a range of temperatures which should resemble the variations of the mean annual temperature on the surface (Nordhoff, 2005; Mandice et al., 2013). This comparison also allowed for an analysis of the level of seasonality within the two data sets, as well as the level of openness of the cave system. The extent of the effects of the exterior temperatures to the measured cave air temperatures, speleothem precipitation, and hydrochemistry within the cave system was also analysed using the comparison between the calculated temperatures and the measured atmospheric temperatures.

35. Examiner's comment: 'they may be limited by' – meaning?

    Page 62: The limitations of the weather station data was explained briefly.

36. Examiner's comment: It is not immediately clear what analyses the candidate did and what was sent to a lab and the data received. At this point the candidate is required to do some of the analytical work herself, and this should be reported.

    Chapter 3: It was made clear in the first introductory paragraph which analyses I personally performed, what samples were sent to which laboratories, and the results obtained.

37. Examiner's comment: Again credit is given to Pickering, 2004 for work done by other authors – this is sloppy and the correct authors need to be referenced.

    Chapter 4: All Pickering (2004) references were removed and replaced with the original references.

38. Examiner's comment: The x-axis of the graphs 4.1 and 4.2 makes no sense. 2011 to 2016 is not a monthly period. The graph is of no value as it stands. And therefore the text makes no sense as the yearly data is reported but the individual years and the scale are not shown.

    Page 67: The axis was adjusted – Time (Months from January …… - December 2016).

39. Examiner's comment: Conclusions are drawn without an adequate argument or explanation. This section should be moved to the discussion and expanded on.

    Page 67: The effects of the distance between the weather stations and the Sterkfontein

Caves system was expanded on in the discussion section (see page 136-137 in Chapter 5).

40. Examiner's comment: The tables in Appendix B should be moved into the text as these are results not supplementary material.

    Page 69: I feel that these statistical tables would just clutter the chapter-essential values which relate to the graphs have been given, the tables are more supplementary and therefore have been placed in Appendix B. I would rather the emphasis be on the graphs, rather than 8 pages of statistical tables.

41. Examiner's comment: Comment as above. Move relevant Appendix C data into text.

    Page 74: Again, I would rather not do this as it would clutter the chapter too much. I can put the table for the speleothems, but not for the drip water - there are 8 pages of tables for drip water! This seems excessive to put into a thesis, and therefore has been placed in Appendix C.

42. Examiner's comment: Section 5.4 doesn't exist.

    Page 76-77: Section number changed to 3.6.3

43. Examiner's comment: Various line graphs – a line graph is not appropriate if the data points on the x-axis have no relationship. In this instance the line graph indicates a change in carbon isotopes from one cave sample to another. But the samples are taken from different places in the cave, unrelated to each other. This occurs throughout the thesis and needs correction.

    Page 80 (and all subsequent pages with line graphs: pages 88 – 98, 104, 107): These line graphs are all actually scatter plots with the points joined. I removed the lines in the relevant graphs, and added polynomial trend lines instead. This was also done for other relevant graphs.

44. Examiner's comment: Chapter 3, section 6.1.

    Page 81: Section number changed to 3.6.1

45. Examiner's comment: Here data sets were correlated using the Pearson product-moment and the r and p-values determined. Data are dismissed based on a poor correlation, or a p-value not within a 90% confidence level. I think this is handled a bit simplistically.

    Page 86-107: The statistical data was briefly discussed with regards to accurate or inaccurate correlations apart from a high p value.

46. Examiner's comment: When you are in a cave temperatures are, sometimes significantly, different from outside. Often the cave is a closed system with no through-flow of air. Therefore, it may be self-evident to assume that there would be very little correlation between the 2 data sets. So this part of the project seems to be an attempt to prove the obvious? If not then you need to make a stronger case for doing these analyses.

Page 86: A stronger case was made for comparing the climate inside the cave system to the exterior system and the correlation between the climatic data. This was done for completion' sake, as well as to determine the extent of open or closedness of the cave system – if the two data sets are similar, it could mean that the exterior temperatures had a greater effect on temperatures within the cave and other systems, such as electro-conductivity. This was added in to page 61.

