School of Geography

University of Nottingham

Exploring Human Interaction with Projected Augmented Relief Model (PARM)

Nachnoer Nuklir Radariawan Arss, S.T., M.Kom.

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ABSTRACT

The Projection Augmented Relief Model (PARM) design comprises a physical landscape model enhanced with digital map and image content using digital projection which allows engaging interaction while presenting geographical information to people. This research explored the ways in which people gain a better understanding of landscape through projection-enhanced physical models compared to flat surface representations using an upland terrain and an urban environment as the case studies. Participants were asked to judge identical geographical information displayed on the PARM and the flat map through a series of questions. The results showed that PARM helps participants to accurately interpret the landscape of an upland terrain (the Lake District model) with an accuracy of 78.9% compared to 66.3% for the flat map. However, the accuracy of the flat map was slightly better (74.8%) than the accuracy of PARM (73.6%) for the urban terrain (University Park Campus, Nottingham). For the Lake District model, the PARM was more accurate and the response time was faster than the flat map for all types of backdrops maps and questions. For the campus model, PARM has higher accuracy for participants that have known the campus for less than 6 months, but the flat map was better for participants who have known the campus for more than 6 months. Another aspect of this study was to explore the accuracy of touch-based interaction with PARM which had been seen to be something viewers expected from previous studies, as reported in Priestnall et al (2017) a finger tracking program was proposed based on a modified algorithm from an existing program developed for the Microsoft Kinect sensor. The program was able to detect and record fingertip coordinates up until the point where the finger merged with the physical model, which was taken as the point of touch. The accuracy of fingertip detection was tested using 8 target points on each of the PARM models (Lake District and campus). Results showed a similar offset, averaged over 50 participants for both models, of 2.48 cm for the Lake District model and 2.58 cm for the campus model. The implications of this level of accuracy between the two models are discussed but generally speaking it was considered that this technological solution would not offer a satisfactory user experience.

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1 Introduction

1.1 Research Background

From ancient times, geographic visualization has played a significant role in human life. The evidence of ancient people using geographic visualization includes paintings and carvings resembling maps on the walls of caves. The techniques of map creation have continually developed to make human life easier by supporting many daily activities, as well as being of fundamental importance to diplomacy and defence considerations from the early modern period.

In the past, people drew maps using cartographic methods in 2-dimensional (2D) form to represent the terrain of the earth. They developed these methods further and visualized the landscape in 3-dimensional (3D) models, some of the earliest examples being for military defence purposes such as raised-relief maps of valleys and mountains in a rice-constructed model in the Han dynasty in 32CE (de Crespigny, R., 2007). Much later, 'plan-reliefs' of fortified settlements were used to support military strategy (Rothrock, 1969), with the physical representation being considered a more natural way of viewing the terrain than a map. The 3D physical model could therefore be considered the most representative 'map' before the digital era.

The starting point of digital technology was between the late 1950s and the early 1970s, during which period technology developed rapidly in every field, including the subject of geography. The development of map technology started with field data acquisition, data processing and data representation. Drawing maps using digital technology helps users to produce digital maps faster and more precisely, and the development of geographical information systems combined spatial analysis with map making. However, such complex maps remained the preserve of specialists until the late 1990s, when the increasing popularity and use of the internet (boosted by consumer adoption of the mobile internet in the 2000s) made digital maps increasingly desirable and useful to consumers. On the other hand, developments in geographic physical models were not as rapid as with digital maps, seeing their popularity fade despite their inherent value as representations of terrain for specialist applications.

Recently, however, the development of geographical 3D physical models has improved in terms of the materials available for making the models, and technologies for sculpting and colouring. Since the 2000s, the nature of 3D physical geographic models has become more dynamic. Dynamic geographical physical models can show a series of geographic information layers or simulations of events over the same physical model, such as changeable map layers and geographic event simulations. One such example is the Projection Augmented Relief Model (PARM) technique introduced by Priestnall et al. (2012)

This emerging technology is a combination of a geographic physical model and digital map and could be viewed as a fusion of arts and technology. It can show multiple layers and simulations of geographical events on the same physical model. The PARM design comprises a physical landscape model, a projector (showing digital map and image content on the model), and on occasions a monitor to show additional information to complement the model display. The physical models are sculpted using a milling machine, or built up in layers using a 3D printer, typically based on Digital Surface Model (DSM) data. The combination of model and projected content creates a tangible display for viewers to explore the model by inspecting it closely from different angles. In addition, observers appear to like to touch the model surface in various ways, sometimes expecting changes to the PARM display as a result (Priestnall et al., 2017).

This research will explore the apparent power of physical landscape models to provide people with an intuitive sense of the landscape. It is clear that PARM displays are engaging but this research explores whether they are also measurably better at presenting geographic information to people, and how people's expectations of interactivity can be addressed, ensuring that such interaction delivers geographic information that suits the viewers' needs. By using a simple natural movement around the model, people can experience PARM's capability to discover geographical information and support geographical analysis using the situated display. Moreover, in some contexts, when wanting to discuss decisions or to have some kind of public consultation or presentation, a fixed geographic area and simpler displays and interactions may be more appropriate than complex interactive or immersive technologies. Overall, the intention is to explore the development of an effective tangible geographic information model. As a result, the experiments will show an interaction between humans and PARM, the latter of which is an output device but also has potential as an interactive display. This research will include an exploration of touch-based interaction using the Microsoft Kinect sensor.

1.2 Aim and Objectives

Given that physical models seem to be engaging and good for visualisation, the aim of this research is to explore whether and how PARM displays help users gain a better understanding of a landscape than flat representations and whether they could support interaction as well as display. The overall objectives of the research are:

(1) To explore the ways in which people gain a better understanding of landscape through projection-enhanced physical models compared to flat surface representations using an upland terrain as a case study.
(2) To explore the capabilities of projection-enhanced physical models in urban environments where the frame of reference includes landmark buildings.
(3) To investigate the accuracy of touch-based interaction on projection-enhanced physical models.

1.3 Structure of The Thesis

The structure of this thesis is as follows: Chapter 1 introduces the research, with background, aims and objectives; Chapter 2 offers a literature review covering the history of landscape representation, the application of physical relief models, finger point interaction and human spatial cognition. The first two research studies are then presented, exploring the capabilities of PARM when compared to a flat map for an upland rural terrain (the English Lake District) in Chapter 3 and for an urban terrain (University Park campus, the University of Nottingham) in Chapter 4. Chapter 5 presents the third research study which focusses on the direct interaction between people and PARM using the Kinect sensor to detect the point at which a finger touches the model surface. Chapter 6 presents a discussion of findings and Chapter 7 concludes and reflects on the wider potential of PARM and some possible future research directions.

2 Review of Terrain Visualization

Terrain visualization aims to offer communication between humans using a natural frame of reference that reflects their view of the world. The earth is divided into two large surface areas: the land surface area (148.940.000 km^2) and the water surface area (361.132.000 km^2) (Pidwirny, 2006). Most humans live on the land surface area which is characterized by a wide range of physical landscape features such as mountains, plains, hills, rivers, and lakes (Riper, 1971). People have come to know or imagine these kinds of landforms through their daily activities, around their home towns, travelling to other places, or today through images or videos on the internet or television. These terrain morphologies have important roles in human life, such as navigation and storytelling, and have therefore been central to various forms of landscape representation.

2.1 Landscape Representations

The development of landscape representations has been an indicator of the changing thoughts of man, and an excellent representation of culture and civilization (Thower, 1972). The earliest known map was created in 6,200 BCE in the Babylonian era (Thower, 1972). In past times, the Inuit developed sharp observational and language skills to mark locations as well as to include spatial references in a homogenous terrain of Arctic ice. This method used simple words and sentences to describe locations or objects. Every feature of the landscape like mountains, rivers, hills, and rock outcrops had a name, the identity of the geographical feature being relevant to events or landmarks from stories that took place there. By naming landmarks and embedding them into their stories, the Inuit nomads used an analogous strategy, imagining the stories to themselves using the key objects or landmarks to navigate long distances to their destination, based on this landscape of words and stories (Berry, 1996; Ellard, 2010; Gagne, 1971;

Kleinfeld, 1971). This method is similar to the language structure used to describe places by Aboriginal tribes of Australia.

The Aboriginal tribes had stories to understand their territories. They created stories from their ancestors to their descendants about the landmarks around their places of living. Such landmarks were described as objects that had a particular size, colour, or shape. The main reason for Aboriginal ancestors to tell stories to their children was to recognize the nature of God's creation. The stories said that on the first day of the creation of the earth, the landscape was created through a song called the Dreamtime. The Dreamtime's narrative described that the Creator let humans live on earth to look after all of the creation on the land. It is a human obligation to participate in the songs to keep the earth's soul alive. Physical characteristics of the landscape around their environment were described within the verses of their songs (Turnbull, 2016). For example, they described a hilly land with undulating tunes and a flat landscape with long legato phrasing. Furthermore, these songlines not only play roles in their traditional life but also aid navigational skills. By connecting different parts of the landscape into creation narratives, people could find their way home, and undertake pilgrimages from one sacred place to another (Chatwin, 1988).

Early Maps

One of the oldest known maps is the Babylon World Map, which dates from the 5th century BCE. Other maps that have survived relate to ancient city plans, known as cadastral plans, such as *Circa* from around 2200 BCE; the city plans known as the *City of Babylon* and the *City of Madakta* dating from 668 and 626 BCE respectively (Tooley, 1978). Babylonian-era maps include aspects of the terrain such as watercourses, irrigation canals, mountains, and cultivated land. This demonstrates that since the ancient era, terrain morphology has had a profound influence on complex civilizations, and the charting of maps was a major concern to those communities, who attempted to represent their world by drawing it into clay, stones, or walls.

Given the variety of mountains, hills, plains, and other kinds of topographical features, people sometimes confuse the location of places in everyday life or fail to recognize the physical and cultural characteristics of places. Several methods evolved that can be used to give people a better understanding of an area or location but of fundamental importance is how physical relief can be portrayed.

2.2 Portraying Relief through Maps

Topographic maps were relatively scarce compared to those now available in the digital era (Collier et al., 2003) and the representation of the third dimension on maps was a challenge. Hachures, hill shading, form lines, and contours are techniques for portraying the elevation of terrain on a map, as explained below (Collier, Forrest, & Pearson, 2003).

Hachures

Hachures were used on early maps from 1799 to configure the slopes on the landscape (Kennely, 2000). This method is quite a straightforward technique to depict the height variation of slopes in a clear way. The directions of hachures are drawn following the steepest gradient and set in rows. The stroke of hachures depicts the length and steepness of the slope. A long thin stroke indicates that the slope is long and shallow, while strokes with a thicker width indicate shorter and steeper slopes. All of the strokes have the same thickness and space in the same row and will be thinner towards the down-slope end. An example of a map using the hachure method can be seen in **Figure 2.1**.

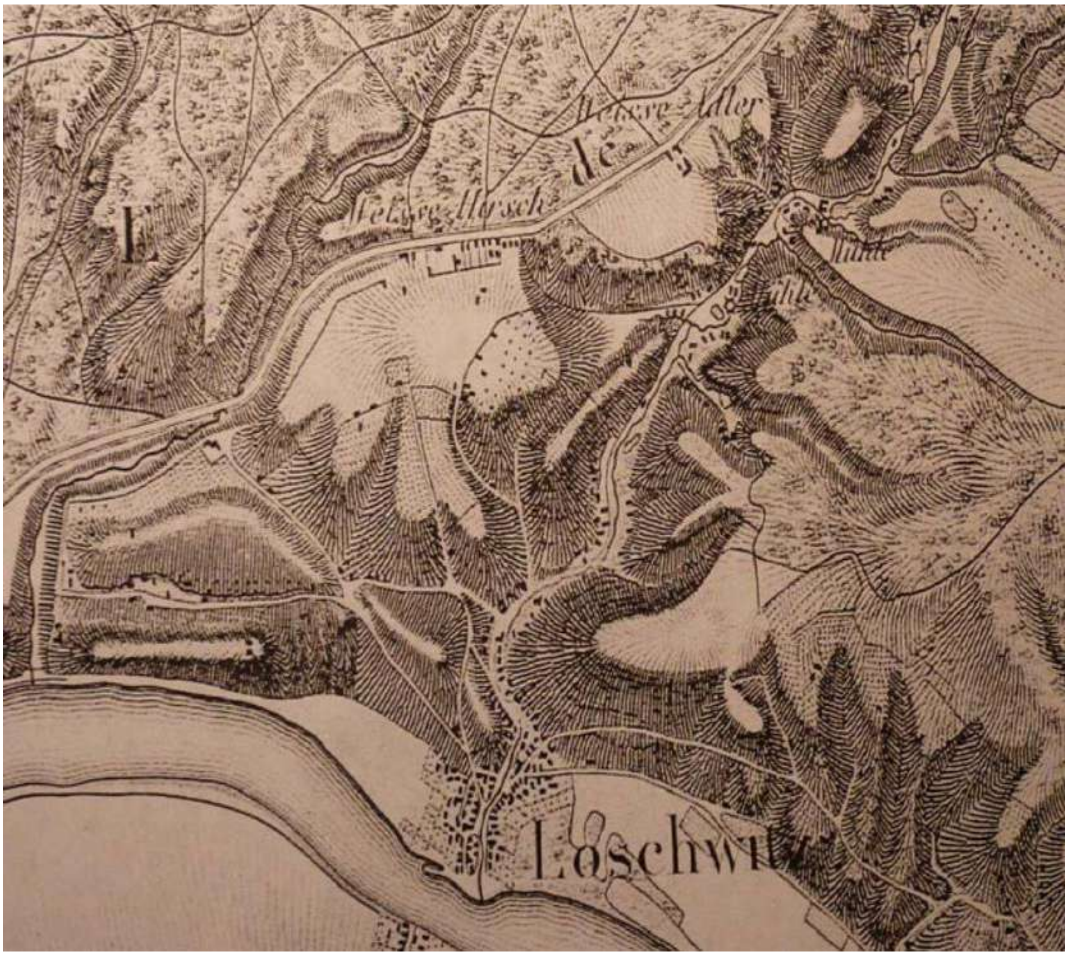


Figure 2.1. Plan de Bataille de Dresde 26 et 27 Août 1813 – Théâtre des Manœvres, Paris 1849

(Koch, 2013)

The depiction of relief maps began with hachures as a slope's direction and the length of the slope. Simultaneously, there were some technical improvements to the drawing of hachures, enabling the depiction of the steepness and the angle of the slope using thicker and denser hachures. Thereafter, an advanced method was created by using an illumination technique to generate a 2D map with a sense of a 3D view. Dufourkarte is an example of hachures and illumination techniques combined (**Figure 2.2**).

Figure 2.2. 'Topographische Karte de Schweiz 1:100.000' or 'Dufourkate', published between 1842 and 1864

(Collier, Forrest & Pearson, 2003)

Hillshading

Hillshading is used in many topographic maps to depict the height variation of terrain on the earth's surface. There are three rules to drawing hillshading on a map based on the angle of illumination: vertical, oblique, and a combination of vertical and oblique. Hillshading is based on the direction of the light source relative to the slope of the land. The steepness is depicted as intensities of 'greyness', but this depends on the direction of the slope in relation to the light source. Hillshading gives a good impression of relief but does not allow relative elevations or slopes to be discriminated very well (Hongyun et al., 2021). **Figure 2.3** shows an example of a map representing hillshading.

Figure 2.3. Hill-shaded map of a portion of the Grand Canyon, Arizona (Kennely, 2008).

Form Lines

Form lines as described by Collier et al. (2003) represent lines of equal height, without specific labels, which can be derived using stereoscopes. The method generally examines aerial photography using stereoscopes, then draws lines of equal height on the landscape before extracting these ‘form lines’ for the map sheets accordingly. One of the first maps to apply this method were those created during the First World War in Egypt and Palestine (**Figure 2.4**).

Figure 2.4. The Merwede River of Nicolaus Cruquius's 1730: *Report of the professors s' Gravesande and Wittichius, and of the land surveyor Cruquius relating to the inspection done of the river Merwede downstream from Gorinchem and relating to the proposed means to prevent inundations*

(Rann, K., 2022)

Contours

Contour lines represent lines of the same elevation, typically at regular intervals and labelled with the height they represent. In other words, if someone walked following a contour line then the elevation of the path would remain the same. Contour lines often create closed regions and must never separate. Closely packed contour lines mark areas of a steep slope where elevation changes rapidly over a short distance, whereas widely spaced contours indicate gentle slopes.

Subsequently, map printing techniques became more advanced using lithographic printing, often combining various forms of relief portrayal, for example, contours and hillshading (**Figure 2.5**). A new style of relief representation was introduced by Eduard Imhof, known as the 'Swiss Style'. This method depicted clear detail, a subtle shadowing technique, and natural atmospheric colours, as can be seen in the depiction of mountains (**Figure 2.6**). However, although those techniques were quite simple to implement, it was still difficult to generate contour maps in the 18th century, therefore contour maps were created from relief models.

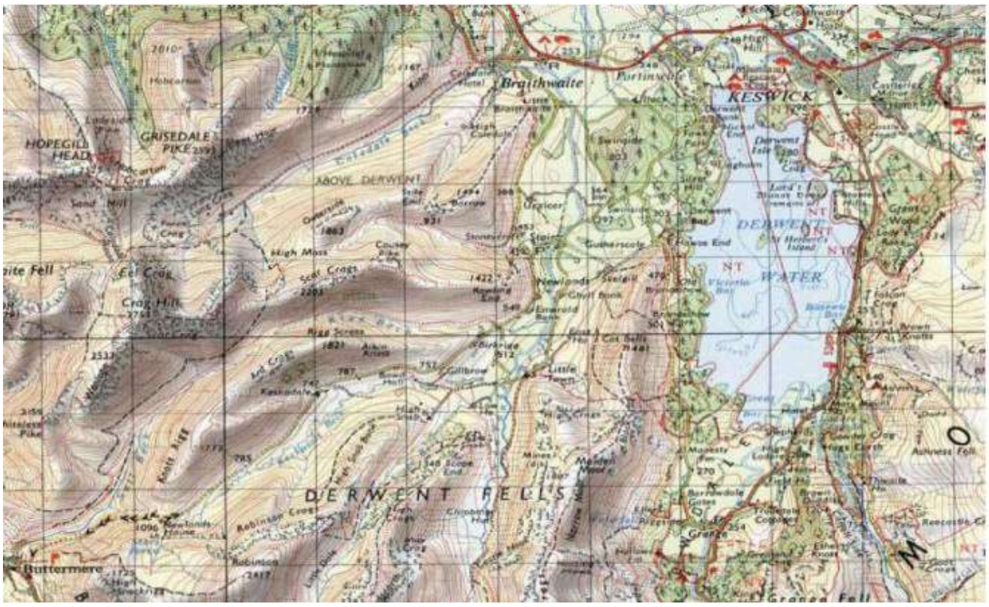


Figure 2.5. Hillshading in combination with contours

(Collier, Forrest & Pearson, 2003)

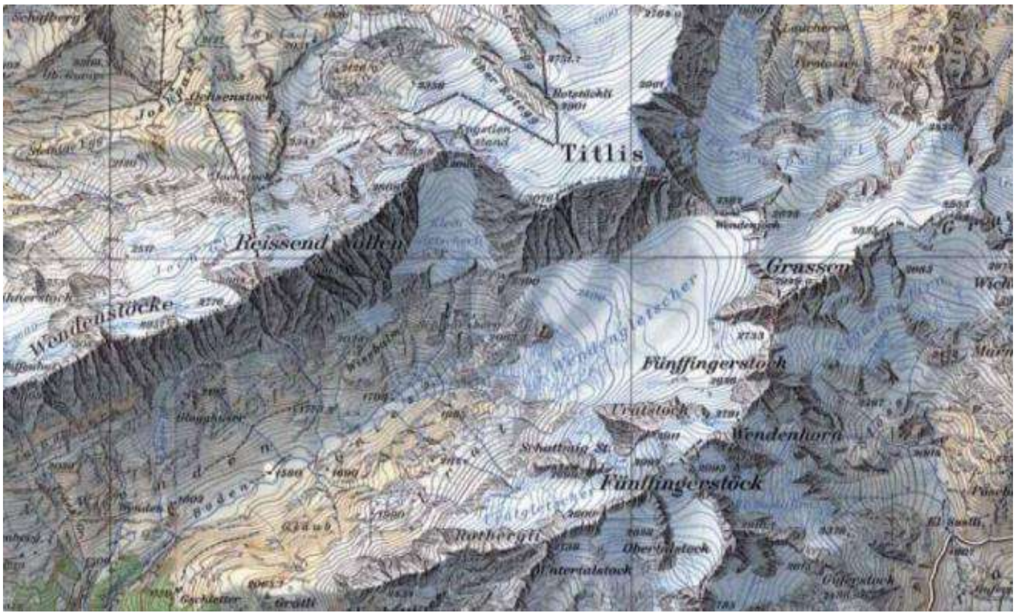


Figure 2.6. The 'Swiss style'

(Collier, Forrest & Pearson, 2003)

2.3 Physical Relief Models

A physical relief model is a solid model that represents the elevation surface of a landscape and often its land cover. Together they form a 3D physical relief model that can be seen and touched. It is one of the solutions to allow the audience to experience the landscape and gain a better understanding of the area.

A marked improvement in 3D terrain models occurred during the 18th century, exemplified by the model of central Switzerland created by Pfyffer von Wyer between 1762 and 1786. Such models were used especially for display purposes rather than to provide accurate dimensions (Dowman & Arora, 2012). Based on Pfyffer's measurements, the 26 m^2 work topographically represents an area of almost 4100 km^2 **(Figure 2.7a**). This model is considered a pioneering work of Swiss cartography (Niederoest, 2002). The most accurate map of Switzerland during the first half of the 19th century is the *Atlas Suisse par Meyer et Weiss* (**Figure 2.7b**), based on a terrain model covering a great area of the Swiss Alps created by Joachim Eugen Mueler (1752-1833). Another work undertaken by Xaver Imfelds in 1896 was a 3D model of the Matterhorn at 1:5.000 (**Figure 2.7c**), followed by Carl Meili's Säntis relief in 1899 (**Figure 2.7d**). Due to the particular importance of relief in the mountainous realm of Switzerland, it has always been a noted centre of relief modelling, as shown in **Figure 2.8** (Raber & Hurni, 2008).

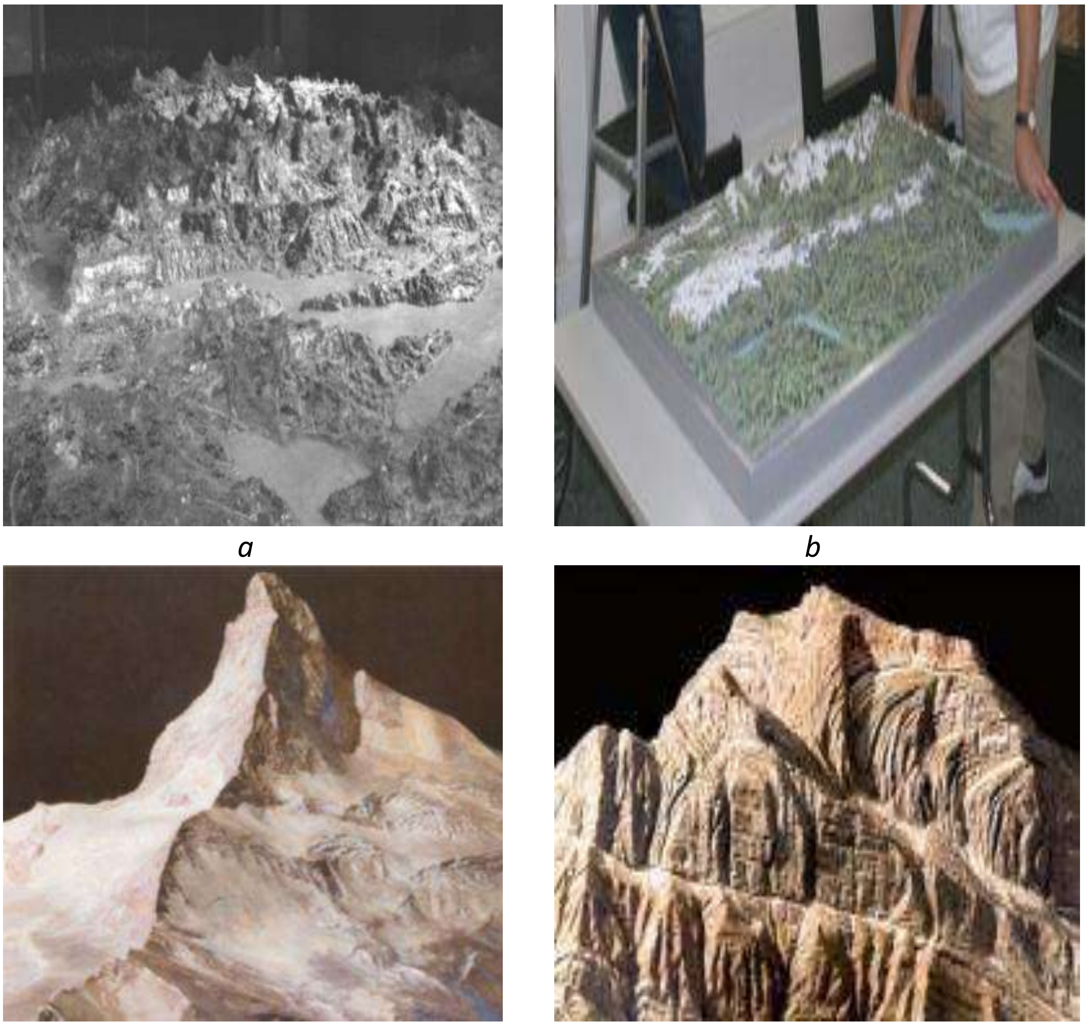


Figure 2.7. Early physical relief models

(a) Lieutenant General Franz Ludwig Pfyffer von Wyher (1716-1802) devoted 20 years of his life to the construction of a relief of Central Switzerland (Nienderoest, 2002); (b) "*Atlas Suisse par Meyer et Weiss*" - great area of the Swiss Alps by Joachim Eugen Mueler in 1752-1833 (Pearson, Schaefer & Jenny, 2008); (c) The Matterhorn – three-dimensional model 1:5.000 in 1896 by Xaver Imfelds (Hammer, 2006); (d) Säntis relief (section) by Carl Meili, 1899

(Raber, 2005).

Object	*Scale*	*Author*	*Year*	*Dim. [cm]*
Switzerland	100,000	Perron C.E.	1896 – 1900	350 x 240
Dents du Midi	16,666	Graff J., Hausamann A., Vaucher J.	1896	75 x 75
Matterhorn (Fig. 3)	5,000	Imfeld X.	1896	74 x 68
Dent Blanche (Fig. 3)	5,000	Mair T.	2005	90 x 70
Titlis / Sustenhorn	25,000	Imfeld X.	1889 – 1890	139 x 62
Urnersee	25,000	Imfeld X.; col.: Heim A.	1877 – 1890	105 x 96
Pilatus	10,000	Imfeld X., Heim A., Meili C., Hürlimann H.	1908 – 1913	125.5 x 84
Rigi	25,000	Imfeld X.; col.: Heim A., Buxtorf A., Baumberger E.	1908	80 x 55
Mythen	5,000	Reichlin J., Heim A.; col.: Imhof E.	1932	37 x 63
Fluhberg	5,000	Oberholzer E.	1952 – 1953	96 x 58
Mürtschenstock (Fig. 3)	10,000	Imhof E.	1920 – 1922	45 x 30
Lenzerheide	25,000	Meili C.; col.: Geiser M.		51 x 87
Luganersee	25,000	Becker F.; col.: Heim A.	1896	70 x 100
Säntis (profile series)	25,000	Escher A., Heim A.		
Säntis	25,000	Meili C.	1904	97 x 51
Säntis	5,000	Meili C.; instructions: Heim A.	1899 – 1903	
Peak Säntis (Fig. 3)	2,500	Meili C.; col.: Heim A.	1899	85 x 55
"Historic and thematic reliefs"				
Jura (Canton of Basel)	60,000	Gressly A.	1860	62 x 46
Rockslide of Elm	4,000	Heim A.	1900	46 x 71
Glacier	18,000	Heim A.		
Torrent	18,000	Heim A.		
Alpi Apuane	50,000	Sacco F.		
Volcano island	10,000	Heim A.		
Workflow series of relief models	20,000	Mair T.	2007	
Glarus' Alps	50,000	Oberholzer J.; col.: Geiser M.	1911	70.5 x 95

Figure 2.8. List of relief models of the Alps with the creators' name, the scale, the year created, and the size of the model

(Raber & Hurni, 2008)

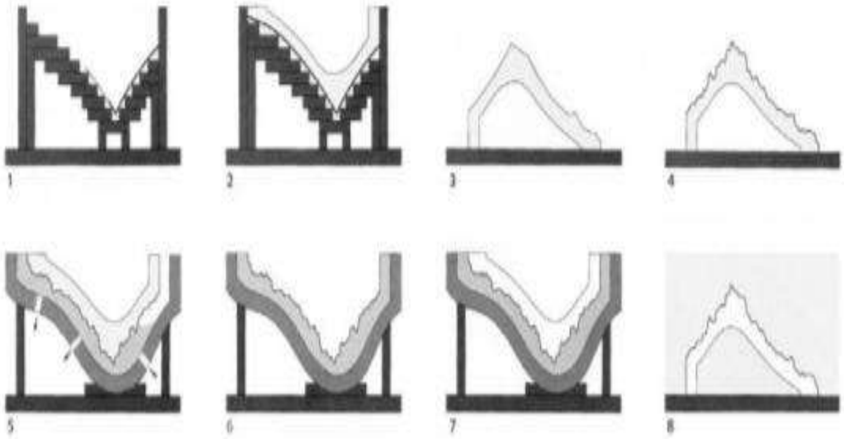


Figure 2.9. Building handmade relief model based on Imhof method

(1) Creating the negative terrain model basic form from wooden parts and smoothing the edge use of lubricant; (2) Fill with 3-5 cm plaster layer; (3) Positive mould form: remove the wooden parts and leave the plaster; (4) Shaping the terrain similar to the real landscape; (5) Put the positive mould into wooden parts with 2-4 cm blank space between them and fill with a gelatinous compound; (6) The negative mould form - remove the original model; (7) Pour plaster into the negative mould; (8) The plaster can be removed after it solidifies. Other moulds can be created using the negative mould form

(Raber, 2005)

The art of terrain modelling in Switzerland reached its first peak towards the end of the 19th century. Prerequisites for this evolution were several new technical achievements like reliable contour maps of the whole country, the invention of photography, the increased popularity of mountain climbing, and a strengthened scientific interest in geology. In 1880-1980, Swiss relief modellers like Xavier Imfeld (1853-1909), Carl Meili (1871-1919) and Eduard Imhof (1895-1986) created many impressive relief works (Hurni, 2008; Pearson, Schaefer & Jenny, 2008). Moreover, due to the impressive nature of their pioneering work, the techniques of model-making by experts such as Eduard Imhof (**Figure 2.9**) have become subjects of research in themselves.

The physical relief model nowadays still has an important role in daily life, such as in information centres for people to understand the location that they are visiting.

Examples of this can be found at visitor centres at recreational areas such as Mount Rainier (**Figure 2.10**) and Mount St. Helen (**Figure 2.11**), both located in Washington state, USA.

Figure 2.10. Mount Rainier's 3D relief model exhibited in the Henry M. Jackson Memorial Visitor Center
(*Courtesy of Dr. Gary Priestnall*)

Figure 2.11. Mount Helen's 3D relief model was exhibited in Mt. Helen Visitor Center.

(Courtesy of Dr. Gary Priestnall)

2.4 Digital 3D Landscape Representations

Since the introduction of computers, the 3D model has taken on new meanings and developed new capabilities. Most maps are still produced in two dimensions, but using computer technology they can be displayed as 3D images on the computer by draping them over digital models of the terrain. Using 3D data, an area can be seen from many angles, points of view, and at a range of scales. This could arguably could be seen to offer the viewer more information than the equivalent 2D map to address issues related to infrastructure development, entertainment, tourism, sustainable management of cultural sites and to tackle the effects of various social and environmental factors (Waite et al., 2013). However, despite the many benefits of 3D visualization, one of the challenges is giving people a quick and easy overview of a landscape.

Further developments of 3D methodologies introduced the concept of ‘virtual reality’. Milgram introduced the mixed reality continuum concept, which states that mixed reality encompasses the real environment, augmented reality, augmented virtuality, and virtual environment (Milgram, 1994) (**Figure 2.12**).

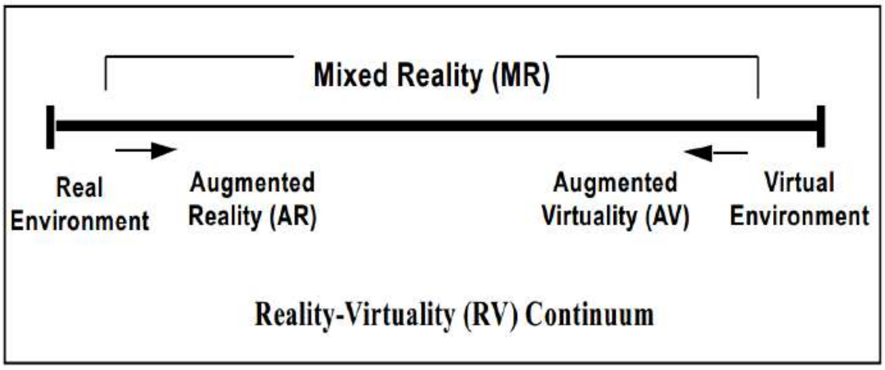


Figure 2.12. Simplified representation of the reality-virtuality continuum (Milgram, 1994)

The concept of augmented virtuality, popularly known as virtual reality (VR), is often to create something that already exists in the real world and represent it as an immersive 3D computer graphic environment. The Oculus Rift is a good example of this kind of technology, with the ability to recognize head and body movements, which allows the user to view the whole environment around the body (360°) and to zoom in on objects they want to focus on (**Figure 2.13**).

Figure 2.13. Oculus Rift console

Oculus Rift visor (top), the rotation of Oculus Rift (bottom).

(Goradia, Doshi & Kurup, 2014)

Augmented reality (AR) delivers virtual elements in real space using some kind of visor or headset. The incorporation of both not only creates an interaction between humans and the object but also complements the real world through digital content. This method is not a *substitute* for reality as in VR, rather it adds to (i.e. *augments*) the real world using additional digital elements

One of the first true AR systems was Tinmith (Piekarski & Thomas, 2002), a user interface technology combining an immersive 3D outdoor AR concept and AR software. The idea was to combine the real world and augment it with an AR application. This technique allows the user to add something in their mind in the space around them without affecting real objects. For instance, people can easily add a tree in the park and see if that fits into the environment. The tree could be moved from one point to another, it could also be rescaled, and changed in colour or texture. Moreover, if it did not match with the user's requirements then they could easily delete it and start again. Tinmith was initially created in 1998 and developed until 2006. This method uses a helmet and visor, backpack, high precision GPS receiver, computer, a video camera for input and gloves to control the AR application (**Figure 2.14**). It was breakthrough technology and a pioneer of AR, underpinning market solutions available now such as Google Glass (Glass, 2021) and HoloLens(Hololens 2, 2021). Per Azuma et al. (2001) stated that an AR framework ought to: (1) integrate the real and virtual objects in the same environment; (2) run intuitively and in real-time; (3) register the real and virtual variables to one another. The quality of AR involvement, in other words, the user experience, may be considered to be of utmost importance. In fact, like in VR, the feeling of presence and the level of realism in the objects being superimposed on reality can be important. AR does not need to replicate real environments in detail as they are visible in the background, however, realism in augmented content can add to the user experience and the sense of "being there" physically and also being involved in the tasks. Together this forms a sense of *immersion*, both in AR and VR situations, is vital in simulating real situations (Botella et al., 2005).

Furthermore, VR technology is a computer-generated environment where the user can explore objects inside VR and make an interaction with the objects for various applications. There were several fields that have used VR applications, such as:

Automotive, for example radars as driver assistance (Gadringer et al., 2018); Healthcare, for example mental health for veterans suffering from PTSD (Jensen, 2021); Tourism, for example accessible and intuitive tools for Milan's Basilica Sant'Ambrogio (Pybus, 2019); Real estate, for example increasing immersion for properties that are to be built (Deaky & Parv, 2018); Learning and development, for example exploring the speech perception abilities for children (Salanger et al., 2020); Sports, for example the analysis of pingpong players (Bozyer, 2015); Entertainment, for example measuring noise incidents due to musical events at the Kai Tak Sports Park in Hongkong (Chung et al., 2017); Well-being, for example effectiveness of medication delivered through VR and video based on students' test scores (Kaplan-Rakowski et al., 2021); Social interaction, for example exploring the experiences of various social VR application (McVeigh-Schultz et al., 2019); Marketing, for example the transformation of library spaces into a VR content (Cabada et al., 2021); Recreation, for example the simulation of lifelike recreation scenes using a helmet as a tool (Xiaohan, 2015); Military, for example creating a virtual training interface for a firing range (Bhagat, 2016), and Journalism, for example creating additional engagement and empathy with users (Sanchez & Luisa, 2020).

Moreover, there are several applications of Augmented Reality that have been published in the past few years, such as buildings/architectural heritage (Merchan et al., 2021), and industrial maintenance and assembly for training purposes (Gavish et al., 2015; Malta et al., 2021), entertainment purposes for indoor or outdoor experiences (Hung, 2021), education for students (Lim et al., 2020), medicine or healthcare augmentation (Adenuga, 2019), and psychological application (Mendez, 2021). Based on many AR applications that have been made for many purposes, including for education, one of the main benefits of implementing it is that it changes the way an issue is representated such that troublesome concepts become simpler to understand. The application can provide information which is suitable to a user's level of knowledge and omit unsuitable information to assist learning of certain subjects. The application leads users to the main focus of a study, and allows for more interactive experiences between the user and the application (Radu, 2014).

Figure 2.14. Tinmith model

(Piekarski & Thomas, 2002)

2.5 Revisiting Physical Models: Augmenting Relief Models with Digital Data

It is now easier to produce physical models from digital data to create a visualization of an object compared to the techniques of the past. This is due to the greater availability of open digital terrain data and cheaper options for 3D fabrication such as milling and 3D printing. One example of 3D topographic milling was used when creating models for PARM using a milling machine (**Figure 2.15**). By using Digital Surface Model (DSM) data, the machine can reproduce the same data in physical form by removing layers of material, being termed a *subtractive* technique. The other technique that can be considered as a method to create tangible visualization is 3D printing. This approach is *additive*, building up an object layer by layer using a range of materials including plaster powder and plastics.

Figure 2.15. Generating PARM model and milling process

The process of generating PARM model based on the hillshade of DSM of Lake District (left); the milling process with Computer Numerically Controlled (CNC) techniques using a Roland MDX-540 machine (right)

(Priestnall et al, 2009)

Modern physical relief models are produced commercially, for example by Solid Terrain Modelling (http://www.solidterrainmodeling.com) and Howard Models (http://www.howardmodels.com/index.html), which are companies creating relief models for a range of contexts including public display. Some models are produced using a milling process combined with colour printing. The advantages of these relief models are the accuracy of the model's shape and detailed coloured textures (**Figure 2.16**).

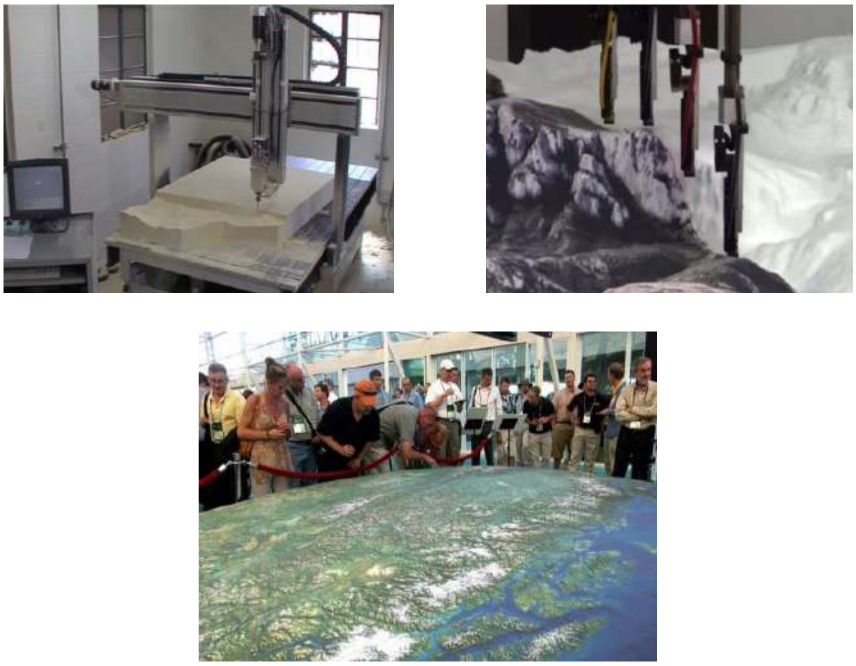


Figure 2.16. Physical relief modelling, colouring and scale experience

The process of creating physical relief modelling of mountains in North America from milling process (upper left), colouring process (upper right) and Quarter Scale BC Experience, ESRI User Conference 2006: 10’ x 18’ (bottom)

(Solid Terrain Modelling, 2013).

Most relief models have static textures, whereas digital data allows flexibility of display, to change the story presented on top of the model. Image projection onto the physical model has the advantage of turning a static physical model into a dynamic physical model. There are several applications for this projection method, such as:

(1) Storytelling: to show the ‘drama’ that happens in an area;
(2) Historical events: Showing a chronicle of past events, usually related to the changes through time;
(3) Project development status: the progress of a project from the initial stage until the final goal;
(4) National, regional or local strategic planning;

(5) Military tactical strategy: to portray clear military activities in an area;
(6) Disaster management simulation: to show disaster predictions, connected to real-time disaster data such as wildfires, tornados, floods and tsunamis;
(7) Training simulation: to help rehearse routes over the terrain;
(8) Search and rescue (SAR) simulation: assisting in searching for missing people in mountains etc.; and
(9) Tourist orientation: showing visitors the shape of the landscape and relative positions of features of interest around them.

Examples of projection display onto relief models can be found in the *Cartographic Representation of Dresden's Historical Development* (Hahmann, Eisfelder & Buchroithner, 2012), showing various kinds of maps draped over the physical model. The project has similarities with PARM in terms of the visualization technique, by projecting a map image onto the physical model.

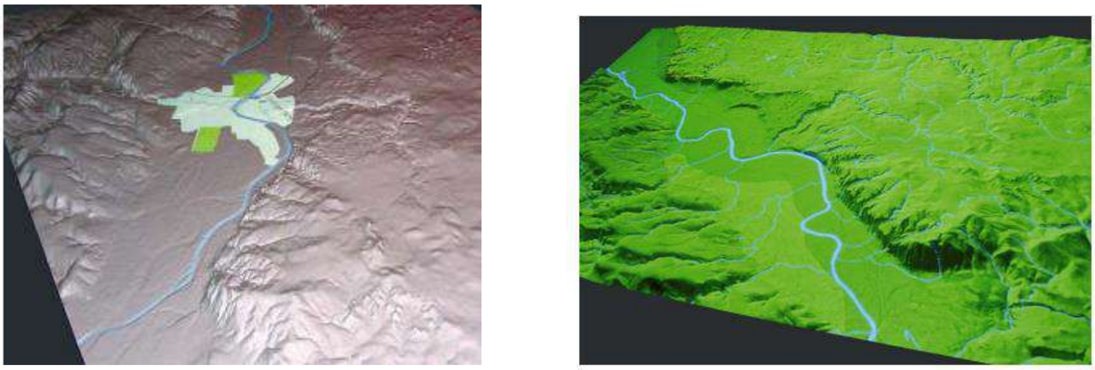


Figure 2.17. The River Elbe

Projection of the Elbe River, showing historic city extents (left) and the potential natural vegetation of the Elbe Basin (right)

(Hahmann, Eisfelder & Buchroithner, 2012)

The exhibition on the *Cartographic Representation of Dresden's Historical Development* was held at the local City Museum in the eponymous city in Germany. The purpose of the exhibition was to attract a broad audience using innovative exhibits. The exhibition contained a 2x1.5 m solid terrain model of the Dresden Elbe Valley. A film was played showing the development of the depicted area since the year 8000 BCE, projected onto the solid terrain model by a video projector with the aid of a tilted mirror, enabling the layers of the model to be changed easily (**Figure 2.17**).

Figure 2.18. Projection Augmented Relief Models (PARM): Tangible Displays for Geographic Information

A selection of data layers used for the projection (upper left); demonstrated at the Mayfest community event, University of Nottingham, 2011 (upper right and bottom)
(Priestnall et al., 2012)

The general affordances of projecting geographic information onto physical relief models were presented in Priestnall et al. (2012) who used for the first time the term Projection Augmented Relief Model (PARM). The first museum installation based on the PARM technique was the *Spots of Time* display (which aimed to convey key events in the childhood of the poet William Wordsworth) connected with particular parts of the landscape (**Figure 2.18**). Furthermore, those key events are also related to poetry that Wordsworth created in adulthood, notably *The Prelude*. The purpose of the model was not only to raise the awareness of the importance of place and memory in Wordsworth's work but also to encourage the visitor to study the original manuscripts on display elsewhere in the gallery space (Priestnall et al., 2012).

2.6 Introducing Human Interaction on 3D Surfaces

A Tangible User Interface (TUI) refers to physical touch using an input device that generates some kind of response or feedback, with the device acting as both input controller and output. On the other hand, a graphical user interface (GUI) uses separate physical tools for input controller and digital output.

The aim of the TUI scheme is to omit the difference between input and output devices by blending the tools into an integrated platform. Furthermore, Hiroshi Ishii and Brygg Ullmer from MIT Media Lab described it as "…an attempt to bridge the gap between cyberspace and the physical environment by making digital information tangible" (Ishii & Ulmer, 1997, p.235), which means treating the digital features and physical things as identical. Ishii and Ulmer identified the nature of TUI in terms of the following:

(1) Physical model integrated with digital features.
(2) Physical model contains interaction techniques as a control.

(3) Physical model as a bridge to actively represent the digital feature.

(4) The output of the system is represented through the physical model.

In addition, from the nature of TUI above, TUI can be considered as one object that occurs in the real and digital world. Users interact with the object to gain output from the object. A good example of the TUI method is the I/O brush. The idea of this research was to explore the colour, texture and movement of an object that can be found in everyday life, by picking it up and brushing with it (Ryokai, Marti & Ishii, 2004). One of the case studies within this project captured eye movements and presented them on the canvas as multiple eye movements (**Figure 2.19**).

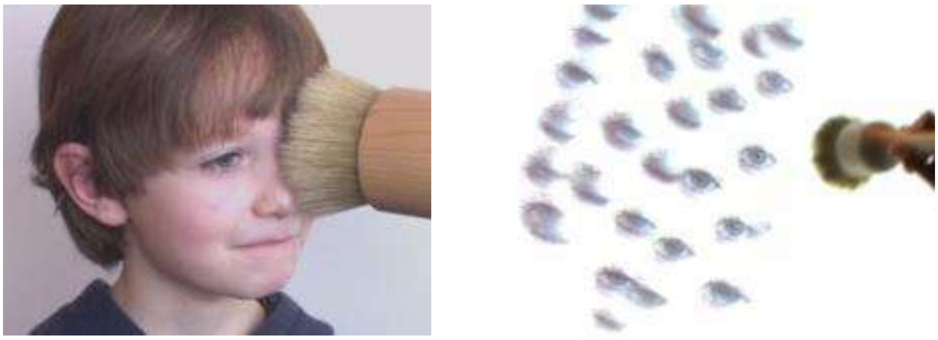


Figure 2.19. Capturing object

Eye movement (left), the painting of multiple eyes movement (right)

(Ryokai, Marti & Ishii 2004)

There are many studies of tangible interfaces, such as *Listen Reader*, an interactive children's storybook triggered by moving one's hands over the book. The tools include RFID tags embedded in the books and additional sensors, such as the LeapPad, which is an augmented book that uses a kind of pen to detect the image or words on the page and a special tint to write or draw on the book (Back, 2001).

Another example is using physical objects such as digital icons like blocks, toys and physical objects as a trigger for digital effects, for example:

(1) Microsoft Actimates puts embedded sensors in toys to allow interactions with the computer game;
(2) StoryMat is an interactive playmat that replays children's stories when the toys projection is projected over the mat;
(3) Kidstory also uses toys to trigger the display of the character on the screen when the toys move near to the tag reader; and
(4) The Tangible ViewPoints uses a physical object to navigate through multiple viewpoint stories. When an object is moved near to the characters, the corresponding images or text is projected.

2.7 Supporting Technologies for PARM

Given that PARM contains a physical relief model and projected digital map data, there are several research projects that have studied the combination of these two components, for example, Illuminating Clay (Piper, Ratti & Ishii 2002a, 2002b), TanGeoMS (Tateosian et al., 2010) and Augmented Reality Sandbox (Kreylos, 2012), as described below.

Illuminating Clay explores the changes of a landscape model surface in real-time using computer-based analysis. The landscape is made from clay and the user can change the shape of the clay while it is captured in real-time by a laser scanner. The depth image variable allows the system to recognize the surface changes and use them as input for landscape analysis. There are several landscape analysis modes within Illuminating Clay, such SCANcast, and two other future modes: CUTcast and CADcast (**Figure 2.20**).

SCANcast was designed as a default parameter for landscape analysis. SCANcast mode is designed to scan the surface of the clay and use the depth image as an input for analysis. SCANcast operates six functions: (1) DEM; (2) slope variation and curvature; (3) shadow and solar radiation; (4) view-shed; (5) least cost of passage; and (6) water flow and land erosion.