47. Examiner's comment: The trend for the Jacovec Cavern is discussed, but no trend is presented? Again with Antechamber 1?

Page 88-96: The trends for the Jacovec Cavern and Antechamber 1 were added to the graphs. Trend lines were also added for Antechamber 2 graphs.

48. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Chapter 5: Overall, the significance of the results was related to the reliability of speleothems as palaeoclimate proxies more often, and more strongly, and is defended more rigourously. The data generated from the analysis of the modern speleothems and drip water samples has been engaged and discussed more rigorously, and a stronger argument has been put forward with regard to the significance of the results.

Page 111: 'Raw carbon isotopic signatures produced from the carbon stable light isotope analysis of the modern speleothems reveal an enriched trend, with an average of -1.61‰ and a range of -2‰ to 2‰, with the exception of the Silberberg Grotto.' was added.

Page 111: 'this enrichment of $\delta^{13}C$ values in the modern speleothems may be

attributed to a combination of numerous factors which have a significant effect on the level of enrichment of the carbon isotope signature.' was added.

Page 111: 'An increase in the percentage saturation with regards to $CaCO_3$ and the progressive precipitation of $CaCO_3$ both result in enriched $\delta^{13}C$ values, as well as progressive transformation of HCO_3 to CO_2 and the subsequent degassing thereof (Polag et al., 2010). The enrichment of the carbon isotopic signature of the modern speleothems therefore may reflect the degree to which these process and factors have affected the $\delta^{13}C$ signature.' was added.

Page 111-112: 'This is the case with respect to the Sterkfontein Caves, as this cave system is regarded as an open cave system, with respect to the locations where the speleothem samples were collected. Due to the open nature of the cave system, the carbon isotope results of the speleothem samples are expected to be a reflection of the $\delta^{13}C$ signature primarily from soil CO_2, which would provide a good indication of the distribution of vegetation on the ground surface.' was added.

Page 112: 'In order to produce reliable correlations with regards to ground surface vegetation distribution, it is therefore preferable to collect speleothem samples for stable carbon isotopic analysis from open caves.' was added.

Page 112: 'the enriched $\delta^{13}C$ values from the modern speleothems correlate well with a drier, more arid environment dominated by C_4 vegetation. Carbon stable light isotope analysis of speleothems provides detailed information regarding the distribution of C_3 and C_4 vegetation from the environment above the cave system. This distribution of vegetation is important to analyse as it reveals information regarding the climatic conditions of the exterior environment during the precipitation of the speleothems. The raw $\delta^{13}C$ values also display a very strong positive correlation in comparison to the distribution of C_4 vegetation, with a Pearson's *r* value of 1, and a very strong inverse relationship with the distribution of C_3 vegetation, with a Pearson's *r* value of -0.99. The p values for these statistical correlations were both within the 90% confidence level, indicating that the correlation is statistically significant. These correlations are also in agreement with the average approximate value of 80% C_4 vegetation cover calculated from the average raw $\delta^{13}C$ signature, according to Talma and Vogel's (1992) method for calculating vegetation types and distribution.' was added.

Page 113: 'as well as due to the numerous factors which may affect the ultimate $\delta^{13}C$ signature of the modern speleothem samples.' was added.

Page 114: ‘These results and interpretations correlate well with the enriched $\delta^{13}C$ values from the modern speleothems, which indicate a drier, more arid environment dominated by C_4 vegetation, and are also consistent with the average approximate value of 80% C_4 vegetation cover calculated from the average raw $\delta^{13}C$ signature.’ was added.

49. Examiner’s comment: Bamford, 1999; Kibii 2004;

Page 114: The references Bamford (1999) and Kibii (2004) were added.

50. Examiner’s comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate’s own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page 114: ‘This shows how the geomorphology and resulting hydrological systems within the karst environment may also play a role in skewing any carbon isotopic signatures produced from the speleothem samples.’ was added.