The basic idea of the future mode CUTcast was to present the 3D information above the surface (e.g. a representation of airflow or temperature conditions above the surface). The system captures the geometry of the surface and calculates and simulates the event upon the surface through projection.

The other future mode, CADcast, was designed to create a user-defined landscape, allowing the surface of the clay to be moulded until it is similar to the landscape data stored in a CAD file. Colour indicators appear to determine if the surface is already suitable with the CAD file or not. The red colour on the surface elevation exceeds the limit of elevation stored in the CAD file. As the elevation reduces, the colour turns blue. This method is a potential way to generate a faster model of a landscape, but unfortunately, it has remained at the developmental stage.

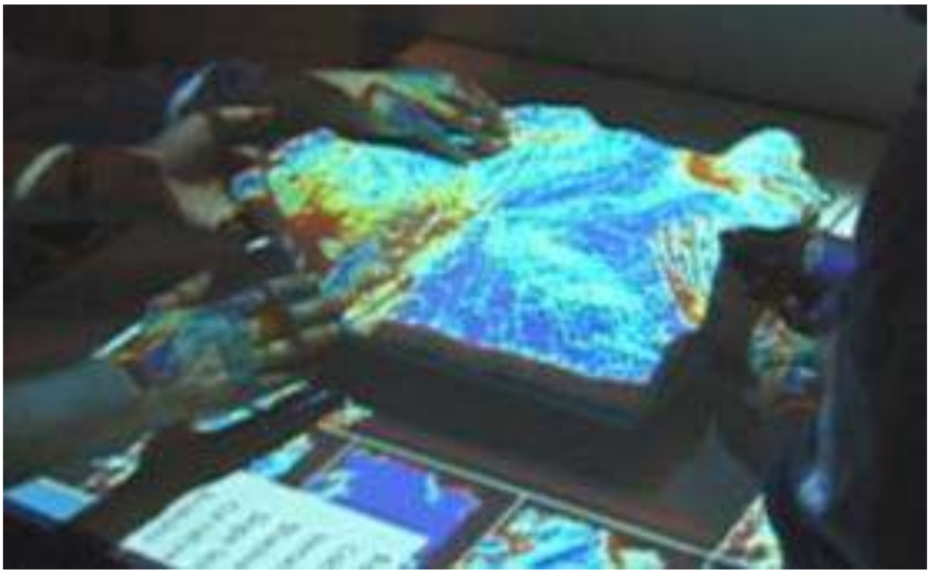


Figure 2.20. The projecting of slope variation onto the Illuminating Clay
The user can manipulate the surface manually

(Piper, Ratti & Ishii, 2002b)

The TanGeoMS research study is similar to Illuminating Clay mentioned above in that it is designed to create a tangible user interface for terrain data. This study encompasses GIS operations, a 3D model, a scanner and a projector. The clay model can be created and manipulated by the user, then the surface of the clay is captured by the scanner. The data from the scanner is then processed using GIS software. The result of the GIS processing appears on the model through the projection (**Figure 2.21**). While quite similar methods, Illuminating Clay and TanGeoMS differ in their model materials; the former is stiffer.

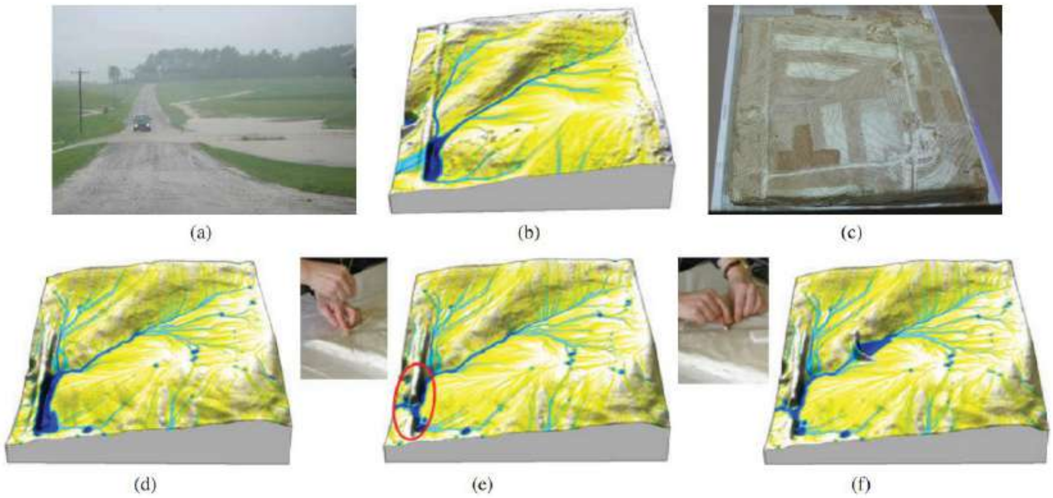


Figure 2.21. TanGeoMS modelling of unpaved road (area: 450x450 m^2) and the simulation of the runoff

(a) A picture of the real situation of actual runoff while experiencing the large storm; (b) the simulation of process-based using real-world elevation data; (c) a 3D land use projected image; (d) the runoff model based on the elevation of the malleable model; (e) the road breach runoff model after manipulating the malleable model; (f) runoff situation based on manipulation of the physical model by creating a check dam

(Tateosian et al., 2010)

The AR Sandbox is a 3D visualization model with the purpose of teaching earth science concepts. This model is a hands-on exhibit using a real sandbox and using projected virtual topography and water features. The tools to run this model are Microsoft Kinect 3D camera, projector and simulation and visualization software.

The user is allowed to shape the sand as desired which is then augmented with projected visualizations of the colour map, contour lines and water simulation (**Figure 2.22**).

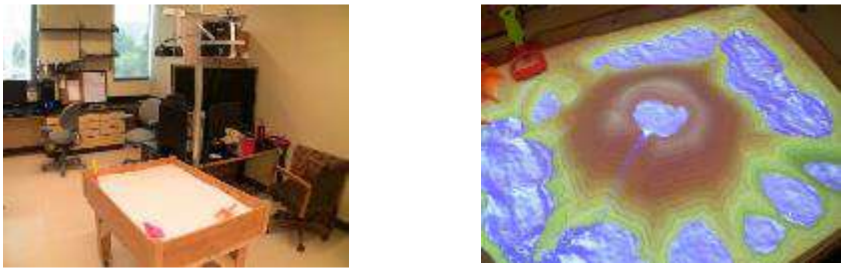


Figure 2.22. Krylos graph

The set-up environment of AR Sandbox (left) and the projected landscape and water simulation (right)

(Krylos, 2012)

AR sandboxes are useful for geoscience experimentation such as oceanography, soil science or cartography to study the physical aspects of the earth. Whilst they are very engaging, they do not allow the representation of real places in any detail, and the techniques for interaction rely on detecting broad changes in the surface and hand gestures rather than precise touch-based interaction.

In the case of PARM, the models cannot be manipulated and so the nature of any interaction is different. Regarding the observation of PARM in the *Spots of Time* case study, the intriguing part of the findings was the users' expectations when interacting with the projected relief model. The observation of the video revealed how people touched the PARM with their fingers often expecting some kind of response (Priestnall, 2012) so it is this touch interaction that would need to be captured rather than the changing shape of the model surface.

The aspect of using the Kinect sensor in the AR sandbox technique that is most relevant to touch-based interaction in PARM would be the detection of the user's hands when creating rainfall events over the sand. In particular, there are tools for detecting the user's finger position as part of hand detection (Kulshreshth, Zorn & LaViola, 2013; Raheja, Chaudhary & Singal, 2011; Ren, 2011).

The PARM technique offers different capabilities to the AR sandbox, allowing subtle detail relating to real landscapes to be explored, and so for geographic applications, users would want more fidelity (i.e. more accurate interactions). To underpin this, we would need to demonstrate that subtle measurable differences can be discriminated and that any interactions are precise enough to be fit for purpose for geographical visualisation and query. To this end, it is important to consider the potential for detecting when a finger touches a part of the physical model.

2.8 Finger Point Interaction

Hand and finger recognition are considered natural gestures in Human-computer Interaction (HCI) in many applications such as games and digital object manipulation. The precise detection of the human hand remains an interesting programming challenge, both detecting the hand and finger positions and tracking their movements.

Several devices have the functionality to detect body movement and those most closely related to this study are the Leap Motion sensor from Leap motion Inc. (formerly OcuSpec Inc.) and the Kinect sensor produced by Microsoft to work alongside the Xbox 360 game console.

The Leap Motion is a peripheral device, with software, to offer a natural user interface based upon hand or finger gestures. The device was launched in May 2013, though the uptake of the product was slower than expected. There was some beta testing within the community to improve the capability of the device using a range of programming languages including C++, objective-C, C#, Java, Python, and JavaScript. There were some applications that can use the Leap Motion controller such as (1) Molecules, which is a Mac-only app that allowed user viewing and editing of 3D renderings of molecules, (2) Cyber-science – Motion, an education application to explore the names and locations of parts of the skull, (3) Exoplanet, to allow exploration of the solar system, and (4) Boom Ball, a simple racquetball game. Although there was some development in enhancing the functionality of the controller, there were problems to be addressed, such as limitations to the working environment for finger recognition, for example, the presence of bright light disrupted its use (Krastev & Andreeva, 2015).

The Kinect was widely used by many research projects or applications related to hand gesture recognition due to its usability and price. The first Kinect sensor was produced in 2010 to accompany the Xbox 360 console game as a body movement recognition device (O'Reilly, Kinect Hacks book, 2012) (Figure 2.23). The Kinect sensor can successfully detect the body shape of people when playing games and so determine actions within those games. The Kinect recognizes body movements by using an RGB camera and depth sensor, not only for body movement but also for facial recognition and voice detection as well. The PrimeSense software was a Kinect software built especially for recognising the skeleton of the human body (Zeng, 2012).

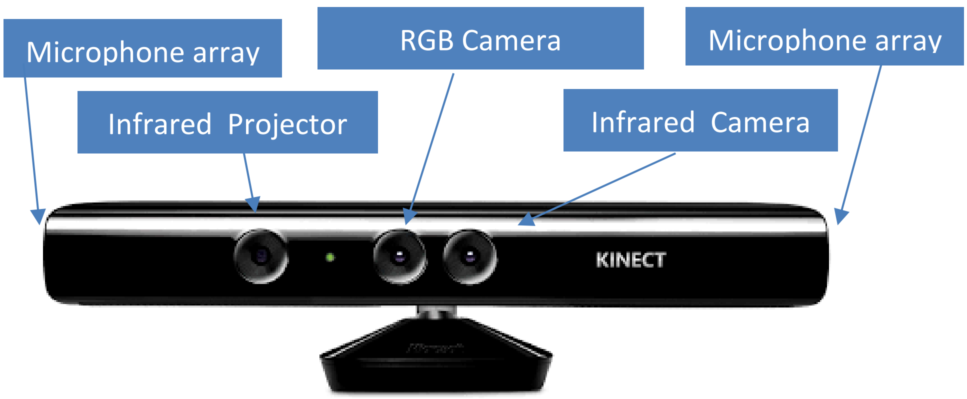


Figure 2.23. Features in Kinect Device

The challenge for PARM, based on previous observations (Priestnall, 2011) is to detect finger movement towards and then touching a bumpy surface. The detection should allow finger recognition in mid-air until it touches either a flat or bumpy surface. To do the tracking, there should be a method to localize the hand recognition. There are several methods to differentiate the hand and the background by using a classifier. One method featured a classifier using skin colour as a cue to detect the human body, although the method becomes more challenging when facing skin-colour manipulation due to illumination, background, camera characteristics and ethnicity (Kakumanu & Makrogiannis, 2006). A spatiotemporal segmentation can be used to determine spatial segmentation, temporal segmentation and recognition (Alon, 2009). Another method is recognizing hand gestures used a depth model (Zeng, 2013) (Figure 2.24). This detected hands by separating them from the background using a threshold (Li, 2012) (Figure 2.25).

Figure 2.24. Distinguished hand detection over the background using colour depth (Zeng, 2013)

Figure 2.25 shows the fingertip detection method. First, points P1, P2 and P0 are detected and a vector is drawn between P1 and P2. The next step is to measure the distance between P0 and the centre of the P1-P2 vector. Subsequently, points P1', P2' and P0' are determined and the same steps followed. The distance between the P1 and P2 vector to point P0 is compared to the distance between the P1' and P2' vector and P0' point. From this example, it can be concluded that P0' was not a fingertip because it is not in the threshold range (Li, 2012).

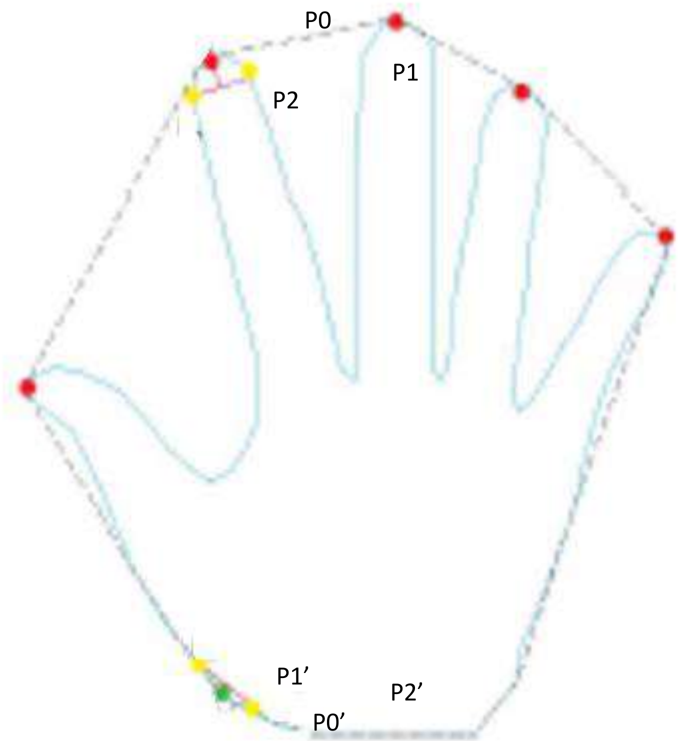


Figure 2.25. Fingertip detection using a 3-point method classifier.

There are extensive open-source shared libraries for Kinect program development mainly in C# and C++ which can be downloaded freely and edited. One of the open-source program libraries related to hand and finger detection with the Kinect sensor is Frantracerkinectft written in C# (Appendix 8). This program used a 3-point classifier (Li, 2012) that could recognize hands and fingers in mid-air (Cerezo, 2012).

Therefore there are some relevant programming tools for detecting fingers, though the challenge would be to identify the points where the fingers touched the model surface if this was to be of use for PARM displays. The fact that PARM features high fidelity models of real places also opens up different requirements for people to understand the landscape that is being visualized. There is a research gap in understanding and even measuring the benefits for human’s ability to orient themselves, to measure distance and relative elevations, and to achieve a quick understanding of location, so it is important to understand human's spatial skills.

2.9 Human Spatial Cognition

The space around humans can be categorized as a place where objects and events exist and happen. Humans live in space every day, such as going to work, gathering, travelling and so on. Furthermore, humans can interact with space; this is called human spatial cognition. This ability is embedded in the human mind to process the environment around them and take the decision to engage in further steps. For example, people examining a traffic jam in the road can decide which path they want to choose. This situation is an example of how humans use spatial cognition to calculate their next action based on momentary facts.

An observational study of human spatial cognition conducted by Kozwolski and Bryant (1977) stated that people who report a confused sense of direction are better at judging the direction of familiar landmarks, and faster at learning the layout of a new environment. The authors asked undergraduates at Wesleyan University to rate how good their sense of direction was on a scale of 1 (poor) to 7 (good). They established that students with a good sense of direction were more accurate in mapping the direction of familiar buildings on the campus. In the next experiment, the students were led in a tunnel, and after being led to the final stage of the tunnel and back, they were asked to indicate the way to the tunnel end. The outcome of both groups was 40° off. In the second test, the group with a sense of direction proved a substantial drop in error. On the contrary, the group with a poor sense of direction showed no alteration. The possible explanation for these findings is that the common usage of direction relates to orientation abilities (Kozlowski & Bryant, 1977).

Another study similar to Kozlowski and Bryant's research was conducted by Sholl (1988) at Boston College. She asked subjects to rate their sense of direction on a nine-point scale from 'easily lost' to 'easily find my way'. Students were classified as possessing a good sense of direction or a poor sense of guidance. The first step of the research involved students being asked to undertake a questionnaire to test their spatial ability. In this instance, the differential of the two groups was non-significant. In the second phase of the research, the students were asked to point to out-of-view landmarks from different imaginary perspectives. The students with a good sense of direction were faster and more accurate than the other group. The outcome of this experiment confirms the main form of reference (one's surroundings) and a secondary form of character whereby one must conceive of where they were in some other location.

A related research study was undertaken to show a self-reported sense of direction, finding and landmark representation abilities. As in Scholl (1988), Cornell, Sorenson & Mio (2003) asked students to rate their sense of direction on a nine-point scale. The results were similar to previous assessments in that students in the group with a good sense of direction had better accuracy in pointing to the landmarks than the poor sense of direction group. Additionally, the group with a good sense of direction was more accurate compared to the other group in identifying a location within an unfamiliar building by using external landmarks (the sun or the campus building) to orient themselves.

The results of experiments that have been undertaken indicate that humans can keep track of their direction by taking advantage of notable landmarks to aid their orientation. Having a good sense of direction is an advantage in learning the correct layout of a new environment (Hund & Nazarczuk, 2009). Landmarks like the sun, moon, distant mountains or even skyscrapers have a special status for navigators because they have an ideal collection of properties that can assist way finders. If they are both very distant and visible, then they are also likely to be very large and immobile, and so are persistent in the view. Large, immobile objects like mountains can be relied upon to stay where they are, and so define locations and directions (Ellard, 2010).

Landmarks are one of the greatest tools of human cognition in helping people know their position in space and to navigate through it. For example, people mentally rotate roads and other features to create a greater correspondence with wider reference frames in the landscape, estimating distance near the viewpoint and far from the viewpoint; for example, someone walking through a complex maze of streets may orient themselves and their position according to a predominant landscape feature such as a mountain or preeminent building. The space around the body is organized by a mental framework which can be defined by three functional spaces related to the interaction of the body to the spatial world. First, knowing how to get from where we are to where we need to be; second, being aware of our immediate surroundings of where we are looking; and third, keeping track of what our bodies are doing. Those functional spaces allow people to represent themselves in the context of geographical objects, landmarks and paths, the reference frame and the perspective (Tversky, 1999).

In relation to human interaction with space, people tend to use a map as an additional tool to help their purpose to reach their destination or to know their environment. Galotti (2007) presented cognitive maps to assess how people interact with maps. There are three types of knowledge involved in forming and using cognitive maps: landmark knowledge is information about particular features within the landscape; route knowledge is information about specific pathways moving from one location into another; and survey knowledge is an awareness of relative locations and estimated distances between landmarks – the very thing captured on a standard map, showing the location of all paths and features (Seagel & White, 1975).

People tend to report using either an orientation strategy or a routeing strategy, but not both. Orientation strategies are cognitive processes that use survey knowledge. This kind of strategy lets the subject think in an allocentric reference frame using global attributes of a landscape. This strategy is also called the survey strategy. A routeing strategy, by contrast, is based on an egocentric frame of reference, whereby routes are defined as those paths available from where the subject is at the moment. A map, if properly used, is an artefact that extends a person's survey knowledge (Montello, Hegarty & Richardson, 2004). It behaves the same as an internal map, except that it is an external one.

People interact with maps differently and that will raise several questions, for example, do all people rotate their maps while reading them? When do people use a map, and why? How do they gesture? Do they point to the map? Regarding these questions, Skagerlund, Kirsh & Dahlback (2012) studied how people interact with a physical map to help navigate through an unfamiliar environment. They asked participants to navigate based on three kinds of navigation information: survey, route and landmark (Herman & Siegel, 1975). Participants were asked to rate themselves as people of high navigational skill or low navigational skill. Each person had their way to find their destination, so maps were used differently by different people depending on their navigational abilities. Navigators with high orientation skills kept the map in the same upright position regardless of how well this matches the current view. Navigators with a low orientation score, on the other hand, prefer to manipulate the map position to align it with their current view. The low navigation ability group used the egocentric framework reference strategy. This strategy was also observed in the context of you-are-here (YAH) maps. Research conducted by McKenzie & Klippel (2014) relating to YAH maps demonstrated that this strategy helps people to analyse where they are on the map and their relationship with the presence of landmarks on maps during way-finding.

After considering human ability with landmark experiments, human ability in comparing maps and images of real landscapes became the subject of research. One of the research projects compared recall of information from topographic maps and photographs in the form of two experiments. The first experiment recalls memories for photographically presented natural landscapes (Montello, 1994). The participants who were considered novice users of topographic maps, were asked to point to the areas on the topographic maps that corresponded to the photographic images based on their memory. The second experiment included experienced topographic map users. These groups were asked to sketch the maps while looking at them rather than working from memory, and then the participants were asked to point out which area of the sketched map that photographic images belonged to. This research allowed the authors to describe how using a topographic map in a scene-matching task influences the recall of topographic-map information (Montello 1994).

In conclusion, human spatial cognition research has developed profoundly in understanding the role of landmarks. The next wave of research tried to understand how people recognize the landmarks around them to find routes to a destination. There is an opportunity to apply some of the experimental psychology approaches to gain a better understanding of the types of spatial frames of reference offered by PARM and how effective these are in certain contexts. For example, A/B testing in psychology is used to test several ideas by comparing between two variables, variables A and B. Each experiment represents a specific case of the overall research study. The A/B test in a controlled experiment can help to refine the tests and to show the ineffectiveness of the strategy and encourage a pivot (Kohavi et al., 2020). The process of the test is by comparing the two versions of ideas and measuring the difference in the performance of each concept, which helps identify issues and improves the method.

2.10 Current Research and Application of Physical Models

Previous studies on the application of physical models have been undertaken by Mendes et al. (2019) where augmented reality and artificial intelligence algorithms were applied to a 3D model of a city for tourism purposes. They used information extracted from OpenStreetMap within a system comprising a projector, 3D printed map and a smartphone. The projector and 3D map were used to give an augmented reality effect for the audience, allowing tourists to interact with it using their smartphone to get a realistic experience of virtual reconstructions of historical places in remote areas. Raskar et al. (1999) combined high-quality graphics systems and physical models of buildings and products in the context of architecture. In this study, multiple ceiling-mounted light projectors graphically augmented table-top scaled physical models of buildings or products. Another study by Calixte & Pierre Leclercq (2017) implemented spatial augmented reality combined with interactive projection mapping (IPM). It was found that such a combination supported a greater understanding of complex shapes.

In terms of augmenting models of landscapes through projection, the project featuring video projected onto the Elbe Valley mentioned earlier in this chapter remains a good example. Priestnall et al. (2012) proposed a research agenda for this general technique using high-definition models and projection, proposing the term Projection Augmented Relief Model (PARM). This study demonstrated that the display was engaging, but revealed that further study was needed to demonstrate whether physical models were better than maps at helping people gain a better understanding of a landscape.

The research gap addressed by this study, therefore, focuses on the factors affecting a user's understanding of landscape when using a projection-enhanced physical model compared to using flat surface representations. It uses two case studies of different environments, an upland terrain (the Lake District) and an urban environment (University Park campus, Nottingham), representing natural rural landscapes and landscapes dominated by human-made landmarks. The study developed an experimental approach using a series of questions related to people's understanding of aspects of the landscape, whilst also varying elements of the content such as the backdrop maps being used. Profiles of users are analysed to give insights into how their background and spatial knowledge affects their judgment. In addition, an exploration of touch-based interaction on projection-enhanced physical models is developed to explore the potential of enhancing users' engagement with the model. In this part of the study, finger detection programs based on the Kinect device are modified to develop a novel technique for identifying the point at which the finger touches the model. The utility and accuracy of this technique are tested on the physical models of the Lake District and University Park Campus.

The development of AR applications has increased over the past few years because AR can be used as a tool to solve problematic concepts for users. Many sectors have used this application, such as medical, healthcare, military, automotive, entertainment, learning and training, educational, marketing, real estate and many more. In the sector related to GIS, several applications have been implemented like Sandbox (Krylos, 2012), TanGeoMS (Tateosian et al., 2010) and Illuminating Clay (Piper et al., 2002). Those applications allowed users to manipulate the object by shaping the material (sand/clay) and seeing the elevation colour changes from the projector. Unfortunately, these applications are not related to modelling terrains representing real placess . From this point of view, the opportunity to develop a niche application arose by combining map images and physical relief models. There is therefore an opportunity to explore the capability of this kind of AR application from the user's perspective.

To summarise this chapter, there have been many applications using physical relief models for many purposes from a few centuries ago until the present day. One of the applications both past and present is for tourism where models in visitor centres can provide additional information to the tourists about the place, either through a static model or enhanced with interactive buttons. People can touch physical models with their fingers in order to feel the surface or can point out interesting places, but the only option for interaction is to use buttons around the side to illuminate certain locations or routes. Based on the review, PARM is an engaging approach to visualizing a landscape, with potential for visitors to interact with the model through the natural gesture of body movement, in particular finger-pointing, but there is a need to explore the affordances of PARM compared to flat maps more carefully.

3 Exploring the Capabilities of PARM for an Upland Rural Terrain

In this experiment, a physical relief model of the Lake District was used. The model provided the ‘frame of reference’ of broad landscape features represented by upland terrain, as is often used in relief models in visitor centres for example. The model had been used in the previous study featuring the ‘Spots of Time’ display (Priestnall et al., 2012) and was shown to be popular and engaging, however, no data were obtained to measure how the physical model helped users to better understand the landscape. Therefore, in this experiment the physical model of the Lake District was compared with flat maps, applying different types of background maps and asking a series of questions relating to people’s interpretation of the landscape.

3.1 Aims

The overall aim of the experiment is to explore the ways in which people gain a better understanding of landscape through projection-enhanced physical models compared to flat surface representations using an upland terrain as a case study. The aims of the Lake District experiment are as follow:

1. To examine if PARM improves participants judgment of how different point locations varied in terms of their relative height and slope, whether one point is visible from the other, and how water would flow between two points.

2. To examine if the model helps with ‘perspective taking’ by asking users to associate 3D perspective views with cones of vision on the map or model.

3. To identify what variables affect people’s ability to gain knowledge from the model

3.2 Designing the Experimental Setup

The experimental setup was designed to allow an individual interpretation of identical geographical information provided by PARM and 2D terrain maps. User interpretation was then recorded and analysed to identify differences in interpretation between the 2D map and PARM.

3.2.1 Tools and Devices

The experimentation used various kinds of tools and devices such as a 3D physical model, a flat board, a metal rig to hold the projector, a projector, a view board, recording devices (camera, video camera, tripod), laser pointer, and a laptop.

The PARM model of the Lake District, UK (Priestnall, 2012) was used in this study (**Figure 3.1**). The model was 60 cm x 60 cm in the horizontal and 2.5 cm in height, made of a lightweight, high-density foam board and all the heights on the surface were exaggerated by 10% . The colour of the surface is white which is the most suitable colour to be projected onto since it offers a clear view of projected presentation compared to other colours. To obtain 2D terrain maps, a white flat wooden board with the dimensions of approximately 150x100 cm was used.

Figure 3.1. PARM Model of Lake District

3.2.2 Participants and Recruitment Process

Some participants were recruited using the Research Participation Scheme System (RPSS) within the University, which gathers participants from the School of Psychology, offering credits for participation. For participants outside the School of Psychology recruitment was undertaken using cash rewards. The announcement was placed on public notice boards around University Park Campus, University of Nottingham, UK.

Each part of the study included 30-50 participants aged between 20-60 years old. There was no requirement for particular background skills. All participants were given information on the study and had to sign a consent form as well as answer the questions on an online form (participants recruited through RSPP) or printed form (for any other participants) about their knowledge of maps before they took part in the study. The consent form and information sheet are provided in Appendix 2 & 3.

Prior to conducting the main study, a pilot study was undertaken to test the set of questions for clarity and effectiveness by using a small number of participants (11 participants) aged between 20-60 years old. Most of the participants were PhD students from a variety of backgrounds and fields of study.

Ethics clearance from the School of Geography, University of Nottingham on the involvement of participants was obtained prior to the experiments (Appendix 1).

3.2.3 Experimentation Environment

The test was undertaken in the SPLINT Lab, Sir Clive Granger Building, University Park, University of Nottingham. The lighting was completely controllable and the test used dimmed lighting to ensure the projected images were visible. Participants were required to sit on a chair and view the model through a view board in order to maintain the same viewing position for each participant in order to reduce bias in the data analysis (**Figure 3.2**).

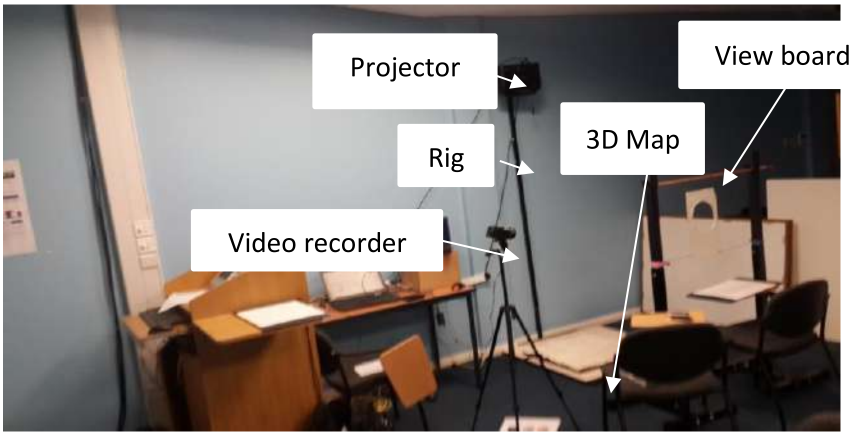


Figure 3.2. The Experimental condition when lights on (top) and lights-off (bottom)

3.2.4 Experimentation Procedures

Participants were provided with a brief description of the experiment and could choose a suitable time to do the experiment via the RPSS portal. Any other interested participants were contacted via email to arrange the experiment schedule and to provide them with relevant information about the experiments, such as the location and the duration of the experiment.

Each participant was assigned an individual experiment session which ran for approximately 50 minutes. The session began with the participant reading the information, completing the consent form and undertaking the online assessment (via Google forms) of their spatial knowledge as described earlier.

Each participant was then required to sit on a chair and was given the chance to ask any questions relevant to the experiment that they are about to do. Once the participant was ready to start, the light in the room was dimmed and a video recorder was turned on. Each session was conducted back-to-back between the 2D map on a flat board and a 3D representation via the PARM, varying the order for different participants. Participants would see the map and the questions through a view board (**Figure 3.3**). The questions were as follows:

1. Notice both lakes, which is the highest lake? A or B
2. Notice both peaks, which is the highest peak? A or B
3. Which point represents the picture below? A or B
4. Which point can see the red point? A or B
5. Which is the steeper slope? A or B
6. Where would water at the blue point probably flow to? A or B

Figure 3.3. A participant see the map through a view board

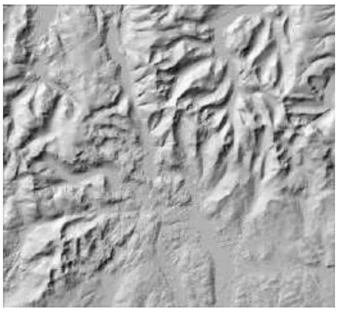
Each participant was asked to give the answer to each question verbally and all answers were noted by the researcher on an excel spreadsheet. All of the answers were also recorded by a video camera to allow playback to recheck the answers and to obtain data on the time required by each participant to answer each question. Participants' correct answers and response times were analysed to determine whether different types of representation (3D physical model or 2D terrain maps) and different types of backdrop maps have any effect on people's understanding of geographical information presented.

3.3 Pilot Study: Refinement of Experimental Setup

3.3.1 Backdrop Maps

There are various styles of map which can display relief, which can stand alone as 2D maps but can also be projected over a relief model to enhance the portrayal of the landscape. A collection of backdrop images of the Lake District from the observation study on the 'spots of time' exhibit (Priestnall, 2012) have been explored to examine their applicability to be used as backdrop maps in this study (**Figure 3.4**). The PARM of the Lake District covered a square area from 2°48'19.567" W 54°34'29.818" N in the North East corner and 3° 11'41.269" W 54°20'42.139" N in the South East corner. All of the backdrop maps were cropped to this area.

Hillshade maps represent an illumination of a surface according to the position of the sun using a greyscale shading effect and can augment the view of PARM. This map was selected as one of backdrop images used in this study as it also offered a representation which was considered to be as close to the un-textured PARM surface as could be represented in 2 dimensions. A hillshade map was created with just enough brightness to portray the relief. An addition of 40% brightness level and 20% contrast of the original hillshade map were applied, resulting in a light grey image which was closer to the 'plain PARM' surface but which showed the relief features (**Figure 3.5**). A lighter tone would have resulted in missing relief features of the map (**Figure 3.6**).



Hillshade map

Contour Map A

Contour Map B

Hillshade map with additional features

Tourist Map

Aerial Map

Figure 3.4. Backdrops Image for Lake District Model 1:50K scale

Figure 3.5. Hillshade map with addition of 40% brightness and 20% contrast

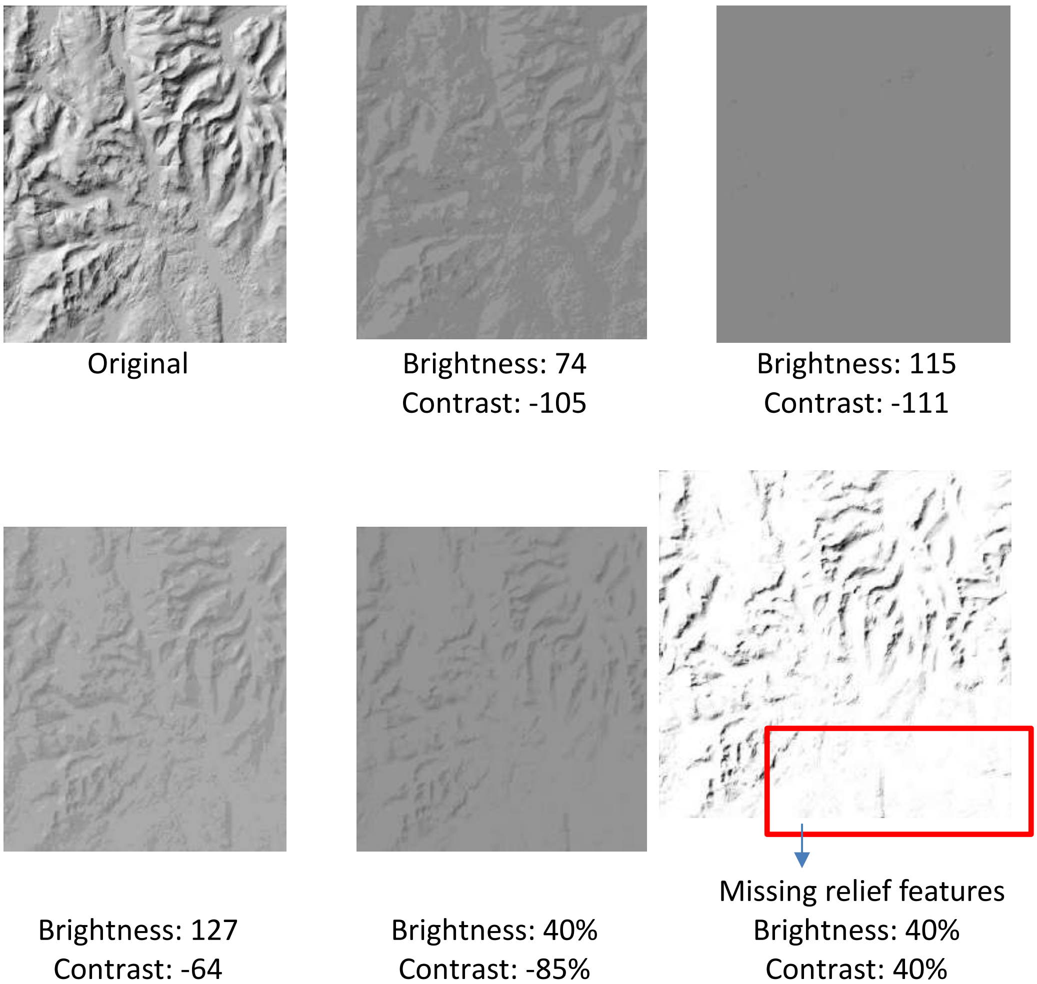


Figure 3.6. Hillshade Subdue: Hillshade Map with different brightness and contrast level

There were two types of contour map used in the 'Spots of Time' presentation which are similar to each other but have slightly different features. Contour map A has contours, labels, roads, lakes and soil density features, while contour map B has contours, labels, roads, lakes, hillshading, and vegetation features. Both types of contour map were the types of maps that people would be familiar with and usually see in daily life. Initially both maps were considered for the experiment, however due to their similarity only contour map A was selected as it reflects a more typical example (without the Hillshade effect) and is referred to as 'contour map' in the main study.

Another backdrop map used in the experiment was the aerial image. It is a complex colour backdrop but does not have any indication of elevation hence would not give a clue on the height of an area.

The other two types of maps in Figure 3.4, the hillshade map with additional features and the tourist map, were regarded as too complex in features, colours, and symbols, when the focus of the study was on the portrayal of relief. These characteristics provided too much background noise which could visually distract participants in answering questions. Therefore, they were not used in the experiment. The maps that were used for the experiment were hillshade, contour map A, lighter hillshade map, and Aerial map.

The backdrop maps were sized at 17.37 cm (h) x 19.05 cm (w) in size using Microsoft PowerPoint 2010 (**Figure 3.7**) to produce a square 2D map of a comparable size to the PARM when projected.

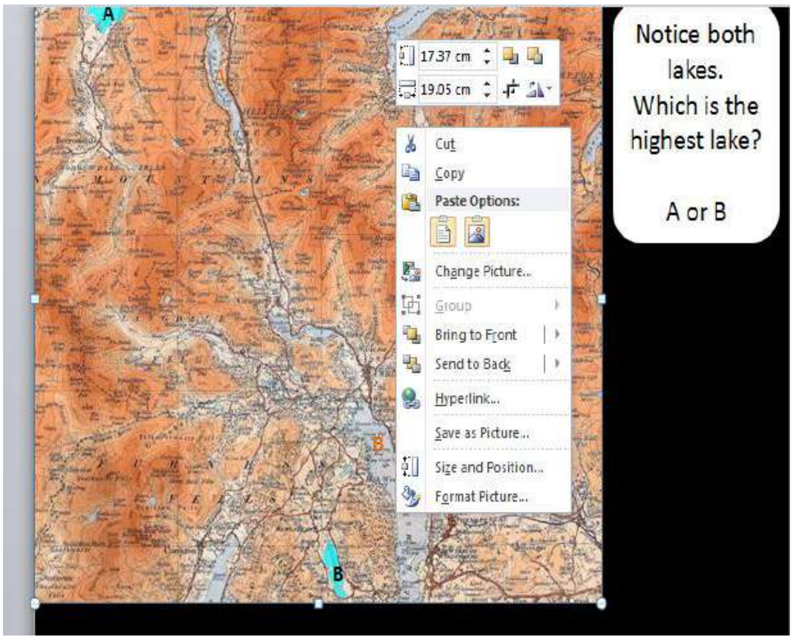


Figure 3.7. Size setting of backdrop map

3.3.2 Projector's set-up

The projector was held using a metal rig and tripod and mounted 2.2m above the surface of the model or flat board and was set at the resolution of 1280x1280 pixels. This projector setup would provide images measuring 60x60 cm for both PARM and flat board.

There were two modes of projection available, 'front' and 'inverted' (**Figure 3.8**). Inverted mode was used in the study so that the participant's view of the projected images was not obscured by the rig. By inverting the images, they appeared 'North up' when viewed from the opposite side to the rig.

Figure 3.8. Front mode (left) and Invert front position (right) of projector

3.3.3 Design of Questions

A set of questions was prepared to examine how participants would interpret geographical information displayed on a 3D model (PARM) and 2D terrain map (flat board). The questions were projected and could be seen on the upper right side of the map or model. The clarity of the questions was tested through a pilot study involving 11 participants who answered and discussed part or all questions to ensure there would be minimum bias or interference when answering the questions. This includes the type of question, the display of questions (font colour/size, position), the wording of questions, the number of questions, and the user position and point of view.

A series of questions was developed that would explore people's ability to distinguish different elevations and also various derivatives of elevation such as slope and water flow. Questions related to visibility offered more complex derivatives of elevation which required the viewer to imagine a different perspective on the landscape. The questions used in the pilot study were:

1. Height of lakes comparison

   The purpose of this question was to compare the elevation of two lake surfaces. The question the participants were asked was: "Notice both lakes, which is the highest lake?" A or B.
2. Height of peaks comparison

   The peaks comparison is to measure the abilities of participant in differentiate the height of two peaks on the model or flat map. The question the participants were asked was: "Notice both peaks, which is the highest peak?" A or B
3. Two cones of vision on map with one 3D picture

   Participants were asked to choose which point of view on the model is similar to the representative picture provided. There were two points of view that they have to compare, represented as cones of vision on the map or model. The question for the participants were asked was: "which point represents the picture below?" A or B

4. Intervisibility test

   To judge whether a particular place can be seen from another place. There will be a main point on the model and two other secondary points. The question asked from which secondary point the main point can be seen. The points were placed such that there was an obstacle for one of the two secondary points that would prevent them having direct line of sight of the main point. The question the participants were asked was: "Which point can see the red point?" A or B

5. Steeper slope

   The steeper slope test is to compare the steepest slope between two slopes marked as lines on the map or model. The question the participants were asked was: "Which is the steeper slope?" A or B

6. Water flow

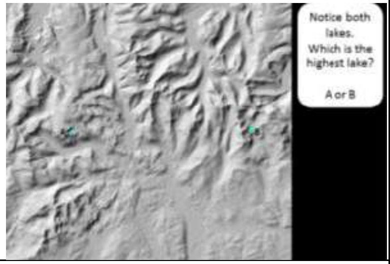
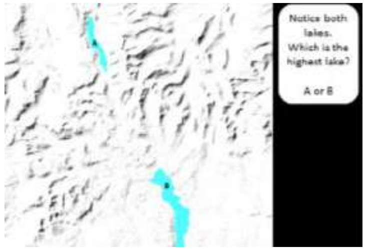
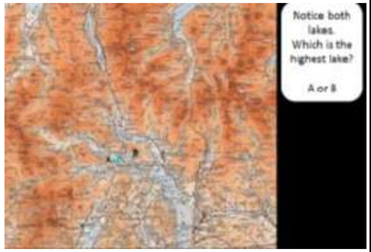
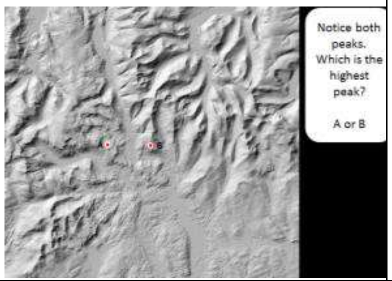
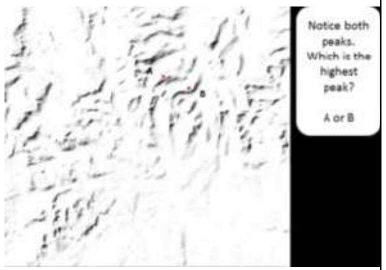
   The water flow question is to test which of two points (A or B) would receive flow from a source point. There will be a main point representing the source of the water and two other secondary points as the potential destinations for water flow. The question the participants were asked was: "Where the water at the blue point will be probably flowing to?" A or B

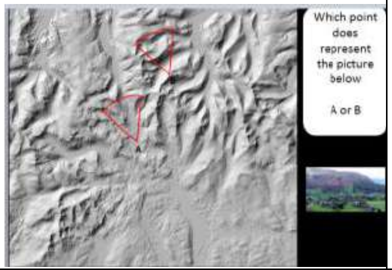
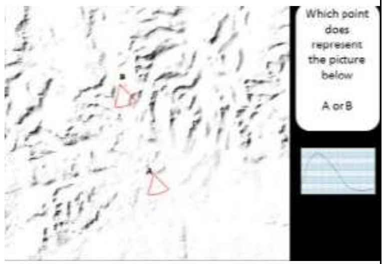
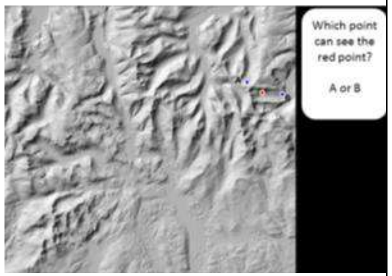
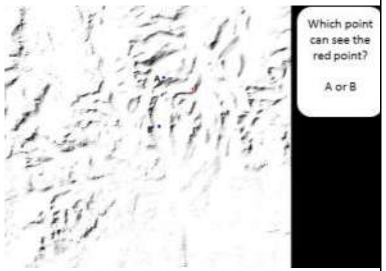
7. Who walk up steeper slope?

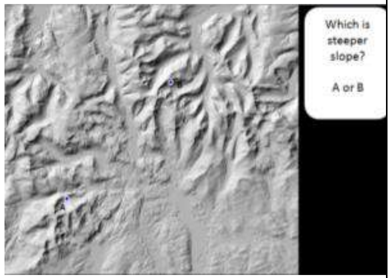
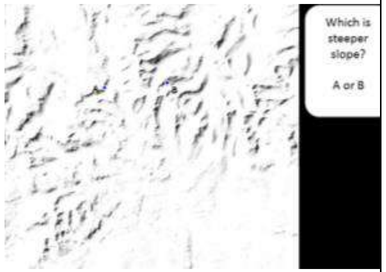
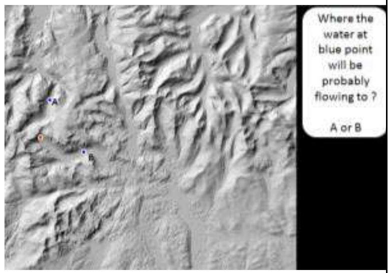
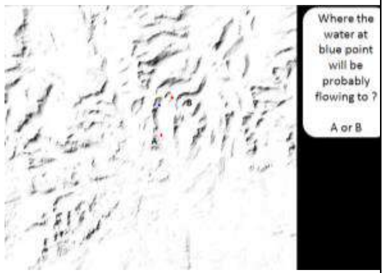
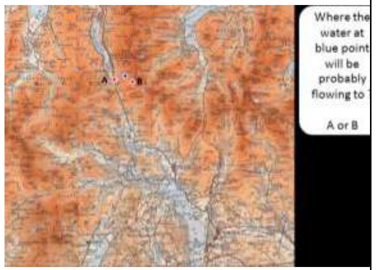
   The participant was shown two animated walking paths contain sloping sections and was asked to determine which path was steepest. The participants were asked was: "Who walked up the steeper slope?" A or B. This question type was later removed due to similarity with steeper slope question.

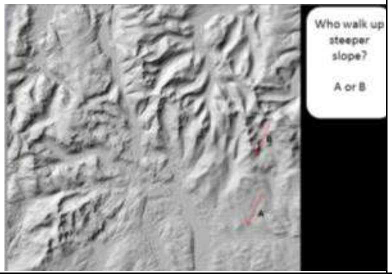
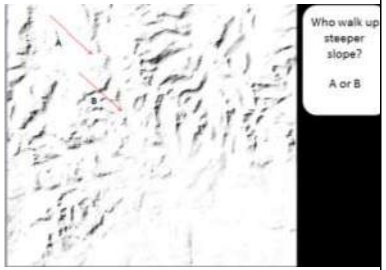
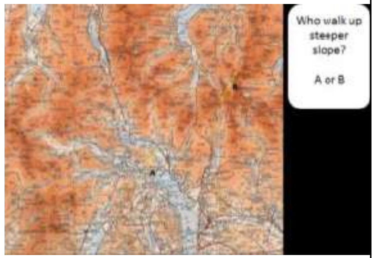
For each type of question, four different background maps were used. There was also variation in the distance between features to compare, some near, some a medium distance, and some far away from each other. For instance, in the height of lake comparison questions, participants were asked to compare the height of two lakes on different backdrop maps and with different distances (near or medium or far) to explore the influence of these two factors on their perception of the elevation of the lakes. Examples of how questions were displayed and the details shown are provided in **Table 3.1**.

Table 3.1. Examples of different type of question displayed in different background map

Type of Questions	**Examples of questions displayed in different background map**			
	Hillshade	**Hillshade 40% brightness**	**Contour Map**	**Aerial**
Height of lakes comparison				
	• Small lake (0-4 cm long on the model) • Distance: Medium (20-40 cm)	• Large lake (>4 cm long on the model) • Distance: Far (40-60 cm)	• Small lake (0-4 cm long on the model) • Distance: Near (0-20 cm)	• Small lake (0-4 cm long on the model) • Distance: Near (0-20 cm)
Height of peaks comparison				
	Distance: Near (0-20 cm)	Distance: Near (0-20 cm)	Distance: Near (0-20 cm)	Distance: Far (40-60 cm)

Type of Questions	**Examples of questions displayed in different background map**			
	Hillshade	**Hillshade 40% brightness**	**Contour Map**	**Aerial**
Two cones of vision on map with one 3D picture				
	Distance: Near (0-20 cm)	Distance: Medium (20-40 cm)	Distance: Near (0-20 cm)	Distance: Medium (20-40 cm)
Intervisibility test				
	Distance: Near (0-20 cm)	Distance: Near (0-20 cm)	Distance: Medium (20-40cm)	Distance: Near (0-20 cm)

Type of Questions	Examples of questions displayed in different background map			
	Hillshade	**Hillshade 40% brightness**	**Contour Map**	**Aerial**
Steeper slope				
	Distance: Medium (20-40 cm)	Distance: Near (0-20 cm)	Distance: Medium (20-40 cm)	Distance: Near (0-20 cm)
Water flow				
	Distance: Near (0-20 cm)	Distance: Near (0-20 cm)	Distance: Near (0-20 cm)	Distance: Near (0-20 cm)

<table>
<tr><th rowspan="2">Type of Questions</th><th colspan="4">Examples of questions displayed in different background map</th></tr>
<tr><th>Hillshade</th><th>Hillshade 40% brightness</th><th>Contour Map</th><th>Aerial</th></tr>
<tr><td>Who walk up steeper slope</td><td>
</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td></td><td>Distance: Near (0-20 cm)</td><td>Distance: Near (0-20 cm)</td><td>Distance: Medium (20-40 cm)</td><td>Distance: Medium (20-40 cm)</td></tr>
</table>

The backdrop maps used for this type of question in Pilot Study were Hillshade, Hillshade with 40% brightness level, Contour Map A, and Contour Map B.