Page 115: ‘This correlation between the significantly depleted, C_3 $\delta^{13}C$ signature from the Silberberg Grotto and the current environmental conditions and vegetation cover directly influencing the signature of the $\delta^{13}C$ values again indicates the reliability of using $\delta^{13}C$ trends from modern speleothems to determine current vegetation type and distribution on the overlying surface, as this depleted trend accurately represents the current vegetation existing specifically above the Silberberg Grotto. This may again reflect on the overall reliability of speleothems as palaeoclimate proxies for vegetation type and distribution.’ was added.

Page 115: ‘The strong correlation of the observed vegetation currently existing above the Sterkfontein Caves system and the overall C_3 and C_4 vegetation distribution calculated from the $\delta^{13}C$ values from the modern speleothems substantiate the use of $\delta^{13}C$ trends from speleothems as paleoclimate proxies for vegetation type and distribution.’ was added.

51. Examiner’s comment: The vegetation cover should be presented diagrammatically, with the distribution of the vegetation shown in relation to the underground caverns.

Page 116: ‘A simple diagram showing the distribution of the different vegetation types with reference to the cave chambers was added.’ was added.

52. Examiner’s comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate’s own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page 116: ‘This however also indicates that certain conditions need to be met in order for the carbon isotopic signature to accurately reflect the vegetation distribution on the ground surface.’ was added.

Page 116: ‘The strong positive correlation obtained from the Pearson product-moment test also confirms that this relationship is statistically significant. This correlation substantiates the overall reliability of using $\delta^{13}C$ values from speleothems as proxies from vegetation type and distribution, and consequently as palaeoclimate proxies, due to the implication of certain environmental and climatic conditions as a result of the distribution and type of vegetation indicated on the ground surface by the $\delta^{13}C$ trends.’ was added.

Page 117: ‘The oxygen isotopes produced from the modern speleothem samples are reasonably negative with an average of -3.6‰, signifying overall long term cooler temperatures and drier conditions during speleothem growth, with seasonal rainfall. Temperatures deduced from the oxygen stable light isotope analysis of the modern speleothem samples reveal a very variable saw tooth pattern, with more depleted, negative oxygen isotope values reflecting drier periods with less rainfall, while less depleted, more positive values reflecting wetter conditions with an increase in warm, frequent rainfall.’ was added.

Page 117: ‘These variations in the oxygen isotope values from particular caverns therefore reflect current climatic and environmental variations between different chambers within the cave system, therefore indicating the reliability of the oxygen isotopes produced from the analysis of the modern speleothems to reflect current climatic and environmental conditions within the cave system.’ was added.

Page 118: ‘as well as in the statistical correlations produced from these calculated

temperatures' was added.

Page 118-119: 'When the calculated idealised temperatures were compared to the actual cave air temperatures, it was found that the idealised temperatures calculated from the experimental equation were much closer in value to the measured air temperatures within the cave system than that of the idealised temperatures calculated using the empirical equation. These idealised temperatures calculated using the experimental equation could thus better predict air temperatures outside the cave environment. This could be due to the experimental nature of the calculation, which would more closely represent natural conditions of speleothem growth and precipitation.' was added.

Page 119: 'This slight difference between the average cave air temperature and the idealised temperatures may also reflect on the reliability of the modern speleothems as proxies for the current atmospheric temperatures,' was added.

Page 119: 'This would therefore indicate that the modern speleothems would be reliable sources of temperature data.' was added.

Page 119-120: 'Variations between the average atmospheric temperatures, the idealised calculated temperatures and the cave air temperatures indicate that significant kinetic fractionation effects have played a role in skewing the calculated temperatures from both equations. This occurs to a lesser degree in the narrower, smaller antechambers than in the Jacovec Cavern, which is quite large. This is due to higher overall humidity in the antechambers, especially Antechamber 1, in comparison to the Jacovec Cavern, which displayed the greatest range of variations in humidity.' was added.

Page 120: 'To this extent, the idealised temperatures may indicate that the modern speleothems would be a reliable source of current temperature data, as the differences between the idealised temperatures and the cave air temperatures and atmospheric air temperatures do not differ by a significant degree, and may be explained by fractionation and climatic effects present in the cave system.' was added.