The participants answers were analysed based on the number of correct answers and the time spent in giving the answer. Therefore, how the question was given is also essential. **Figure 3.9a** below shows a question with four alternative answers, A, B, C, and D. After the pilot this multiple question type was considered to give too many options regarding the test speed and accuracy. Alternatively, a two-alternative forced choice (2AFC) was chosen which is a task method commonly used in experimental design to test the speed and accuracy of an answer (**Figure 3.9b**).

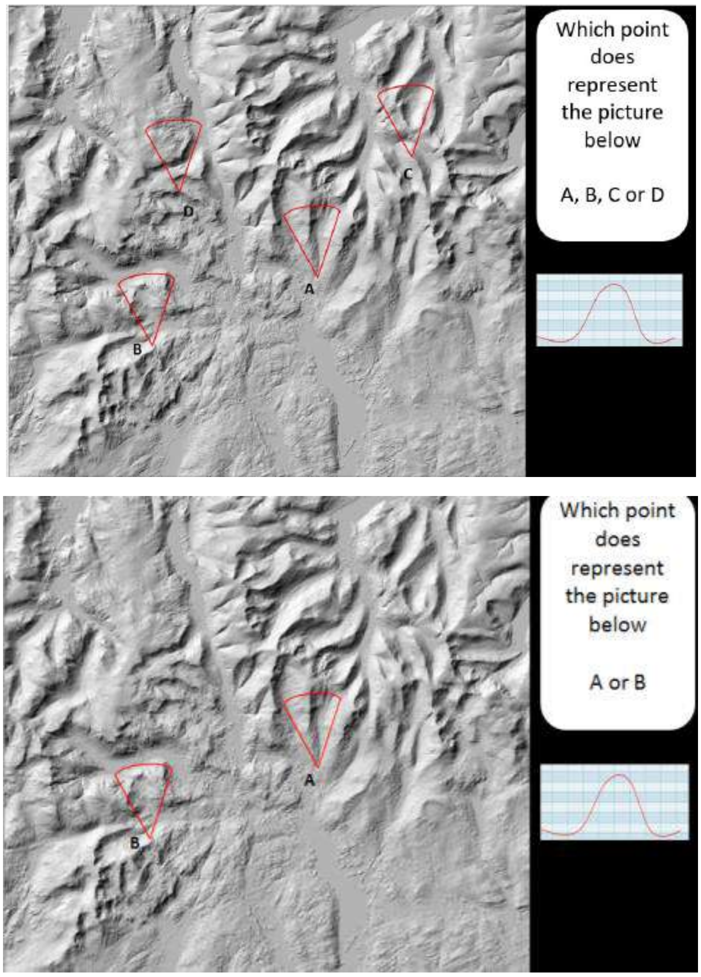


Figure 3.9. Example of multiple answer question (top); Example of 2AFC questions (bottom)

During the pilot study, the clarity of some questions was seen to be influenced by how the questions were displayed, including the labelling and marking. Using symbols like triangles, squares or stars appeared to cause distraction to the participant's view. Those symbols have sharp edges that will create a perception that 2 marked points is closer to each other. Alternatively, a round symbol was considered a better option for the main study to avoid bias to the participant's perspective (**Figure 3.10**).

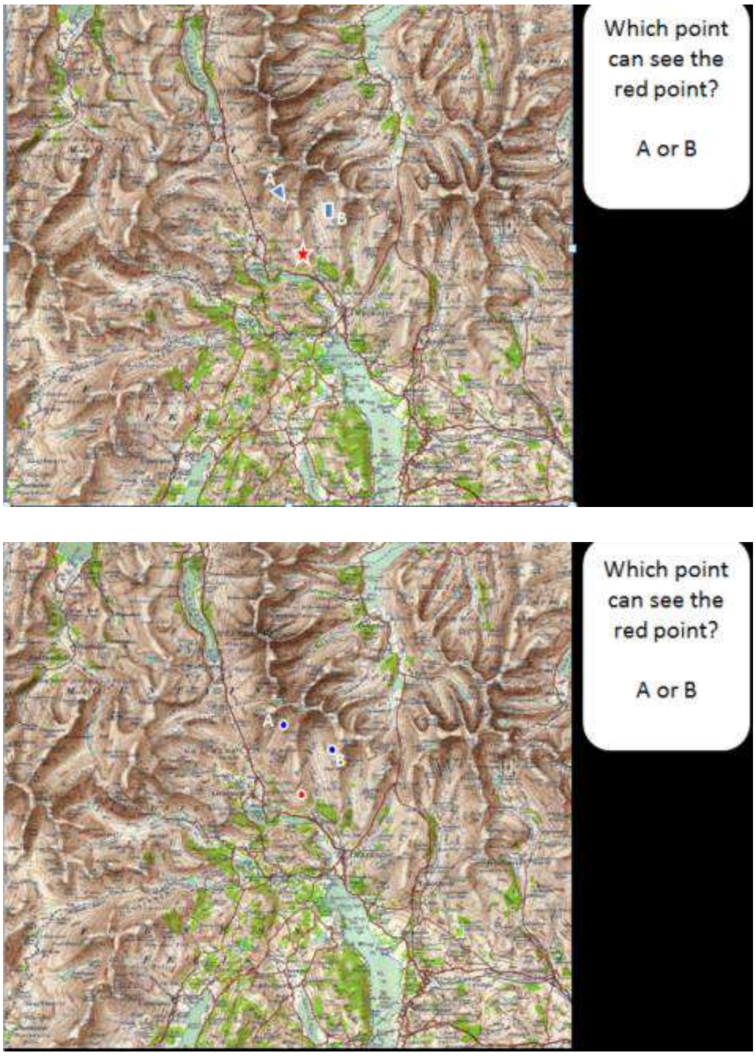


Figure 3.10. Different marking symbols on a map

The colour of marking symbols and letters had to be readable as well as distinct compared to the background/backdrop image. This is particularly true when the map and questions were projected into the 3D model which has uneven surfaces which created changes in the shape of the letters and symbols. Each backdrop map has different background colours, therefore different colours of marking were used for different maps. For examples, the line colour of red was suitable for the hillshade map, while a yellow colour of the line would be more suitable for the contour map and the aerial image. Illustrations of different colours of symbols and letters can be seen in **Figure 3.11**.

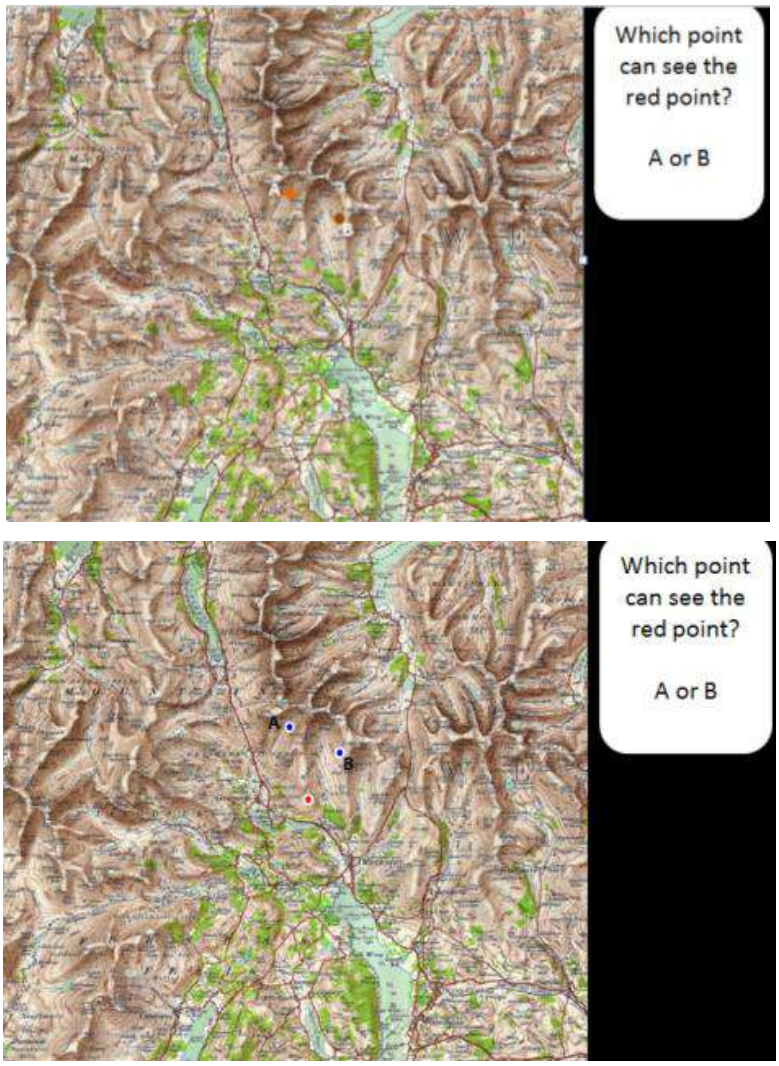
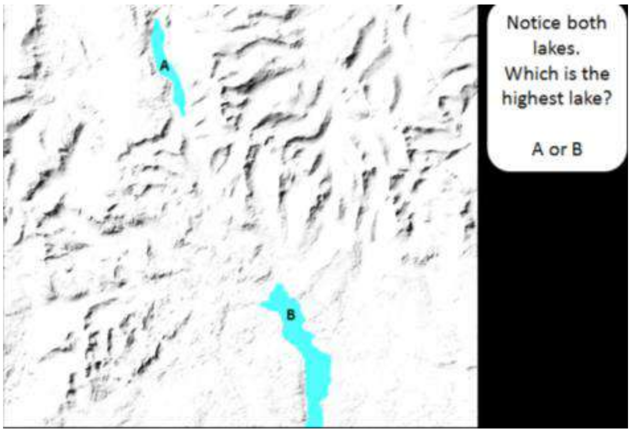


Figure 3.11. Different colours of marking symbols and letters on a map

The position of markings could also affect the user's perception. For instance, placing the question's labels inside the lakes would give an unintentional clue to the participant to discriminate the height between two lakes. To minimise bias, it would be better to put the question's labels near the lake because the object is the lake that has a certain area to be noticed and not the labels position only (**Figure 3.12**).



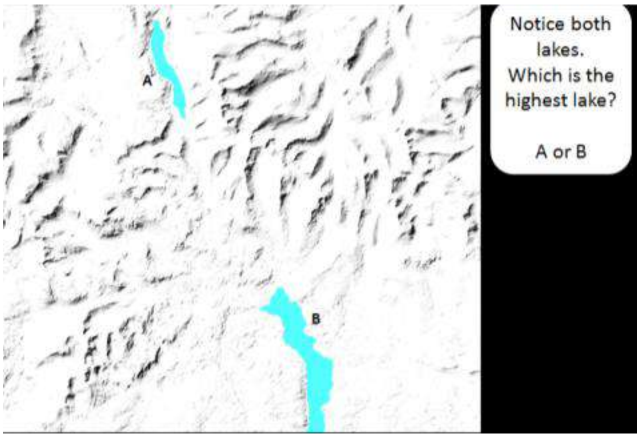


Figure 3.12. Example of Placement of Question Label on Map

The use of markings in the cone of vision type question was also discussed. The idea of the cone of vision test is to examine how participants understand the terrain shape. This method uses a shading technique where the area outside of the cones was displayed in a darker shade. A problem observed was that it could conceal the area outside the cones of vision (**Figure 3.13a**). Alternatively, a cone view was created without this shading method, displaying only the outline of the cone, and this seemed clearer as it did not obscure the detail of the backdrop image around the cone (**Figure 3.13b**).

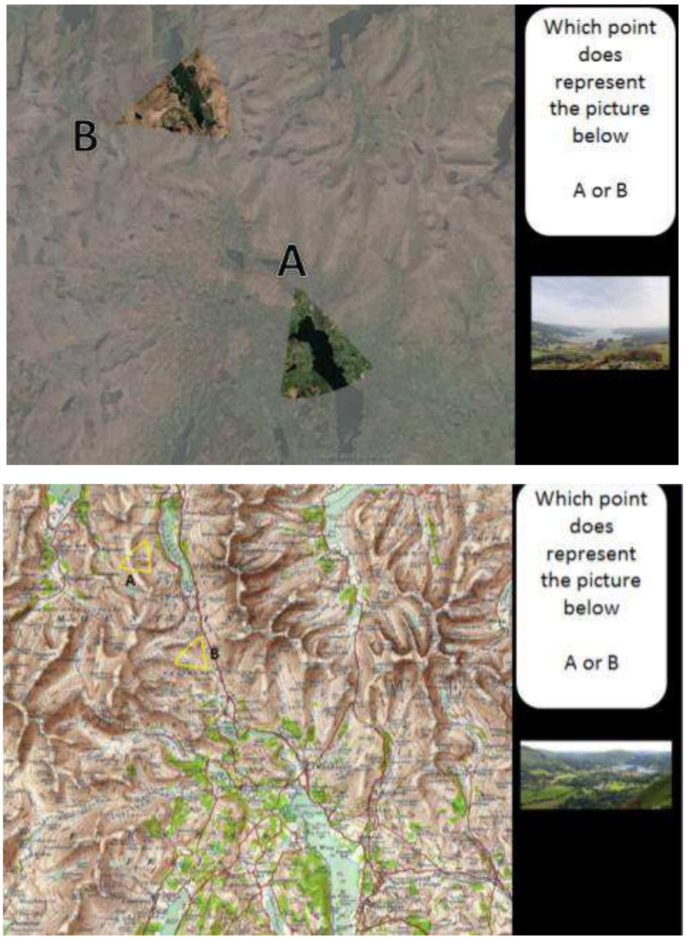


Figure 3.13. Marking in the cone of vision type question with shading (top); Marking without shading (bottom)

3.3.4 Further reflections

The preliminary study suggested that there were clear differences between participants' responses using the PARM and the flat maps, but importantly it also revealed some issues with the experimental design which could be modified for the main study. From observation of the pilot study, the viewing position of each participant was not the same, as some used the viewing board and others didn't. It was clear that this did affect the behaviour of the participants so it was decided that a view board should be used for all participants in the main experiment.

As a result of observations during the pilot study, the questions “Who would walk a steeper slope” was eliminated from the main study due to the possibility of causing bias to the participant perceptions. There appeared to be a difference in how people perceived steep slope slopes when thinking about walking the landscape, trying to imagine how arduous the route might be, rather than comparing the slopes of two short lines in a more quantitative fashion.

3.4 Main Study

In the main experiment participants were given six types of questions (two of each question type) as follow:

1. Height comparison between lakes
2. Height comparison between peaks
3. Cone vision Comparison
4. Intervisibility test
5. Steeper slope comparison
6. Water flow test

There were 96 questions where 48 questions were displayed on the 3D physical model and the other 48 were on a flat board with 4 different background maps i.e., Hillshade map, Hillshade map with addition of 40% brightness level and 20% contrast (Hillshade Subdued), Contour map, and Aerial image with scale of 1:50K in details shown in **Table 3.2** below.

Table 3.2. Number of Questions Given in the Experiment

Type of map	PARM	Flat map
Hillshade*	12	12
Contour*	12	12
Hillshade Subdued*	12	12
Aerial*	12	12
Total	*48*	*48*

*Consists of an equal number of 6 type of questions, i.e. Cone, Intervisibility, Lake, Peak, Steep, Waterflow.

In order to measure how the 3-dimensional features of the physical model may help participants with their judgement, the questions have been designed according to several relevant variables and factors as provided in **Table 3.3**. For example, for the Height of Lake comparison type of question, the distance between the lake in question on the physical map was varied i.e., near (distance between 2 lakes were 0-28.5 cm), medium (distance were 28.5-57 cm), and far (57-85.6 cm). This variation will then be analysed to determine whether distances between lakes affected participants in judging the difference in height between the lakes. In general, it could be assumed that if the lakes were in a closer position to each other, it would be easier to compare their height. Another issue was whether higher lakes on the physical model would be easier to compare than lower lakes. The position of the lakes on the physical model was therefore varied.

A complete list of questions is provided in Appendix 4. The questions were given in a controlled randomized order so that questions on the same type of backdrop map would not be given in sequence. This was done to minimise bias due to extended exposure on one backdrop map for example. It was also ensured that each participant had equal numbers of near and far factors. All participants have the same question type and variables (near, medium, or far or low, medium and high).

Table 3.3. Variables and Factors for Each type of Question

No.	Variables	Factors	
Height comparison between lakes			
(1)	Distance between lakes A and B	Near Medium Far	0 cm - 28.5 cm 28.5 cm - 57 cm 57 cm - 85.6 cm
(2)	Heights of Lakes	Low Medium High	0 cm - 0.8 cm 0.8 cm - 1.6 cm 1.6 cm - 2.4 cm
(3)	Lakes position from the participant	Near Medium Far	0 cm - 20 cm 20 cm - 40 cm 40 cm - 60 cm

No.	Variables	Factors	
Height comparison between peaks			
(1)	Distance between Peaks A and B	Near Medium Far	0 cm - 28.5 cm 28.5 cm - 57 cm 57 cm - 85.6 cm
(2)	Heights of Peaks	Low Medium High	0 cm - 0.8 cm 0.8 cm - 1.6 cm 1.6 cm - 2.4 cm
(3)	Peaks position from the participant	Near Medium Far	0 cm - 20 cm 20 cm - 40 cm 40 cm - 60 cm
Cone of vision Comparison			
(1)	Distance between Cones A and B	Near Medium Far	0 cm - 28.5 cm 28.5 cm - 57 cm 57 cm - 85.6 cm
(2)	Heights of Cones	Low Medium High	0 cm - 0.8 cm 0.8 cm - 1.6 cm 1.6 cm - 2.4 cm
(3)	Direction of the cones	North South West East	
(4)	Cones position from the participant	Near Medium Far	0 cm - 20 cm 20 cm - 40 cm 40 cm - 60 cm
Intervisibility test			
(1)	Distance between points A and B	Near Medium Far	0 cm - 28.5 cm 28.5 cm - 57 cm 57 cm - 85.6 cm
(2)	Heights of points	Low Medium High	0 cm - 0.8 cm 0.8 cm - 1.6 cm 1.6 cm - 2.4 cm
(3)	Points position from the participant	Near Medium Far	0 cm - 20 cm 20 cm - 40 cm 40 cm - 60 cm

No.	Variables		Factors
Steeper slope comparison			
(1)	Distance between Steeps A and B	Near Medium Far	0 cm - 28.5 cm 28.5 cm - 57 cm 57 cm - 85.6 cm
(2)	Heights of steeps	Low Medium High	0 cm - 0.8 cm 0.8 cm - 1.6 cm 1.6 cm - 2.4 cm
(3)	Steeps with similar direction		Horizontal, vertical, diagonal
(4)	Steeps with different direction		Vertical - diagonal
(5)	Steeps position from the participant	Near Medium Far	0 cm - 20 cm 20 cm - 40 cm 40 cm - 60 cm
Water flow test			
(1)	Position from the participant	Near Medium Far	0 cm - 20 cm 20 cm - 40 cm 40 cm - 60 cm

3.5 Results

3.5.1 Profile of Participants

Data for accuracy and response time from 42 participants were analysed statistically using MS Excel and SPSS Statistics v24. Accuracy data are the percentage of correct answers, while response time data was calculated based on response data of the correct answer only, which was a requirement for analysing the A/B test results, with false answers not counting as they would cause biase in the results. Data from participants involved in the pilot study were not included in the main study as they would have prior knowledge of the experiment and the landscape itself. Profiles of participants according to information they provided can be seen in **Table 3.4** and **Figure 3.14**.

Table 3.4. General Profile of Participants – Lake District Model

Details	Number (percentage)
Total participant	42
Female participant	25 (59.5%)
Male participant	17 (40.5%)
Participant who has visited Lake District	10 (23.8%)
Participant who has observed a physical map	26 (61.9%)
Participant who has used ArcGIS software	None

Participant's awareness of aerial maps and contour maps is shown in **Figure 3.14**. Most participants have no knowledge or experience in using aerial and contour maps, with 65% and 49% answering 'no', respectively.

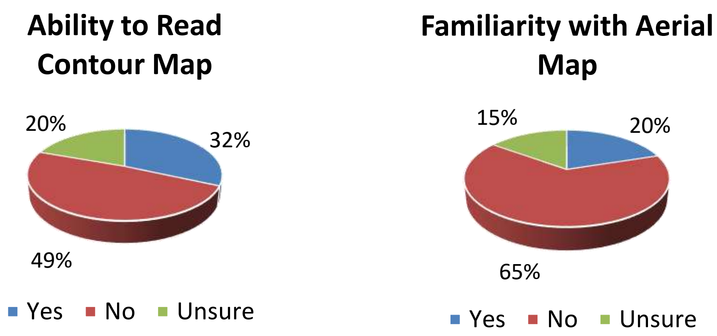


Figure 3.14. Participant map awareness

Google maps is widely known as an application to assist with providing directions and the pie chart in **Figure 3.15** provides information about the participant's frequency of use of the application. Almost all participants have used it in various occasions with only 2% having never used the application.

Participants were given three types of question in regard to their experience in using maps. A higher proportion of participants considered themselves to occasionally experience difficulties when reading maps or being confused in determining cardinal directions (61-66%). Whereas 32-34% of them claimed that they know how to read a map well without having any disorientation (Figure 3.16).

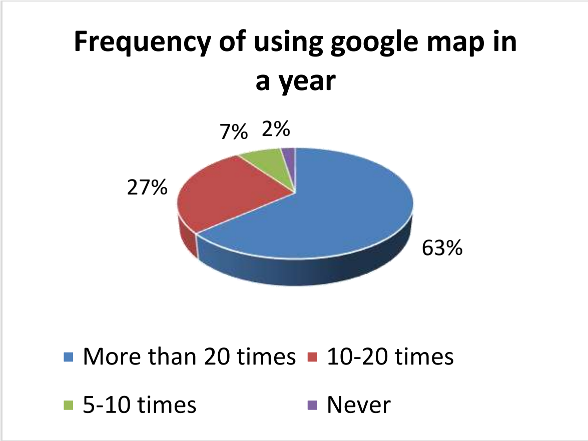


Figure 3.15. Participant use of google map

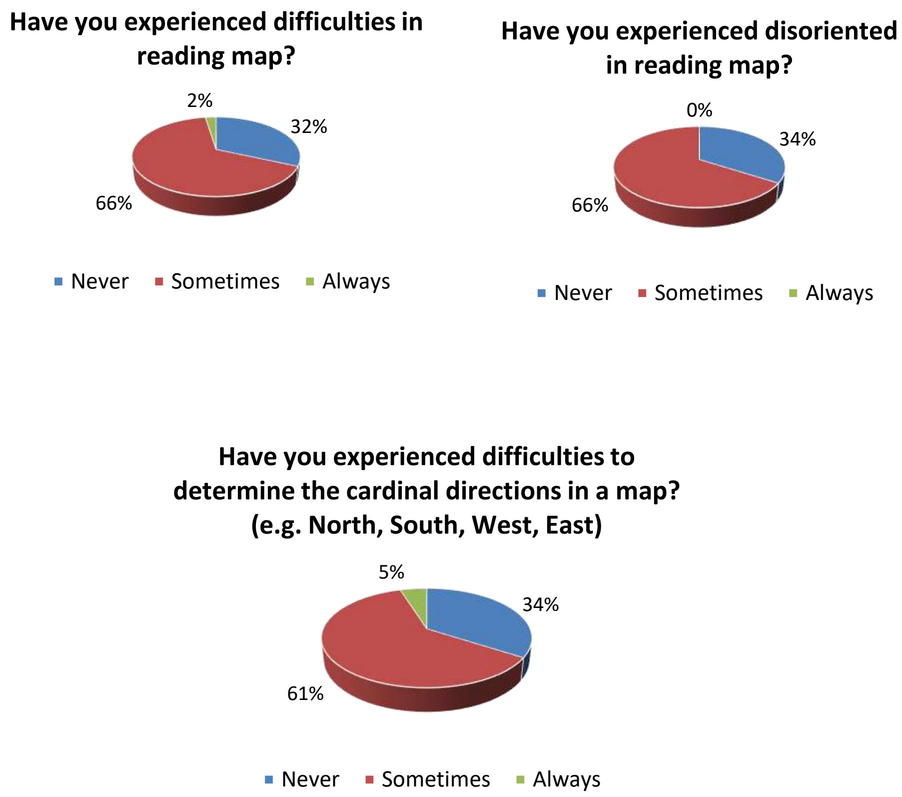


Figure 3.16. Number of participants having trouble in reading map or determining directions

3.5.2 Accuracy and Response Time of PARM and Flat Map Based on Type of Backdrop map

For all 4 types of backdrop map, PARM showed higher accuracies than the flat map. The difference in accuracy between PARM and flat map ranged between 7% to 17% for different backdrop maps. The highest difference was shown for the aerial map (17%) and the lowest was shown for the contour map (7%). Statistical analysis (**Table 3.5, 3.6** & **Table 3.7**) shows that different types of representation (PARM and Flat Map), as well as the interaction between different type of map and backdrop image, resulted in significant effects on accuracy at the 95% confidence level (sig <0.05). Whereas different types of backdrop map also gave significant effects statistically on accuracy.