53. Examiner's comment: Again, another graph that does not work. The air temperature outside the cave is given as inside relative to the sample numbers – and is a straight line. Makes no sense.

Page 120: The lines between points on the graphs were removed.

54. Examiner's comment: It is difficult to distinguish whether the discussion is another

review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page 120-121: The $\delta^{18}O$ values produced from the drip water samples collected from July 2015 to August 2016 reflect an irregular saw-tooth pattern of predominately negative, depleted oxygen isotope values. This is particularly observed during December 2015 to August 2016, during which there is a pronounced decrease in $\delta^{18}O$ values, which increase gradually towards August 2016. This decrease is reflected by both the cave air temperature and relative humidity measured within the cave system. These depleted $\delta^{18}O$ values represent progressively cooler and drier conditions, which corresponds to a certain degree to the seasons in which the $\delta^{18}O$ values decrease, which includes late summer, autumn and winter months. This correlation between the $\delta^{18}O$ trends and seasonal variations indicates the reliability of the $\delta^{18}O$ trends from the drip water and speleothem samples to produce accurate climatic data. The $\delta^{18}O$ values also display a large range of values; possibly indicating that very little flattening of the $\delta^{18}O$ trends has occurred as a result of evaporative or kinetic fractionation.' was added.

Page 121: 'The $\delta^{18}O$ values produced from the drip water samples may have been affected by numerous local, regional and temporal scale factors, resulting in variations within the $\delta^{18}O$ signatures (see Chapter 2, section 2.4.2). These variations may be attributed to fractionation effects, which indicate physical or chemical processes which have resulted in variations in the isotopic ratios of a phase or compound (Noah, 2010) (see Chapter 2, section 2.4.2). Kinetic fractionation plays a very important role in the interpretation of $\delta^{18}O$ values from speleothems and drip water, due to the fact that this process results in the irreversible enrichment of ^{18}O isotopes in the isotopic (White, 2004). Further effects of kinetic fractionation are bound to steps within the hydrological cycle (Noah, 2010). Variations within the $\delta^{18}O$ values produced from the drip water samples may therefore by attributed to kinetic fractionation effects, and may account for any abnormally enriched $\delta^{18}O$ outlier samples.' was added.

Page 121: ‘The amount of precipitation and the atmospheric air temperatures may also have contributed to fractionation effects with regards to the $\delta^{18}O$ signatures produced from the drip water samples, and are related to Rayleigh distillation, which takes place during the course of the hydrological cycle, and within the cave system (Noah, 2010) (see Chapter 2, section 2.4.2). In order to preserve calcite supersaturation, gaseous CO_2 is removed at a constant rate from the drip water solution. However, this results in the enrichment of ^{18}O in the drip water solution, and may therefore account for the abnormally enriched $\delta^{18}O$ values produced from the drip water samples. With regards to the hydrological cycle, fractionation caused by Rayleigh distillation usually occurs during the evaporation or condensation of water (Fairchild et al., 2006), and the effects thereof are usually determined by the amount of precipitation, leading to a gradual depletion of ^{18}O isotopes in the drip water samples during heavy rainfall events (White, 2004; Noah, 2010).’ was added.
Page 122: ‘This may be observed in the $\delta^{18}O$ trends produced from the analysis of the modern drip water and speleothem samples, and as a result, variations within the trends produced may be attributed to fractionation effects taking place in the cave environment.’ was added.

Page 122: ‘This effect may be observed in the $\delta^{18}O$ values produced from cave chambers which experienced lower overall humidity, such as in Antechamber 2. Kinetic fractionation effects can be observed in the $\delta^{18}O$ values produced from the drip water samples from Antechamber 2, as the values are either abnormally enriched or depleted, indicating the presence of significant kinetic fractionation effects’ was added.
Page 122: ‘Overall, all of these fractionation effects have a significant effect on the $\delta^{18}O$ trends produced from drip water and speleothems, and influence the climatic information produced by analysing the $\delta^{18}O$ values. It is therefore important to understand these effects, in order to accurately interpret climatic data produced from the analysis of $\delta^{18}O$ trends from drip water and speleothems samples.’ was added.

55. Examiner’s comment: The outliers are explained away rather superficially. There could be less review of the literature and more detailed explanations and discussion of the results. The results are based on the use of 2 equations. A careful consideration of the value and limitations of these equations is required.

Page 122: A more thorough explanation of the outliers was provided.

56. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page 123: 'As a result, it may be assumed thus far that the $\delta^{18}O$ values produced from the modern drip water and speleothem samples would produce reliable climate data with respect to temperature and precipitation. This would indicate that overall, speleothems are reliable palaeoclimate proxies.' was added.

Page 123: '(see Chapter 2, section 2.4.2). The correlation between the raw oxygen isotope trends produced from the modern drip water samples and seasonal variations observed from measured atmospheric temperatures and precipitation indicate that the oxygen isotopes from the drip water samples may provide insight with regard to seasonality.' was added.

Page 123: 'These include evaporative cooling, fracture flow and heat transport process, and cave air ventilation processes (Cuthbert et al., 2014). The effect of evaporative cooling can be seen in abnormally low temperatures produced from the drip water and speleothem $\delta^{18}O$ trends in comparison to other temperatures from the same chamber, at the same time period. This may be due to the fact that cooling effects result in more negative, depleted oxygen isotope values, and therefore lower overall calculated temperatures. This makes the temperature data calculated from the drip water samples unreliable when comparing them to the mean temperature data from the ground surface (Cuthbert et al., 2014).' was added.

Page 124: 'Fracture flow and heat transport process may also be observed in the temperatures produced from the drip water and speleothem $\delta^{18}O$ trends which are abnormally high.' was added.

Page 124: 'Recording these environmental factors may also assist in determining which chambers to sample, in order to produce the most accurate climate data from $\delta^{18}O$ trends.' was added.

Page 124: 'Temperatures produced from the drip water and speleothem $\delta^{18}O$ trends, which were lower than normal may have been produced by the $\delta^{18}O$ values from

samples located closer to chamber entrances, especially in chambers such as Antechamber 1, which are close to very large, main chambers or ventilation shafts, and thus more susceptible to cave air ventilation effects. These effects may alter the drip water temperatures by changing the relative humidity within the cave environment, which in turn controls the rate of evaporation, and therefore the rate of cooling of the drip water. This can result in drip water temperatures which are much lower due to a larger concentration of more negative, depleted oxygen isotope values, and therefore the temperatures produced would not represent the mean temperatures on the ground surface (Cuthbert et al., 2014). Cave air ventilation variations may also be related to temperature fluctuations between the cave interior and the exterior environment (Mattey et al., 2008; Noah, 2010), but these have the greatest effect in areas closest to cave entrances (Fairchild et al., 2006) (see Chapter 2, section 2.4.3). This may also account for large variations in the calculated temperatures from chambers and drip water samples located closest to chamber entrances or cave shafts.' was added.

57. Examiner's comment: The outliers are explained away rather superficially. There could be less review of the literature and more detailed explanations and discussion of the results. The results are based on the use of 2 equations. A careful consideration of the value and limitations of these equations is required.

    Page 124-125: The differences and limitations of the two equations used was explained more thoroughly.

58. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

    Page 125: 'All of these factors may also have affected the statistical correlation between the measured temperatures and the calculated temperatures.' was added.

59. Examiner's comment: The leap to consideration of global glacial-interglacial changes in ocean isotope values is a step too far, from measuring samples in a small cave. This needs to be explored in some detail and discussed.

Page 126: The effects of global glacial-interglacial changes in oxygen isotopes on variations in the drip water oxygen isotopes was explained in more detail.

60. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page 126: 'This could be due to kinetic fractionation effects, as well as cave air ventilation effects which alters the chambers' pCO_2 values, and consequently, the $\delta^{18}O$ values produced from the drip water samples. This would affect the ultimate temperatures produced from the $\delta^{18}O$ drip water values. Rapid degassing of CO_2 in the drip water from Antechamber 1 and 2 may also account for calculated temperatures higher than that of the cave air temperatures.' was added.