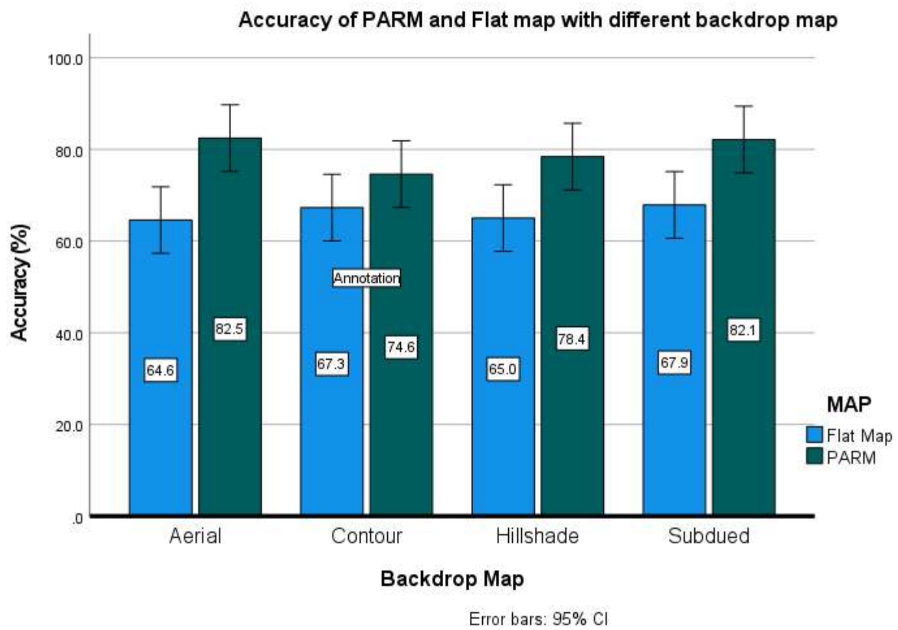


Figure 3.17. Accuracy of PARM and Flat Map with Different Backdrop Map

Table 3.5. Descriptive Statistics of Accuracy of PARM and Flat Map with Different Backdrop Map

	MAP	Mean	Std. Deviation	N
Aerial	Flat Map	64.9	10.0	42
	PARM	81.9	13.6	42
	Total	73.3	14.7	84
Contour	Flat Map	67.1	16.0	42
	PARM	74.0	12.2	42
	Total	70.5	14.6	84
Hillshade	Flat Map	66.1	13.7	42
	PARM	78.4	11.6	42
	Total	72.2	14.1	84
Hillshade_Subdued	Flat Map	67.1	15.1	42
	PARM	81.5	14.8	42
	Total	74.3	16.5	84

Table 3.6. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM with Different Backdrop Map and Flat Map with Different Backdrop Map

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop	657.035	3	219.012	1.580	.195	.019
Backdrop * MAP	1202.670	3	400.890	2.892	.036	.034
Error (Backdrop)	34095.155	246	138.598			

Table 3.7. Tests of Between-Subjects Effects of Accuracy between PARM and Flat Map with Different Backdrop Map

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1770694.651	1	1770694.651	5610.383	.000	.986
MAP	13651.000	1	13651.000	43.253	.000	.345
Error	25880.043	82	315.610			

The response time for all types of backdrop map on flat maps is higher than the PARM (**Figure 3.18**). For the Flat map, participants tend to answer quicker on the Aerial map, Hillshade map, Subdued map and the last one is on the Contour map. However, different patterns were shown by the PARM where response time was the quickest for Aerial, followed by Contour, Hillshade, and Subdued. Statistical analysis shows that different types of representation (PARM and Flat Map) resulted in significant effects on response time at the 95% confidence level (sig <0.05) (**Table 3.9** & **Table 3.10**). Different types of backdrop map had no significant effect statistically on response time.

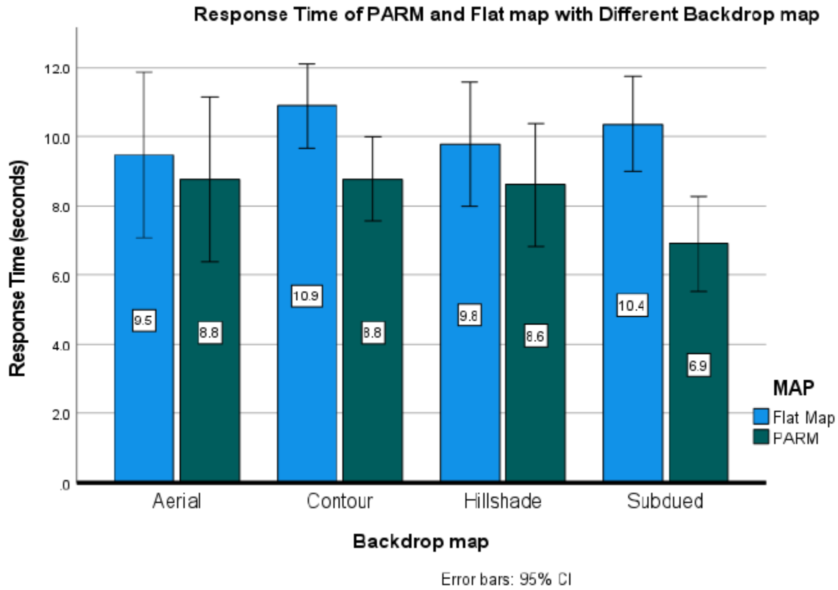


Figure 3.18. Response Time of PARM and Flat Map with Different Backdrop Map

Table 3.8. Descriptive Statistics of Response Time of PARM and Flat Map with Different Backdrop Map

Backdrop Map	MAP	Mean	Std. Deviation	N
Aerial	Flat Map	9.5	3.9	42
	PARM	8.8	10.3	42
	Total	9.1	7.7	84
Contour	Flat Map	10.9	4.5	42
	PARM	8.7	3.4	42
	Total	9.8	4.1	84
Hillshade	Flat Map	9.8	5.4	42
	PARM	8.6	6.2	42
	Total	9.2	5.8	84
Hillshade_Subdued	Flat Map	10.4	5.8	42
	PARM	6.9	2.3	42
	Total	8.6	4.8	84

Table 3.9. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM and Flat Map with Different Backdrop Map

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop	61.167	3	20.389	.927	.428	.011
Backdrop*MAP	93.535	3	31.178	1.417	.238	.017
Error (Backdrop)	5411.555	246	21.998			

Table 3.10. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map with Different Backdrop Map

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	28411.447	1	28411.447	445.108	.000	.844
MAP	291.388	1	291.388	4.565	.036	.053
Error	5234.098	82	63.830			

3.5.3 Accuracy and Response Time of PARM and Flat Map Based on Type of Question

The comparison of PARM and Flat Map based on the different types of questions is shown in **Figure 3.19**. Overall, the results suggested that PARM gave a better portrayal than flat maps regarding the types of questions, Cone of Vision, Intervisibility, Height of Lakes, Height of Peaks, Steep Slopes, with the most substantial difference being observed with waterflow. The least significant was the intervisibility type of question, with 8% difference between PARM and the flat map. Statistical analysis shows (**Table 3.12** & **Table 3.13**) that different types of representation (PARM and Flat Map) as well as different types of questions resulted in significant effect on accuracy at 95% confidence level (sig <0.05). However, interaction between different types of map and types of question showed no significant effect statistically on accuracy.

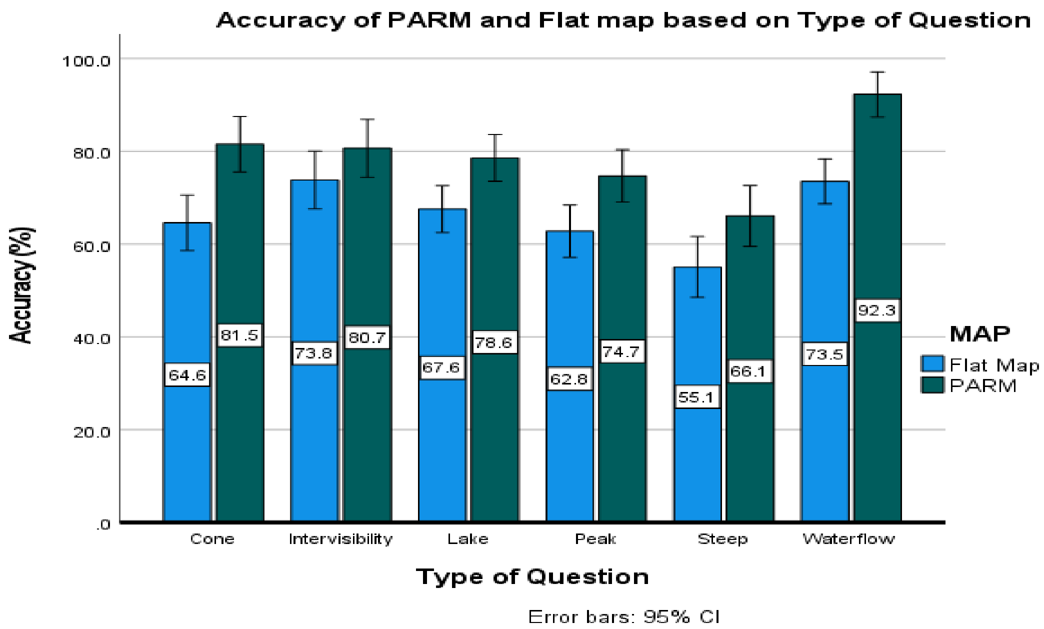


Figure 3.19. Accuracy of PARM and Flat Map Based on Type of Question – Lake District Model

Table 3.11. Descriptive Statistics of Accuracy of PARM and Flat Map with Different Type of Question – Lake District Model

Type of Question	MAP	Mean	Std. Deviation	N
Cone	Flat Map	64.6	20.1	42
	PARM	81.5	18.8	42
	Total	73.1	21.1	84
Intervisibility	Flat Map	73.8	22.2	42
	PARM	80.7	18.1	42
	Total	77.2	20.5	84
Height_of_Lake	Flat Map	67.6	15.9	42
	PARM	78.6	16.9	42
	Total	73.1	17.2	84
Height_of_Peak	Flat Map	62.8	14.8	42
	PARM	74.7	21.6	42
	Total	68.8	19.3	84
Steep	Flat Map	55.1	21.6	42
	PARM	66.1	21.1	42
	Total	60.6	21.9	84
Waterflow	Flat Map	73.5	19.2	42
	PARM	92.3	11.4	42
	Total	82.9	18.3	84

Table 3.12. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map with Different Type of Question – Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	24138.455	5	4827.691	14.842	.000	.153
Type_of_Question*MAP	2003.038	5	400.608	1.232	.293	.015
Error(Type_of_Question)	133363.715	410	325.277			

Table 3.13. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map with Different Type of Question – Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2656041.977	1	2656041.977	5610.383	.000	.986
MAP	20476.501	1	20476.501	43.253	.000	.345
Error	38820.064	82	473.415			

Figure 3.20 provides information on response time of participants answering different types of questions on PARM and flat maps. The substantial result is that most of the participants have a slower time in answering all types of questions on the flat map compared to PARM. The most difference is shown by the lake comparison, whilst the slightest difference is shown by the waterflow question. Statistical analysis shows (**Table 3.15** & **Table 3.16**) that different types of questions resulted in a significant effects on response time at the 95% confidence level (sig <0.05). However, different types of representation (PARM and flat map) as well as interaction between different type of map and type of question gives no significant effect statistically on response time.

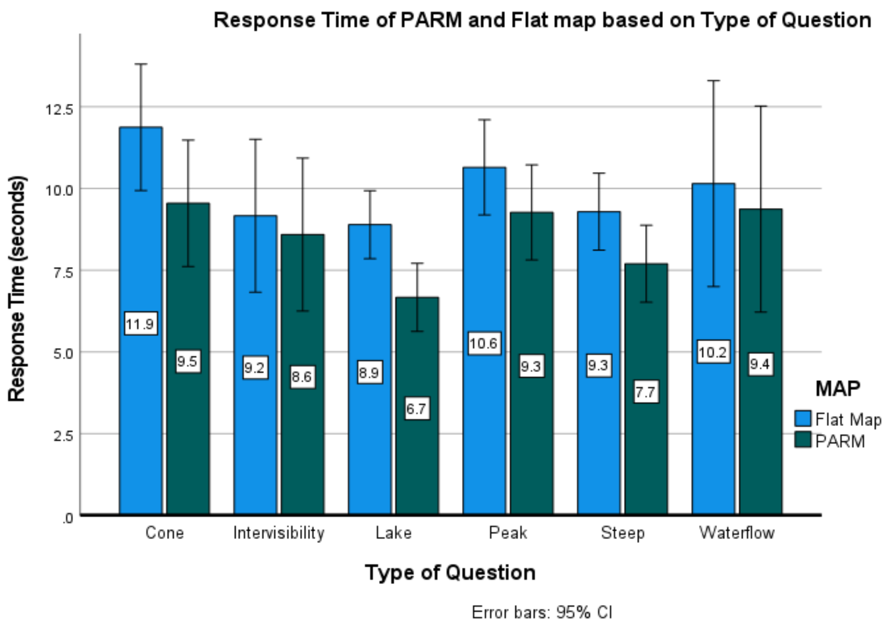


Figure 3.20. Response Time of PARM and Flat Map with Different Type of Question – Lake District Model

Table 3.14. Descriptive Statistics of Response Time of PARM and Flat Map with Different Type of Question – Lake District Model

Type of Question	Mean	Std. Deviation	N
Cone	11.9	7.8	41
	9.5	4.1	41
	10.7	6.3	82
Intervisibility	9.2	4.2	41
	8.6	9.8	41
	8.9	7.5	82
Height_of_Lake	8.9	4.2	41
	6.7	2.3	41
	7.8	3.5	82
Height_of_Peak	10.6	4.8	41
	9.3	4.5	41
	10.0	4.7	82
Steep	9.3	4.3	41
	7.7	3.2	41
	8.5	3.8	82
Waterflow	10.2	5.4	41
	9.4	13.3	41
	9.8	10.1	82

Table 3.15. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM and Flat Map with Different Type of Question – Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	471.889	5	94.378	3.023	.011	.036
Type_of_Question*MAP	53.248	5	10.650	.341	.888	.004
Error(Type_of_Question)	12488.875	400	31.222			

Table 3.16. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map with Different Type of Question – Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	42235.614	1	42235.614	472.062	.000	.855
MAP	269.153	1	269.153	3.008	.087	.036
Error	7157.631	80	89.470			

3.5.4 Accuracy and Response Time of PARM Based on Type of Map and Type of Questions

The Accuracy of PARM on different types of representations and questions is illustrated in **Figure 3.21**. Based on the type of backdrop map, the subdued map was found to be suitable for almost all type of questions (79.8%-88.1% accuracy), except for the steep slope question where 60.7% accuracy was obtained. In contrast, when the aerial map was used as backdrop, a considerably higher accuracy was shown for the steep slope type of question. Statistical analysis shows (**Table 3.17, 3.18** & **Table 3.19**) that different types of questions, different types of backdrop maps, and interaction between different types of backdrop map and type of question resulted in significant effects on accuracy of PARM at the 95% confidence level (sig <0.05). Post Hoc analysis (**Table 3.20**) shows Hillshade, Subdued and Aerial map considered as a group due to their similar result. Contour map was a different group because of the different result in accuracy and response time of flat map and PARM based on the question types.

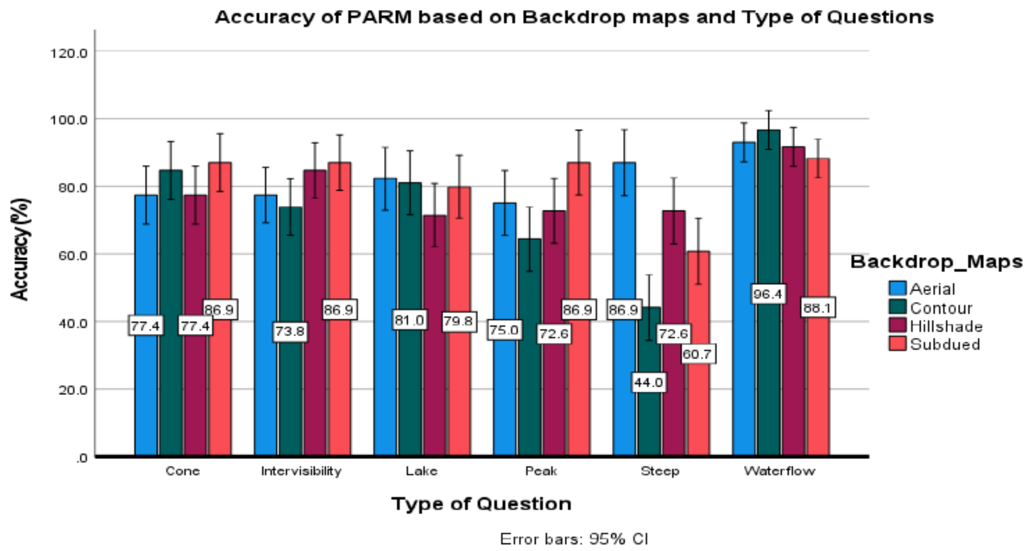


Figure 3.21. Accuracy of PARM on Different Type of Map and Question

Table 3.17. Descriptive Statistics of Accuracy of PARM on Different Type of Map and Question

Type of Question	Backdrop Maps	Mean	Std. Deviation	N
Cone	Aerial	77.4	33.5	42
	Contour	84.5	23.4	42
	Hillshade	77.4	27.5	42
	Subdued	86.9	27.2	42
	Total	81.5	28.2	168
Intervisibility	Aerial	77.4	25.2	42
	Contour	73.8	33.6	42
	Hillshade	84.5	25.9	42
	Subdued	86.9	22.3	42
	Total	80.7	27.3	168
Height_of_Lake	Aerial	82.1	28.8	42
	Contour	81.0	29.1	42
	Hillshade	71.4	35.2	42
	Subdued	79.8	29.3	42
	Total	78.6	30.7	168
Height_of_Peak	Aerial	75.0	33.6	42
	Contour	64.3	35.4	42
	Hillshade	72.6	29.6	42
	Subdued	86.9	24.8	42
	Total	74.7	31.9	168
Steep	Aerial	87.0	27.2	42

Type of Question	Backdrop Maps	Mean	Std. Deviation	N
	Contour	44.0	35.3	42
	Hillshade	72.6	27.5	42
	Subdued	60.7	35.8	42
	Total	66.1	35.2	168
Waterflow	Aerial	92.9	20.9	42
	Contour	96.4	13.0	42
	Hillshade	91.7	18.9	42
	Subdued	88.1	21.6	42
	Total	92.3	18.9	168

Table 3.18. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM on Different Type of Map and Question

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	62311.508	5	12462.302	16.556	.000	.092
Type_of_Question * Backdrop_Maps	54593.254	15	3639.550	4.835	.000	.081
Error(Type_of_Question)	617261.905	820	752.758			

Table 3.19. Tests of Between-Subjects Effects of Accuracy of PARM on Different Type of Map and Question

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	6285873.016	1	6285873.016	6072.524	.000	.974
Backdrop_Maps	10198.413	3	3399.471	3.284	.022	.057
Error	169761.905	164	1035.134			

Table 3.20. Post Hoc Analysis of Accuracy of PARM on Different Type of Map and Question (Ryan-Einot-Gabriel-Welsch Range[a,b])

Backdrop_Maps	N	Subset	
		1	2
Contour	42	74.008	
Hillshade	42	78.373	78.373
Subdued	42		81.548
Aerial	42		81.944
Sig.		.243	.428

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 172.522.
a. Alpha = .05.
b. Critical values are not monotonic for these data. Substitutions have been made to ensure monotonicity. Type I error is therefore smaller.

Figure 3.22 shows the response time of PARM on different types of representation and question. The Cone of Vision and Lake question types have a similar response time on Aerial, Contour, Hillshade and Subdued type of maps. However, more variance is shown for the other types of question. The most significant response time is a Waterflow question on the Aerial map followed by Height of Peaks question on the contour map. The subdued map had the fastest response time compared to others. Statistical analysis shows (**Table 3.22** & **Table 3.23**) that different types of question, different types of backdrop map, and interaction between different types of backdrops, representation and type of question gives no significant effect on response time of PARM at 95% confidence level (sig <0.05).

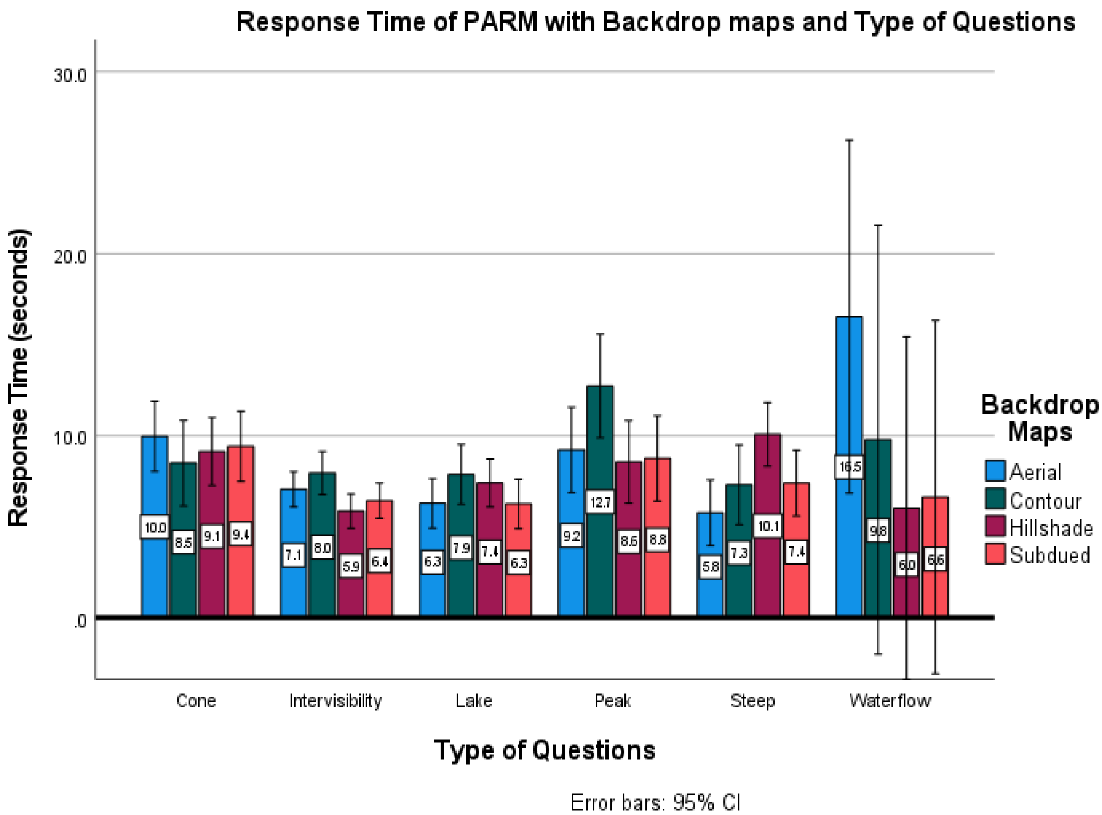


Figure 3.22. Response Time of PARM on Different Type of Map and Question

Table 3.21. Descriptive Statistics of Response Time of PARM on Different Type of Map and Question

Type of Question	Backdrop Maps	Mean	Std. Deviation	N
Cone	Aerial	10.0	6.3	31
	Contour	8.5	5.8	21
	Hillshade	9.1	5.4	33
	Subdued	9.4	4.1	31
	Total	9.3	5.4	116
Intervisibility	Aerial	7.1	3.2	31
	Contour	8.0	3.0	21
	Hillshade	5.9	2.0	33
	Subdued	6.4	2.7	31
	Total	6.7	2.8	116
Height_of_Lake	Aerial	6.3	3.2	31
	Contour	7.9	5.2	21
	Hillshade	7.4	4.6	33
	Subdued	6.3	1.9	31
	Total	6.9	3.8	116
Height_of_Peak	Aerial	9.2	6.1	31
	Contour	12.7	9.3	21
	Hillshade	8.6	5.2	33
	Subdued	8.8	6.2	31
	Total	9.5	6.7	116
Steep	Aerial	5.8	2.3	31
	Contour	7.3	4.2	21
	Hillshade	10.1	7.7	33
	Subdued	7.4	3.9	31
	Total	7.7	5.3	116
Waterflow	Aerial	16.5	52.3	31
	Contour	9.8	6.5	21
	Hillshade	6.0	2.2	33
	Subdued	6.6	2.1	31
	Total	9.7	27.1	116

Table 3.22. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM on Different Type of Map and Question

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	1087.864	5	217.573	1.561	.169	.014
Type_of_Question * Backdrop_Maps	2546.015	15	169.734	1.218	.253	.032
Error(Type_of_Question)	78056.136	560	139.386			

Table 3.23. Tests of Between-Subjects Effects of Response Time of PARM on Different Type of Map and Question

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	47280.948	1	47280.948	283.442	.000	.717
Backdrop_Maps	364.229	3	121.410	.728	.537	.019
Error	18682.737	112	166.810			

3.5.5 Accuracy and Response Time of Flat Map Based on Type of Map and Type of Questions

Figure 3.23 and **Figure 3.24** shows variation on accuracy and response time of participant answers with different backdrop map and type of question on the Flat Map. Statistical analysis (**Table 3.25** & **Table 3.26**) shows that interaction between the type of question and type of backdrop map resulted in significant effects on accuracy at the 95% confidence level (sig <0.05). However, interaction between type of questions and type of backdrop map had no significant effect statistically on response time (**Table 3.28** & **Table 3.29**).