Page 126: 'This indicates the presence of kinetic fractionation effects, which may be responsible for variations within $\delta^{18}O$ values from the drip water and speleothem samples, and as a result, the calculated temperatures.' was added.

Page 127: 'These effects however may also represent variations in changing cave climatic conditions, which would not be as prominently displayed in the measured cave air temperatures. As a result of this, the fact that these small variations are evident in the temperatures calculated from the drip water and speleothem samples but do not significantly alter the overall trends in comparison to the cave air temperatures reveals that the speleothems may produce reliable temperatures, and may be considered reliable palaeotemperature proxies.' was added.

Page 127: 'and this would account for the variations observed in the calculated temperature trends' was added.

Page 128: 'Variations in cave air ventilation may also alter the pCO_2 of the cave chambers, which may lead to variations in the $\delta^{18}O$ values produced from the drip water samples, and as a result, altered calculated temperature values. Slower degassing of CO_2 within the drip water samples during these periods may also result in depleted $\delta^{18}O$ values, and as a result, cooler calculated temperatures as compared to the cave air temperatures and atmospheric air temperatures. Faster drip rates during

this period may also be responsible for a decrease in $\delta^{18}O$ values, and thus lower calculated temperatures. This correlates well with the drip rates measured, as faster drip rates are associated with increased precipitation and groundwater recharge, characteristic of warmer seasonal periods, taking a lag period into account.' was added.

Page 128-129: 'Taking this system into account along with the fractionation effects responsible for variations in the calculated temperatures, the calculated temperatures overall may be correlated well with the atmospheric air temperatures, exhibiting the reliability of using speleothems as palaeotemperature proxies.' was added.

Page 129: 'Kinetic fractionation effects may be responsible for this variation, as well as cave air ventilation effects which alters the chambers' pCO_2 values, and consequently, the $\delta^{18}O$ values produced from the drip water samples. This would affect the ultimate temperatures produced from the $\delta^{18}O$ drip water values. Rapid degassing of CO_2 in the drip water from Antechamber 1 and 2 may also account for calculated temperatures higher than that of the cave air temperatures. Higher humidity during this period could also affect the value of the calculated temperatures.' was added.

Page 129: 'as well as cave air ventilation effects, rapid degassing of CO_2 from drip water, and slower drip rates.' was added.

Page 129: 'This shows that overall, the calculated temperatures do resemble the cave air temperature trends to a certain degree, but significant fractionation factors need to be taken into consideration, particularly the inverse relationship between evaporative and kinetic fractionation and air temperatures.' was added.

Page 129: 'and this could account for the variations observed in the calculated temperature trends' was added.

Page 130: 'Overall, the close resemblance of these calculated temperatures to the idealised temperatures indicates that the temperatures calculated from the drip water and speleothem samples are reliable, and that speleothems in general in these cave climatic conditions are reliable palaeotemperature proxies.' was added.

Page 131: 'With regards to the correlation between the temperatures calculated using equation 2 and the idealised temperatures calculated using equation 2, the inverse relationship between fractionation effects and resulting temperatures needs to be taken

into consideration before the reliability of the calculated temperatures may be assessed. When taken into account, these calculated temperatures do correlate well with the atmospheric air temperatures to a certain degree, indicating their reliability, however they do not reflect a correlation as reliable as that of the temperatures calculated using equation 1.

Overall, it can be said that the temperatures calculated using equation 1, the empirical equation, represent current temperature conditions to a better degree as compared to the temperatures calculated using equation 2 (the experimental equation). This may be due to a narrower range of temperatures represented by the empirical equation, which fits in with the range of atmospheric and cave air temperatures obtained for the Sterkfontein Caves system. It also may represent the overall mineralogy of the speleothems to a better extent that that of the experimental equation. The empirical equation may also have produced more reliable temperatures by taking more fractionation effects into account, and taking into account the variation produced by these effects. This would result in a temperature trend which more closely resembles the cave air and atmospheric temperatures, with smaller variations within the trend accounting for fractionation effects.' was added.

61. Examiner's comment: The possibility also exist that the varied values of drip water may be a mix of water from different origins and different aged waters.

    Page 132: 'as well as due to the mixing of water from differing sources and of differing ages.' was added.

62. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

    Page 132: 'As a result of this effect, precipitation in northern South Africa is less depleted in $\delta^{18}O$ than rainfall at higher latitudes, as South Africa occupies the lower portion of the mid-latitudes.' was added.

    Page 132: 'These enriched $\delta^{18}O$ values for South African precipitation may affect the

$\delta^{18}O$ values produced from drip water and speleothems, as drip water $\delta^{18}O$ is greatly influenced by meteoric precipitation $\delta^{18}O$ values.' was added.

63. Examiner's comment: The possibility also exist that the varied values of drip water may be a mix of water from different origins and different aged waters.

Page 132-133: 'It may also be attributed to the mixing of water of differing origins and ages in the karst system. The presence of this lag effect within the drip rate measurements provides evidence for the reliability of these drip rates representing the precipitation occurrence and variations for the Sterkfontein Caves area.' was added.

64. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page 133: 'These variations reflected in the drip rates measured from the Sterkfontein Caves system provides evidence for the drip rates as proxies for modern precipitation occurrence, amount and variations.' was added.

Page 134: 'which affect $\delta^{18}O$ values in meteoric precipitation and as a result, affect the $\delta^{18}O$ values of drip water resulting from meteoric precipitation.' was added.

Page 134: 'This reflection of rainfall seasonality within the $\delta^{18}O$ drip water trends indicates the accuracy of the $\delta^{18}O$ values in representing current precipitation conditions, and may indicate that speleothem drip water $\delta^{18}O$ values may produce reliable interpretations with regards to precipitation events and intensity, as well as resulting climatic interpretations.' was added.

Page 134: 'This has also been observed in the $\delta^{18}O$ values of the drip water and speleothem samples, as these precipitation event interpretations coincide with climatic and temperature data deduced from the $\delta^{18}O$ values. With regards to temperature interpretations, it has also been concluded that depleted $\delta^{18}O$ values represent cooler, drier conditions, while enriched $\delta^{18}O$ values represent warmer, wetter conditions. This may be reflected in the $\delta^{18}O$ trends with respect to drip rate

and ultimately precipitation events and intensity as well.' was added.

Page 134: 'and the variations in the drip water $\delta^{18}O$ trends may thus be interpreted accordingly.' was added.

Page 135: 'These interpretations may also be extended to the $\delta^{18}O$ trends produced from the drip water samples with regards to precipitation events and intensity, and coincide with interpretations made regarding cooler and drier conditions associated with depleted $\delta^{18}O$ values and warmer, wetter conditions associated with enriched $\delta^{18}O$ values with respect to the temperatures calculated from the drip water and speleothem $\delta^{18}O$ values. As a result, it is evident that the correlation between the temperature and precipitation information produced from the drip water and speleothem $\delta^{18}O$ values reliably represent current environmental and climatic conditions and variations.' was added.

65. Examiner's comment: Conclusions are drawn without an adequate argument or explanation. This section should be moved to the discussion and expanded on (with regards to variations in rainfall recorded at different weather stations, and their effects of the $\delta^{18}O$ values of the drip water samples.).

Page 136-137: 'Differences between rainfall recorded at the different weather stations may also have affected the $\delta^{18}O$ values of the drip water samples in the Sterkfontein Caves system. Differences between the rainfall trends recorded by the two stations has possibly been attributed to the distance between them (see Chapter 3, section 3.6.1). As the Krugersdorp weather station is situated closer to the Sterkfontein Caves site, the rainfall patterns from this weather station, especially for 2015 and 2016, should reflect the rainfall conditions at the Sterkfontein Caves site more accurately, and may be reflected in the $\delta^{18}O$ values produced from the modern drip water and speleothems, as well as the drip rates measured. However, altitudinal effects due to the distance between the weather stations and the cave site may account for variations between the drip water $\delta^{18}O$ values and the recorded rainfall at the weather stations. Wind effects may also have varied the precipitation events and intensity between the weather stations and the cave site, due to the distance between them. This in turn may have resulted in variations between the $\delta^{18}O$ values produced from the drip water samples, and the rainfall trends this $\delta^{18}O$ values are assumed to reflect. Due to the distance between the weather stations and the Sterkfontein Caves site, the climatic data produced by the weather stations might produced an average trend which would be more useful in determining longer