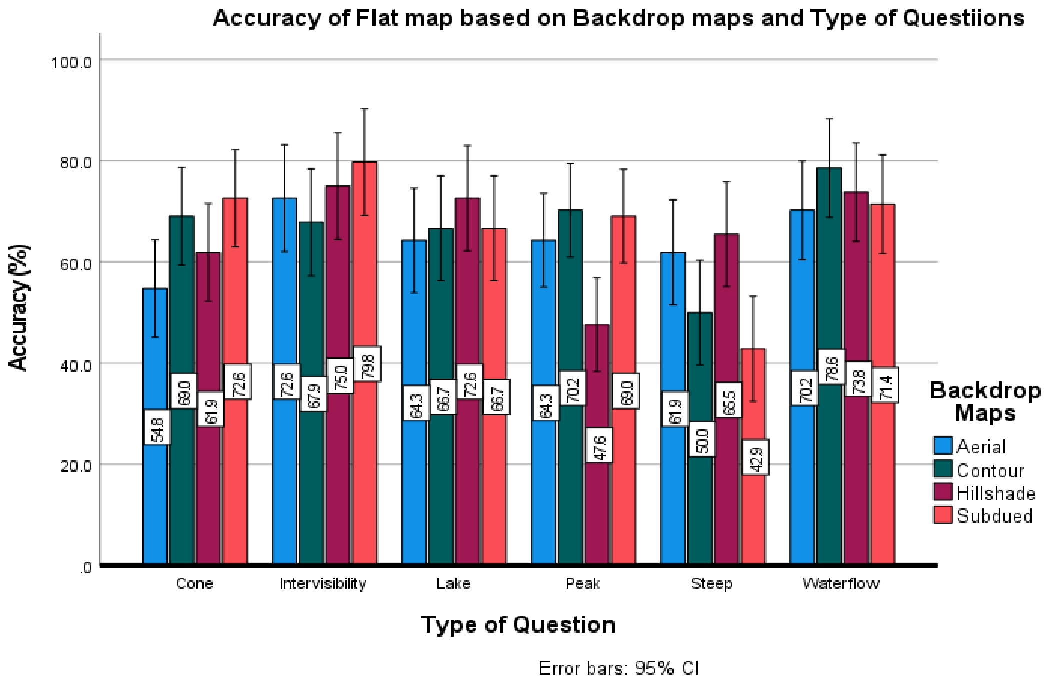


Figure 3.23. Accuracy of Flat Map on Different Type of Map and Questions

Table 3.24. Descriptive Statistics of Accuracy of Flat Map on Different Type of Map and Questions

Type of Question	Backdrop Maps	Mean	Std. Deviation	N
Cone	Aerial	54.8	28.8	42
	Contour	69.0	31.1	42
	Hillshade	61.9	34.6	42
	Subdued	72.6	31.6	42
	Total	64.6	32.1	168
Intervisibility	Aerial	72.6	37.0	42
	Contour	67.9	36.3	42
	Hillshade	75.0	33.6	42
	Subdued	79.8	31.4	42
	Total	73.8	34.6	168
Height_of_Lake	Aerial	64.3	37.1	42
	Contour	66.7	37.7	42
	Hillshade	72.6	31.6	42
	Subdued	66.7	28.5	42
	Total	67.6	33.8	168
Height_of_Peak	Aerial	64.3	31.8	42

Type of Question	Backdrop Maps	Mean	Std. Deviation	N
	Contour	70.2	33.2	42
	Hillshade	47.6	24.6	42
	Subdued	69.0	31.1	42
	Total	62.8	31.4	168
Steep	Aerial	61.9	34.6	42
	Contour	50.0	27.1	42
	Hillshade	65.5	34.0	42
	Subdued	42.9	39.2	42
	Total	55.0	34.9	168
Waterflow	Aerial	70.2	31.4	42
	Contour	78.6	31.5	42
	Hillshade	73.8	35.3	42
	Subdued	71.4	29.5	42
	Total	73.5	31.9	168

Table 3.25. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of Flat Map on Different Type of Map and Questions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	42254.464	5	8450.893	7.983	.000	.046
Type_of_Question * Backdrop_Maps	40930.060	15	2728.671	2.578	.001	.045
Error(Type_of_Question)	868065.476	820	1058.616			

Table 3.26. Tests of Between-Subjects Effects of Accuracy of Flat Map on Different Type of Map and Questions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	4420200.893	1	4420200.893	3813.539	.000	.959
Backdrop_Maps	959.821	3	319.940	.276	.843	.005
Error	190089.286	164	1159.081			

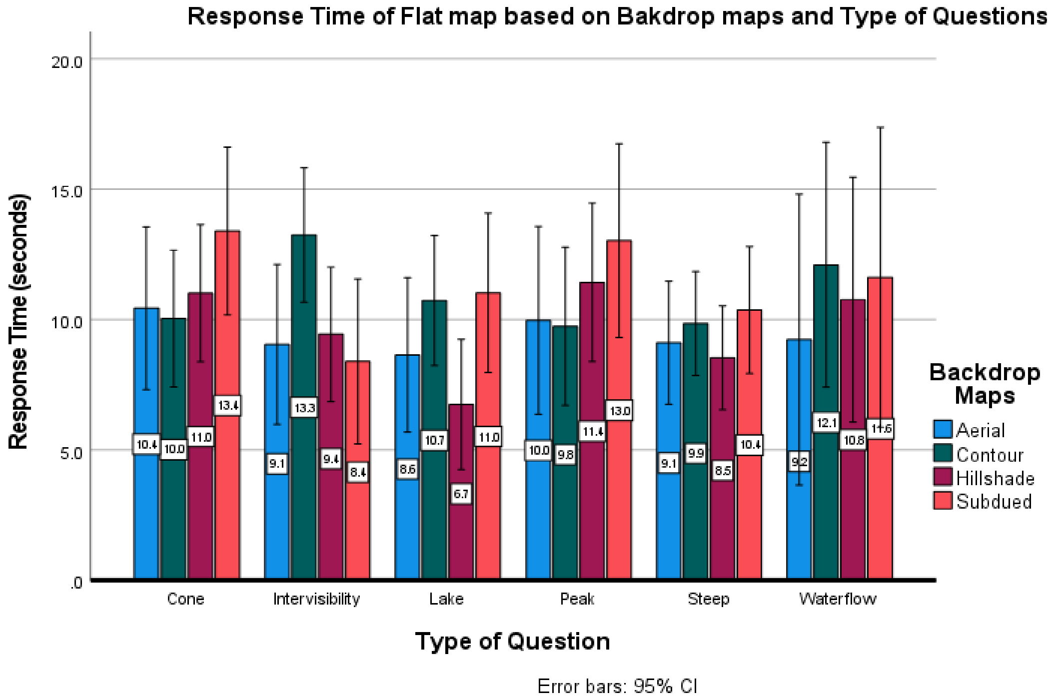


Figure 3.24. Response Time of Flat Map on Different Type of Map and Questions

Table 3.27. Descriptive Statistics of Response Time of Flat Map on Different Type of Map and Questions

Type of Question	Backdrop Maps	Mean	Std. Deviation	N
Cone	Aerial	10.4	5.5	17
	Contour	10.0	6.8	24
	Hillshade	11.0	6.1	24
	Subdued	13.4	7.4	16
	Total	11.1	6.5	81
Intervisibility	Aerial	9.1	3.7	17
	Contour	13.2	7.6	24
	Hillshade	9.4	7.5	24
	Subdued	8.4	3.9	16
	Total	10.3	6.5	81
Height_of_Lake	Aerial	8.6	3.9	17
	Contour	10.7	9.0	24
	Hillshade	6.8	3.2	24
	Subdued	11.0	6.1	16
	Total	9.2	6.3	81

Type of Question	Backdrop Maps	Mean	Std. Deviation	N
Height_of_Peak	Aerial	10.0	3.4	17
	Contour	9.8	6.35	24
	Hillshade	11.4	10.2	24
	Subdued	13.0	7.2	16
	Total	10.9	7.4	81
Steep	Aerial	9.1	4.5	17
	Contour	9.9	6.0	24
	Hillshade	8.5	3.7	24
	Subdued	10.4	4.9	16
	Total	9.4	4.9	81
Waterflow	Aerial	9.2	4.7	17
	Contour	12.1	9.2	24
	Hillshade	10.8	16.8	24
	Subdued	11.6	9.9	16
	Total	11.0	11.4	81

Table 3.28. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of Flat Map on Different Type of Map and Questions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	280.553	5	56.111	1.329	.251	.017
Type_of_Question * Backdrop_Maps	643.952	15	42.930	1.016	.437	.038
Error(Type_of_Question)	16260.199	385	42.234			

Table 3.29. Tests of Between-Subjects Effects of Response Time of Flat Map on Different Type of Map and Questions

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	108730.120	1	108730.120	671.965	.000	.804
Backdrop_Maps	260.684	3	86.895	.537	.658	.010
Error	26536.696	164	161.809			

3.5.6 Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Gender

The graph (**Figure 3.25**) shows female participants were better at answering questions on PARM compared to male participants although there was no difference when they were answering questions on the Flat Map. In terms of measuring accuracy based on gender and backdrop map on both PARM and Flat Map, **Figure 3.26a** shows that Hillshade subdued, Contour and Aerial map have an impact for the male compared to female participants. Nevertheless, the Hillshade backdrop was apparently better for female participants. **Figure 3.26b** shows the comparison of accuracy by gender on each backdrop map on both PARM and Flat Map. Overall, it is shown that all male and female participants had a better judgment on PARM than Flat Map for all types of backdrops. Statistical analysis (**Table 3.31** & **Table 3.32**) shows that interaction between type of backdrop map and gender resulted in significant effects on accuracy at the 95% confidence level (sig <0.05).

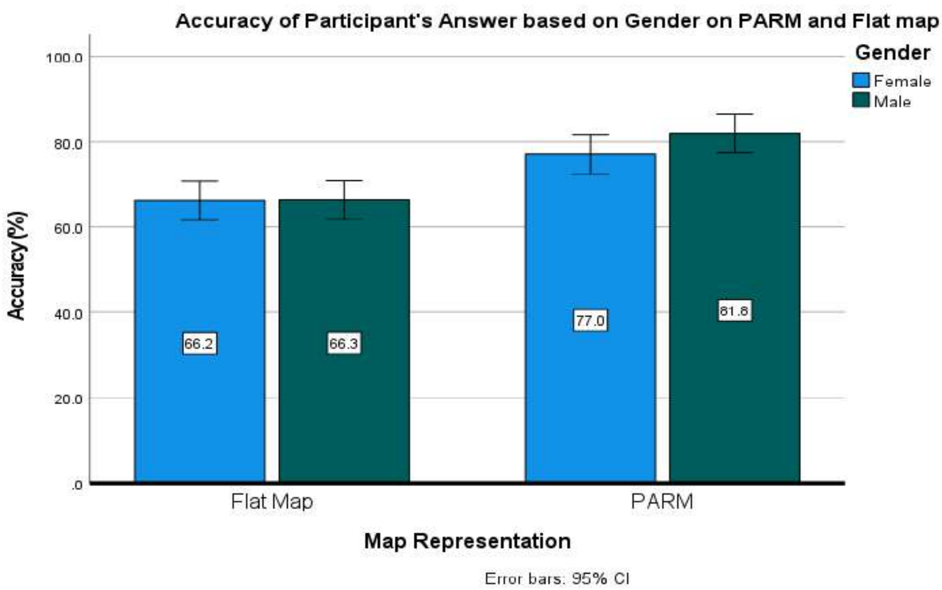


Figure 3.25. Accuracy of PARM and Flat Map with Different with Different Participant Gender - Lake District Model

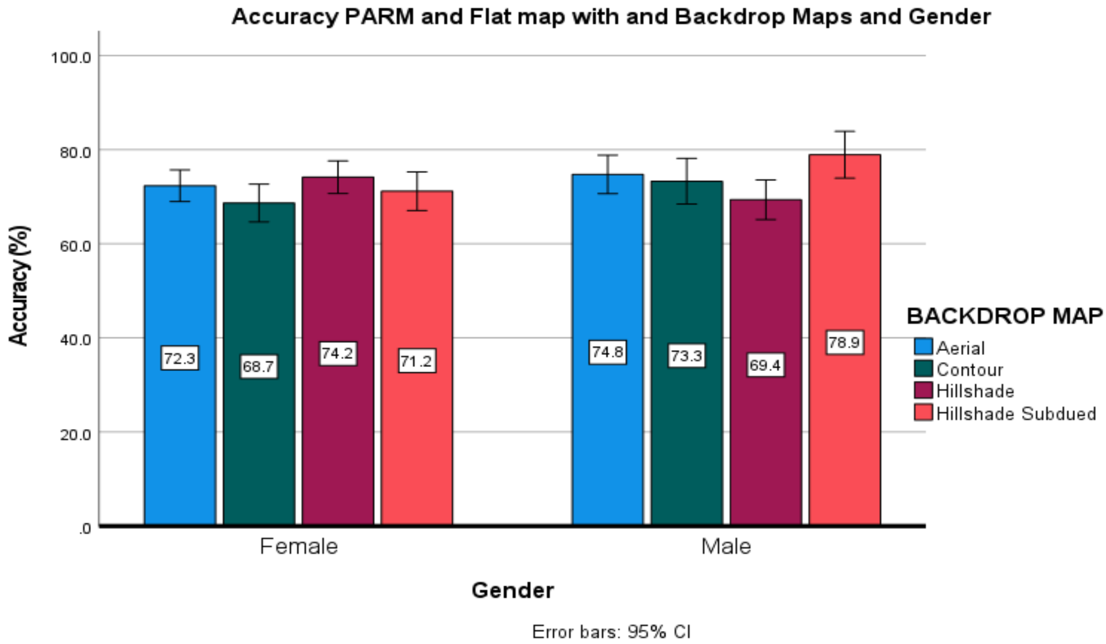


Figure 3.26a. Accuracy of PARM and Flat Map with Different Type of Backdrop Map and Gender - Lake District Model

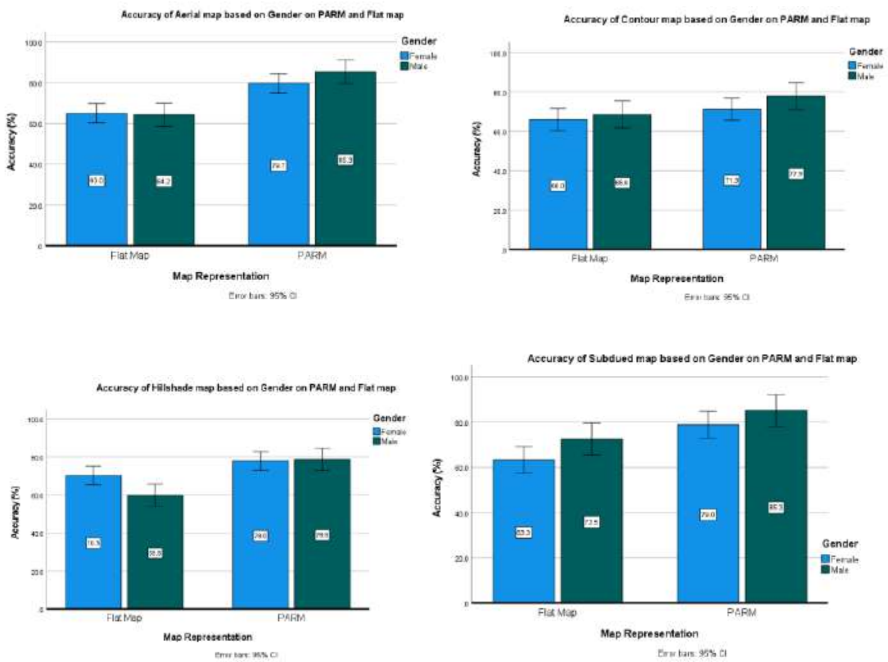


Figure 3.26b. Accuracy of PARM and Flat Map with Each Type of Backdrop Map and Gender - Lake District Model

Table 3.30. Descriptive Statistics of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Gender - Lake District Model

Backdrop Map	MAP	Gender	Mean	Std. Deviation	N
Aerial	Flat Map	Female	65.0	10.8	25
		Male	64.2	9.2	17
		Total	64.7	10.0	42
	PARM	Female	79.7	16.2	25
		Male	86.0	8.1	17
		Total	81.9	13.6	42
	Total	Female	72.3	15.5	50
		Male	74.8	13.7	34
		Total	73.3	14.7	84
Contour	Flat Map	Female	66.0	18.3	25
		Male	68.6	12.3	17
		Total	67.0	16.0	42
	PARM	Female	71.3	13.4	25
		Male	77.9	9.3	17
		Total	74.0	12.2	42
	Total	Female	68.7	16.1	50
		Male	73.3	11.7	34
		Total	70.5	14.6	84
Hillshade	Flat Map	Female	70.3	11.5	25
		Male	59.8	14.5	17
		Total	66.1	13.7	42
	PARM	Female	78.0	14.0	25
		Male	78.9	7.3	17
		Total	78.4	11.7	42
	Total	Female	74.2	13.3	50
		Male	69.4	14.9	34
		Total	72.2	14.1	84
Hillshade_subdued	Flat Map	Female	63.3	14.6	25
		Male	72.5	14.4	17
		Total	67.1	15.1	42
	PARM	Female	79.0	16.2	25
		Male	85.3	12.0	17
		Total	81.6	14.8	42
	Total	Female	71.2	17.2	50
		Male	78.9	14.5	34
		Total	74.3	16.5	84

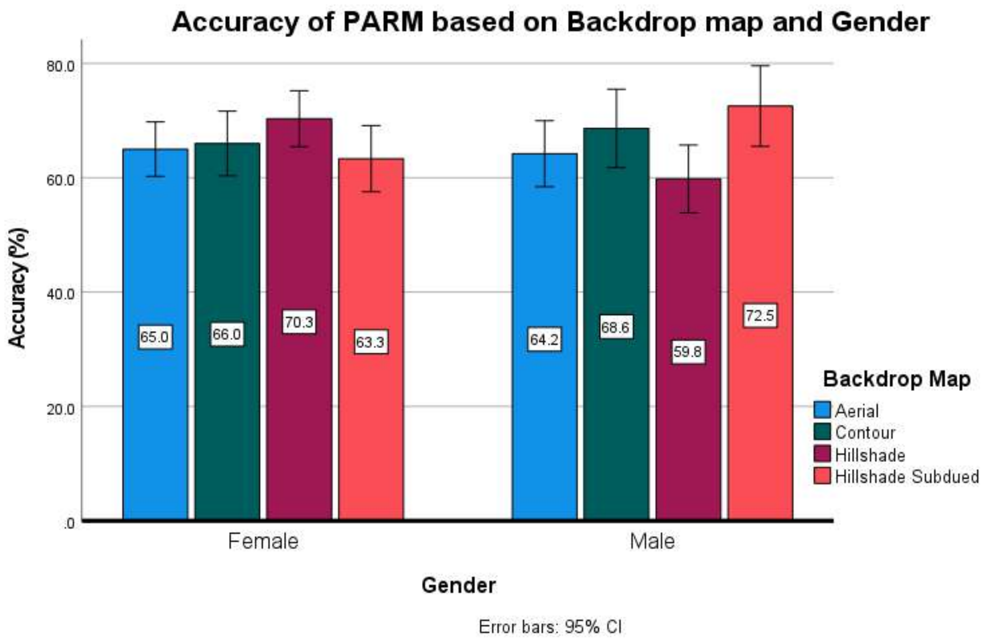
Table 3.31. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop	810.093	3	270.031	2.037	.109	.025
Backdrop * MAP	1161.836	3	387.279	2.921	.035	.035
Backdrop * Gender	1728.029	3	576.010	4.345	.005	.052
Backdrop*MAP *Gender	540.817	3	180.272	1.360	.256	.017
Error(Backdrop)	31817.714	240	132.574			

Table 3.32. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map Based on Type of Map and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1717727.461	1	1717727.461	5512.366	.000	.986
MAP	14105.960	1	14105.960	45.267	.000	.361
Gender	503.681	1	503.681	1.616	.207	.020
MAP * Gender	451.401	1	451.401	1.449	.232	.018
Error	24929.076	80	311.613			

In terms of measuring gender and backdrop maps on PARM only, on Aerial and Subdued map, female and male participants had the same accuracy in both cases. However, on the hillshade map, they had almost no difference and male participants had better accuracy than female on Contour map. In terms of accuracy on gender, the trends show females had better results on Aerial and Subdued while male participants performed better on hillshade and contour. Statistical analysis shows (**Table 3.33-3.36**) that interaction between the type of backdrop map and gender on Flat map resulted in a significant effect on accuracy at the 95% confidence level (sig <0.05).



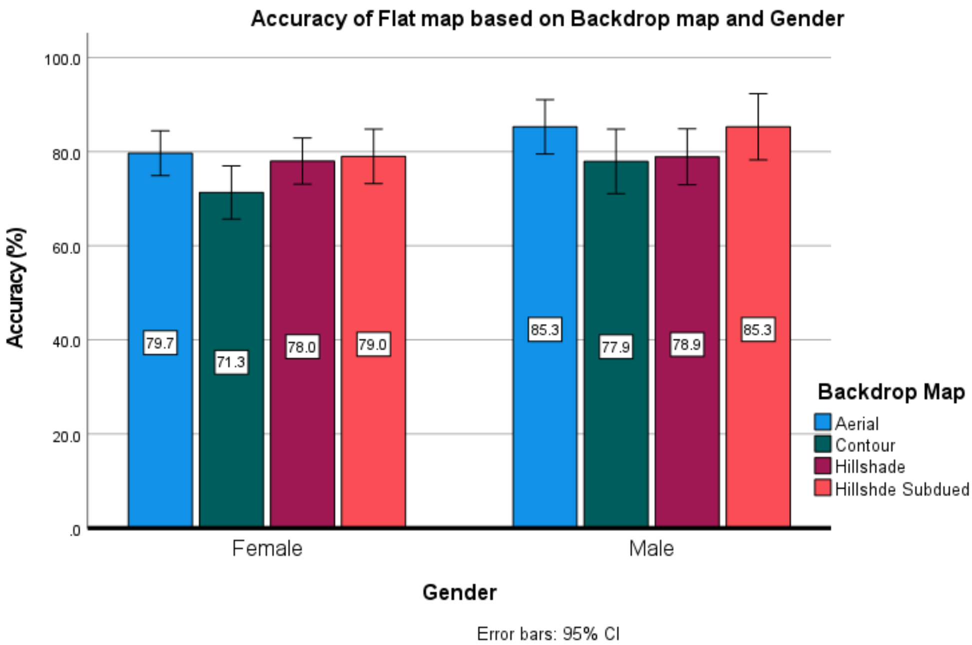


Figure 3.27. Accuracy of PARM (top) and Flat Map (bottom) with Different Type of Backdrop Map and Participant Gender

Table 3.33. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop_Map	1644.022	3	548.007	5.602	.001	.123
Backdrop_Map*Gender	215.133	3	71.711	.733	.534	.018
Error(Backdrop_Map)	11738.040	120	97.817			

Table 3.34. Tests of Between-Subjects Effects of Accuracy of PARM Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1021577.222	1	1021577.222	2654.602	.000	.985
Gender	954.366	1	954.366	2.480	.123	.058
Error	15393.302	40	384.833			

Table 3.35. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of Flat Map Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop_Map	327.908	3	109.303	.653	.582	.016
Backdrop_Map*Gender	2053.713	3	684.571	4.091	.008	.093
Error(Backdrop_Map)	20079.675	120	167.331			

Table 3.36. Tests of Between-Subjects Effects of Accuracy of Flat Map Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	710256.199	1	710256.199	2979.333	.000	.987
Gender	.716	1	.716	.003	.957	.000
Error	9535.774	40	238.394			

3.5.7 Response Time of PARM and Flat Map Based on Type of Backdrop Map and Gender

In terms of measuring response time of female and male on both modes, the PARM is better than on the Flat Map. Moreover, female participants have a faster response time on the flat map and PARM compared to male participants (**Figure 3.28**). Female participants on the Aerial backdrop map had longer response times than male participants. For the other three backdrop maps, males had a faster response time than females although on Contour and Hillshade subdued map had similar results by below 0.5 second difference (**Figure 3.29**). Statistical analysis shows (**Table 3.38** & **Table 3.39**) that interaction between the type of backdrop map and gender as well as interaction between different types of maps, different backdrop, and different gender gives no significant effect statistically on response time.