term variations in climate, and as a result, might not reflect smaller climatic variations exhibited by variations in the $\delta^{18}O$ values and drip rates of the drip water samples. The location of the weather stations with regards to the surrounding environment would also be at prime locations to capture weather data with minimal influences, whereas numerous influences such as wind activity, human activity and the influence of surrounding low-lying vegetation and topography might affect the climatic conditions experienced by the Sterkfontein Cave site. These affects may therefore be represented to a certain degree by the $\delta^{18}O$ signatures of the speleothems and drip water within the cave system. Overall, these factors may account for the variability between the recorded precipitation and temperature data from the weather stations, and the ultimate climatic data produced from the speleothem and drip water $\delta^{18}O$ trends.

Overall, the correlation between the $\delta^{18}O$ values from the drip water samples, the drip rate and the average precipitation for the area is overall very good, providing evidence that the $\delta^{18}O$ values from the drip water samples are reliable indicators of current precipitation conditions, and therefore would be reliable palaeoprecipitation proxies.' was added.

66. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page 138: 'This may to a certain degree indicate the reliability of the electro-conductivity of the drip water samples in representing current cave conditions.' was added.

67. Examiner's comment: The electro-conductivity described Antechamber 1 having the highest ventilation which is contradictory to the observed ventilation in Table 3.1. This needs to be explained further.

Page 139: The ventilation trends obtained from the analysis of the electro-conductivity of the drip water samples compared to the observed ventilation within the cave system was explained. 'This, however, is in contrast to the observed

ventilation of the three chambers. As the observed trends between decreasing exterior temperatures and electro-conductivity is only very slight, it may be assumed that this is not a reliable measure of air ventilation within the three chambers with respect to electro-conductivity. This is in keeping with the fact that there is very little statistically significant correlation between the exterior temperatures and interior cave temperatures (see Chapter 4), indicating that the exterior temperatures had a minimal effect on the hydrochemistry within the cave system. In addition, the slight trends observed here may have been affected by the constant movement of people along the tourist path within Sterkfontein Caves. This would affect Antechamber 1 the greatest, as Antechamber 1 is closest to, and has to the best access to the tourist path within the cave system.' was added.

68. Examiner's comment: It is difficult to distinguish whether the discussion is another review of the literature or a discussion of the candidate's own samples. This section needs to be more focused. The chapter needs to discuss the significance of the findings in relation to determining whether modern speleothems and drip water are proxies for past environments. This does not come through clearly or strongly and needs to be defended more rigorously. The onus is on the candidate to make the argument, not the reader.

Page140: 'This indicates the reliability of the drip water samples for further climatic analysis, as it demonstrates that very little exterior influences have affected the drip water samples.' was added.

Page 141: 'This correlation again also reveals the reliability of the drip water samples in representing current cave climatic conditions accurately with respect to the hydrochemical composition of the drip water.' was added.

Page 141: 'Overall, the hydrochemical composition and analysis of the drip water samples indicates the reliability of using drip water and speleothems as paleoclimate proxies in this case, as the hydrochemistry indicates very little exterior influence on the drip water samples, and thus implies that the climatic data produced from the analysis of the drip water samples would prove to be accurate with regards to current climatic conditions.' was added.

69. Examiner's comment: delete 'modern'.

Page 149: The word 'modern' was deleted.

70. Examiner's comment: There are two identical records for Broom with different dates – is this correct?

Page 153: Broom (1938) reference was changed.

71. Examiner's comment: Kibii, J.M. (2000), Kibii, J.M. & Clarke, R.C. (2003), Kibii, J.M. (2004), Kibii, J.M., Clarke, R.C. & Tocheri, M.W. (2011).

Page 161: References added: Kibii, J.M. (2000), Kibii, J.M. & Clarke, R.C. (2003), Kibii, J.M. (2004), Kibii, J.M., Clarke, R.C. & Tocheri, M.W. (2011).