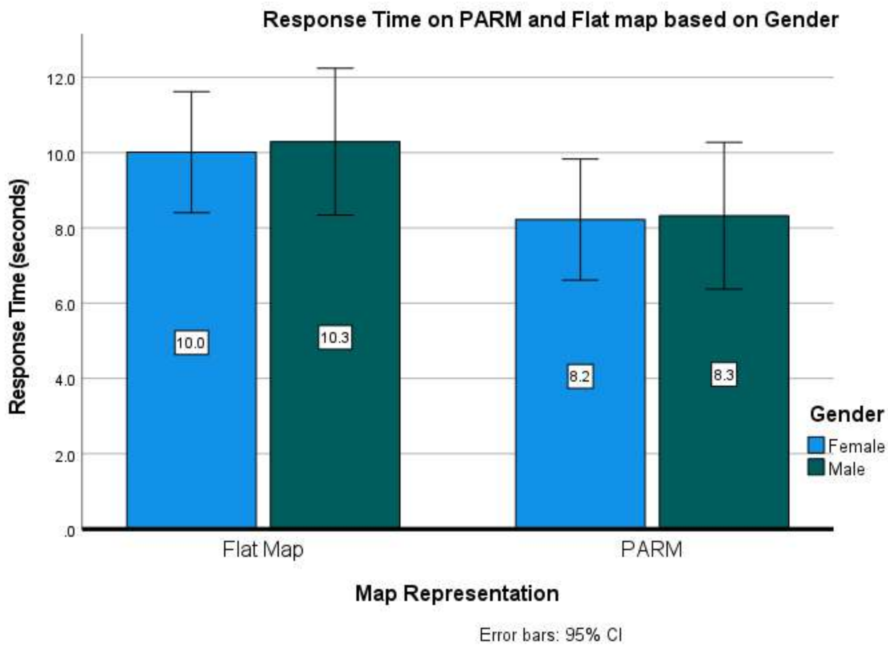


Figure 3.28. Response Time on PARM and Flat map based on Gender

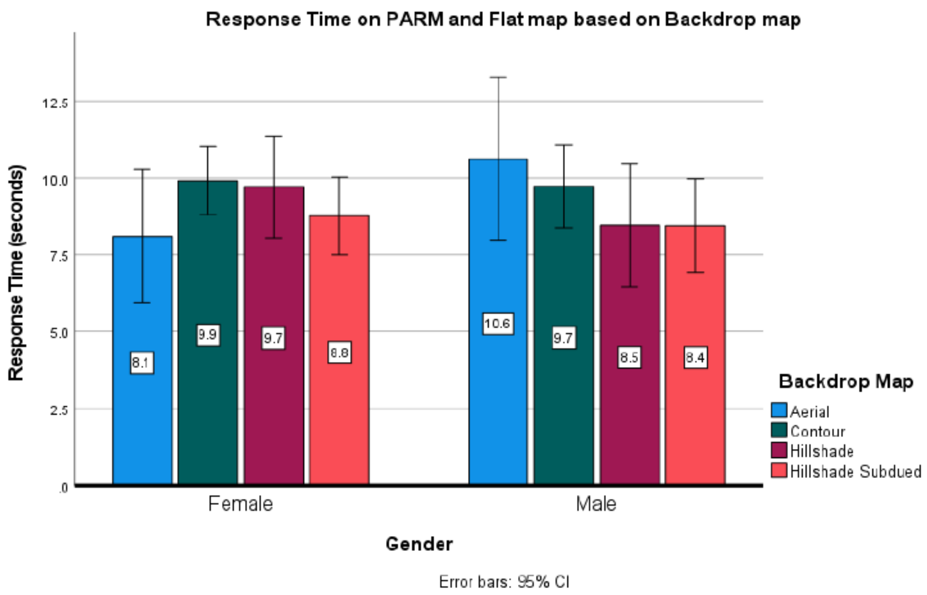


Figure 3.29. Response Time of PARM and Flat Map with Different Type of Backdrop Map and Gender

Table 3.37. Descriptive Statistics of Response Time of PARM and Flat Map Based on Type of Backdrop Map and Gender

Backdrop Maps	MAP	Gender	Mean	Std. Deviation	N
Aerial	Flat Map	Female	9.1	3.5	25
		Male	10.1	4.5	17
		Total	9.5	3.9	42
	PARM	Female	7.1	2.7	25
		Male	11.2	15.8	17
		Total	8.8	10.3	42
	Total	Female	8.1	3.2	50
		Male	10.6	11.4	34
		Total	9.1	7.7	84
Contour	Flat Map	Female	10.5	4.2	25
		Male	11.5	4.9	17
		Total	10.9	4.5	42
	PARM	Female	9.4	4.0	25
		Male	7.9	2.1	17
		Total	8.8	3.4	42
	Total	Female	9.9	4.1	50
		Male	9.7	4.1	34
		Total	9.8	4.1	84
Hillshade	Flat Map	Female	9.9	6.1	25
		Male	9.6	4.3	17
		Total	9.8	5.4	42

Backdrop Maps	MAP	Gender	Mean	Std. Deviation	N
	PARM	Female	9.5	7.8	25
		Male	7.3	2.2	17
		Total	8.6	6.2	42
	Total	Female	9.7	6.9	50
		Male	8.5	3.5	34
		Total	9.2	5.8	84
Hillshade_subdued	Flat Map	Female	10.6	6.8	25
		Male	10.0	4.3	17
		Total	10.4	5.8	42
	PARM	Female	6.9	2.4	25
		Male	6.9	2.3	17
		Total	6.9	2.3	42
	Total	Female	8.8	5.3	50
		Male	8.4	3.8	34
		Total	8.6	4.8	84

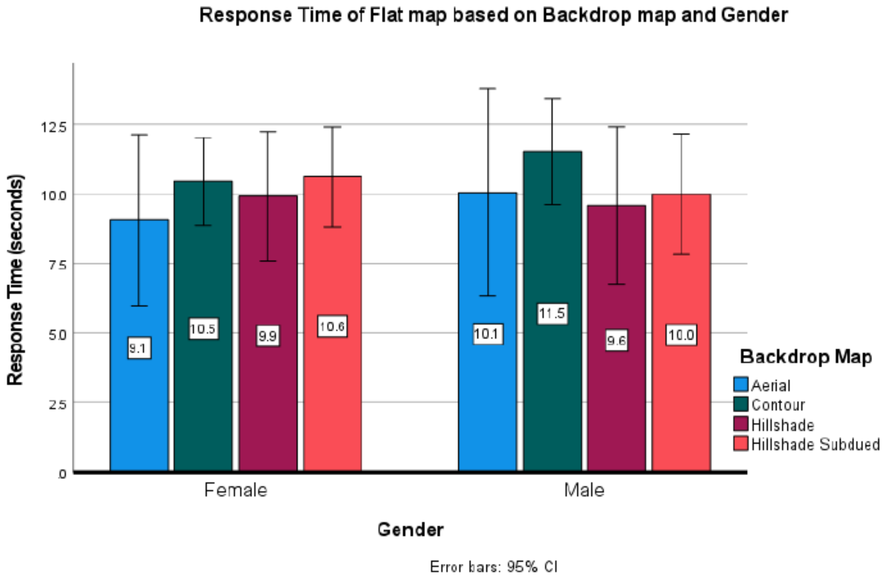
Table 3.38. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM and Flat Map Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop_Map	62.898	3	20.966	.976	.405	.012
Backdrop_Map*Gender	159.813	3	53.271	2.481	.062	.030
Backdrop_Map*MAP	101.486	3	33.829	1.575	.196	.019
Backdrop_Map*Gender * MAP	98.316	3	32.772	1.526	.208	.019
Error(Backdrop_Map)	5153.427	240	21.473			

Table 3.39. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map Based on Type of Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	27489.399	1	27489.399	420.450	.000	.840
Gender	2.971	1	2.971	.045	.832	.001
MAP	285.984	1	285.984	4.374	.040	.052
Gender * MAP	.649	1	.649	.010	.921	.000
Error	5230.478	80	65.381			

In terms of response time for gender and backdrop maps on PARM only, female and male were similar with the best result on Subdued (**Figure 3.30**). On Contour and Hillshade map, male participants had quicker responses than females although were much slower on Aerial. Statistical analysis shows (**Table 3.40-3.43**) that for both PARM and Flat Map gender as well as the interaction between the type of map gender had no significant effect statistically on response time.



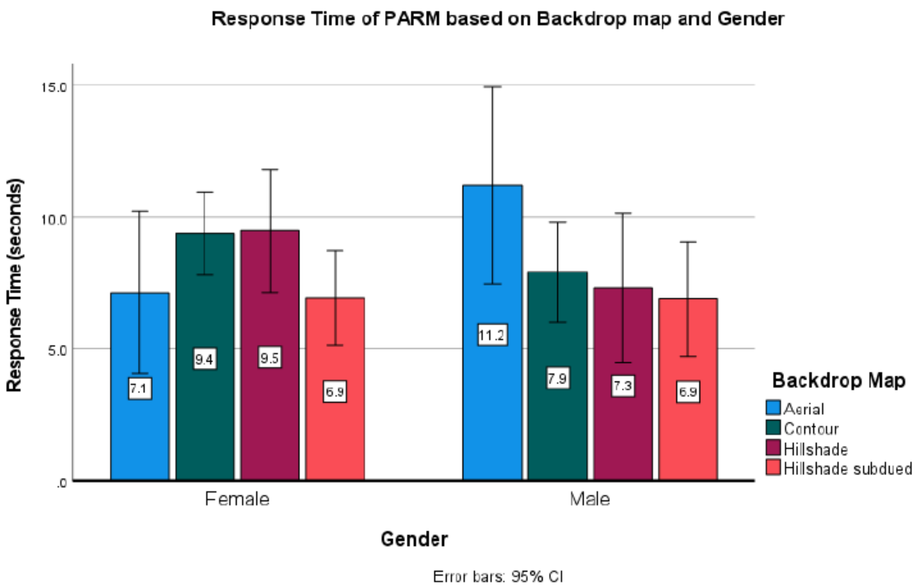


Figure 3.30. Response Time of PARM (top) and Flat Map (bottom) with Different Type of Backdrop Map and Participant Gender

Table 3.40. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop_Map	114.269	3	38.090	1.090	.356	.027
Backdrop_Map*Gender	234.517	3	78.172	2.237	.087	.053
Error(Backdrop_Map)	4193.514	120	34.946			

Table 3.41. Tests of Between-Subjects Effects of Response Time of PARM Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	11083.850	1	11083.850	203.431	.000	.836
Gender	.421	1	.421	.008	.930	.000
Error	2179.380	40	54.484			

Table 3.42. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of Flat Map Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop_Map	50.115	3	16.705	2.088	.105	.050
Backdrop_Map*Gender	23.611	3	7.870	.984	.403	.024
Error(Backdrop_Map)	959.913	120	7.999			

Table 3.43. Tests of Between-Subjects Effects of Response Time of Flat Map Based on Type of Backdrop Map and Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	16691.532	1	16691.532	218.827	.000	.845
Gender	3.199	1	3.199	.042	.839	.001
Error	3051.098	40	76.277			

3.5.8 Accuracy of PARM and Flat Map Based on Type of Question and Gender

Figure 3.31 shows the overall comparison of gender on both models based on type of questions. Statistical analysis shows that the male participants had slightly better results compared to female participants. Nevertheless, the steep slope question type was slightly better for female than male participants. Statistical analysis shows (**Table 3.45** & **Table 3.46**) that the interaction between type of question and gender has significant effects statistically on accuracy.

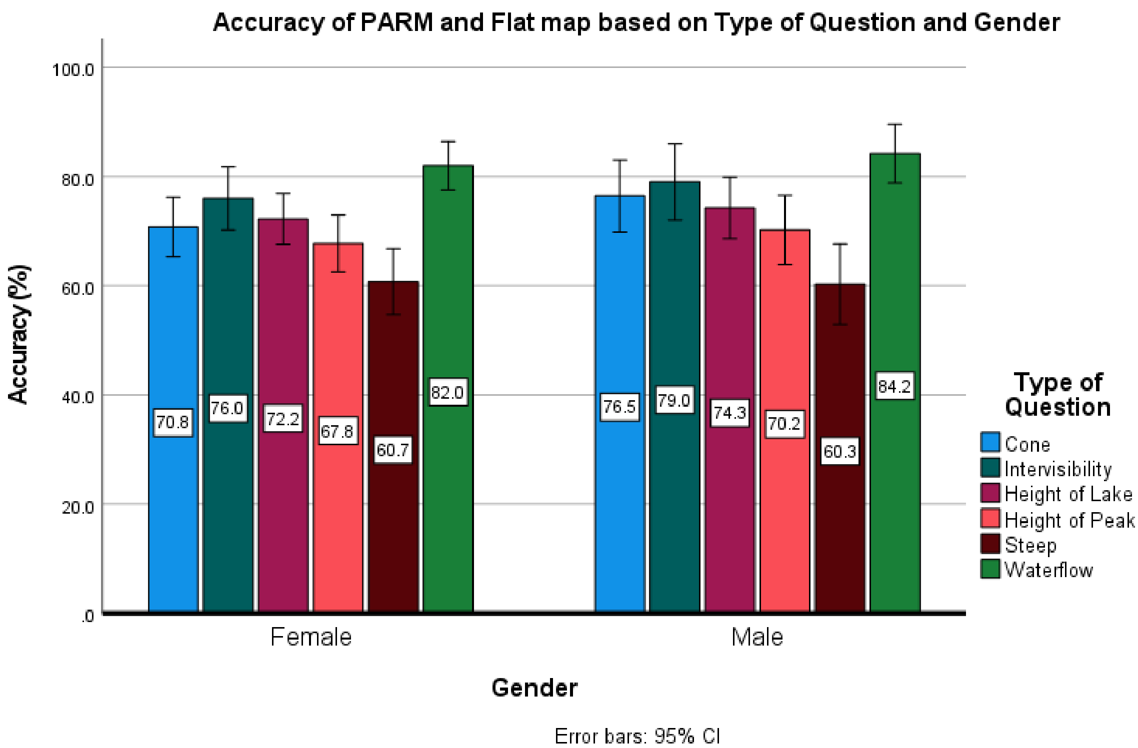


Figure 3.31. Accuracy of PARM and Flat Map with Different Type of Question and Participant Gender - Lake District Model

Table 3.44. Descriptive Statistics of Accuracy of PARM and Flat Map Based on Type of Question and Gender - Lake District Model

Type of Question	MAP	Gender	Mean	Std. Deviation	N
Cone	Flat Map	Female	64.0	21.4	25
		Male	65.4	18.5	17
		Total	64.6	20.1	42
	PARM	Female	77.5	21.0	25
		Male	87.5	13.3	17
		Total	81.5	18.8	42
	Total	Female	70.8	22.1	50
		Male	76.5	19.4	34
		Total	73.1	21.1	84
Intervisibility	Flat Map	Female	72.5	23.9	25
		Male	75.7	20.0	17
		Total	73.8	22.2	42
	PARM	Female	79.5	19.7	25
		Male	82.3	16.0	17
		Total	80.7	18.1	42
	Total	Female	76.0	22.0	50
		Male	79.0	18.1	34
		Total	77.2	20.5	84
Height_of_Lake	Flat Map	Female	67.0	18.0	25
		Male	68.4	12.6	17
		Total	67.6	15.9	42
	PARM	Female	77.5	17.7	25
		Male	80.1	16.0	17
		Total	78.6	16.9	42
	Total	Female	72.3	18.4	50
		Male	74.3	15.4	34
		Total	73.1	17.2	84
Height_of_Peak	Flat Map	Female	63.0	15.9	25
		Male	62.5	12.5	17
		Total	62.8	14.5	42
	PARM	Female	72.5	23.9	25
		Male	77.9	18.0	17
		Total	74.7	21.6	42
	Total	Female	67.8	20.7	50
		Male	70.2	17.1	34
		Total	68.8	19.3	84
Steep	Flat Map	Female	56.0	20.1	25
		Male	53.7	24.1	17
		Total	55.0	21.6	42

Type of Question	MAP	Gender	Mean	Std. Deviation	N
	PARM	Female	65.5	22.0	25
		Male	66.9	20.2	17
		Total	66.1	21.1	42
	Total	Female	60.8	21.4	50
		Male	60.3	22.9	34
		Total	60.6	21.9	84
Waterflow	Flat Map	Female	74.5	18.9	25
		Male	72.1	20.0	17
		Total	73.5	19.2	42
	PARM	Female	89.5	13.3	25
		Male	96.3	5.9	17
		Total	92.3	11.4	42
	Total	Female	82.0	17.9	50
		Male	84.2	19.0	34
		Total	82.9	18.3	84

Table 3.45. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	23836.943	5	4767.389	14.383	.000	.152
Type_of_Question*MAP	2253.674	5	450.735	1.360	.239	.017
Type_of_Question*Gender	399.443	5	79.889	.241	.944	.003
Type_of_Question*MAP * Gender	383.635	5	76.727	.231	.949	.003
Error(Type_of_Question)	132580.637	400	331.452			

Table 3.46. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map Based on Type of Question and Gender - Lake District

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2576479.167	1	2576479.167	5513.642	.000	.986
MAP	21153.000	1	21153.000	45.267	.000	.361
Gender	757.441	1	757.441	1.621	.207	.020
MAP * Gender	679.290	1	679.290	1.454	.231	.018
Error	37383.333	80	467.292			

Figure 3.32 shows male participants overall had better accuracy that female. Waterflow had the best accuracy for both female and male participants, however the steep slope question type had the lowest result for both male and female participants. On Flat map, the graphs show male participants had better accuracy on intervisibility, height of lakes and cone vision, nevertheless female participants had better accuracy on the other 3 type of question (waterflows, steeper slope and height of peaks). Statistical analysis shows (**Table 3.47-3.50**) that for both PARM and Flat Map different gender as well as interaction between different type of question and different gender had no significant effect statistically on accuracy (no difference between male and female participants).

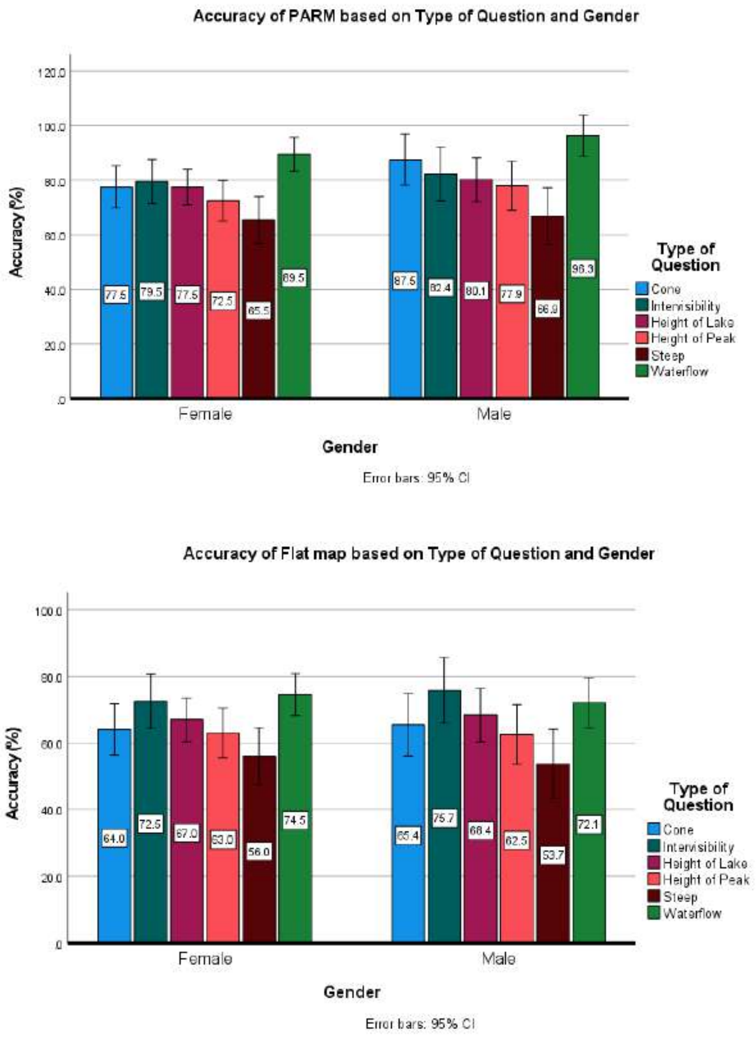


Figure 3.32. Accuracy of PARM (top) Flat Map (bottom) with Different Type of Question and Participant Gender - Lake District Model

Table 3.47. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	15639.455	5	3127.891	10.920	.000	.214
Type_of_Question*Gender	520.407	5	104.081	.363	.873	.009
Error(Type_of_Question)	57287.132	200	286.436			

Table 3.48. Tests of Between-Subjects Effects of Accuracy of PARM Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1532269.001	1	1532269.001	2654.928	.000	.985
Gender	1435.668	1	1435.668	2.488	.123	.059
Error	23085.662	40	577.142			

Table 3.49. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of Flat Map Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	10451.163	5	2090.233	5.552	.000	.122
Type_of_Question*Gender	262.671	5	52.534	.140	.983	.003
Error(Type_of_Question)	75293.505	200	376.468			

Table 3.50. Tests of Between-Subjects Effects of Accuracy of Flat Map Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1065363.167	1	1065363.167	2980.522	.000	.987
Gender	1.064	1	1.064	.003	.957	.000
Error	14297.672	40	357.442			

3.5.9 Response Time of PARM and Flat Map Based on Type of Question and Gender

Having consided the effect of gender on accuracy, the effect on response time was then analysed. Based on data presented in **Figure 3.33**, PARM had quicker response times than the Flat map for male and female participants, with male participants having a quicker average result than females (Figure 3.33a). The detailed graph (Figure 3.33b) shows only the waterflow question type was quicker for female than male participants. Statistical analysis shows (**Table 3.52** & **Table 3.53**) that different gender, interaction between type of question and different gender, and interaction between different type of map, different question, and different gender gives significant effects statistically on response time.

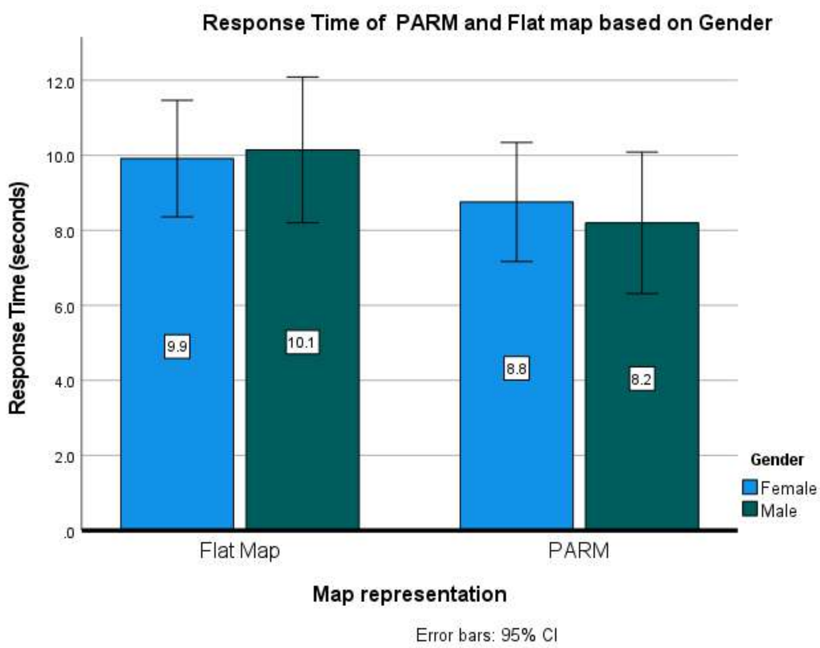


Figure 3.33a. Response Time of Map Representation and Gender - Lake District Model

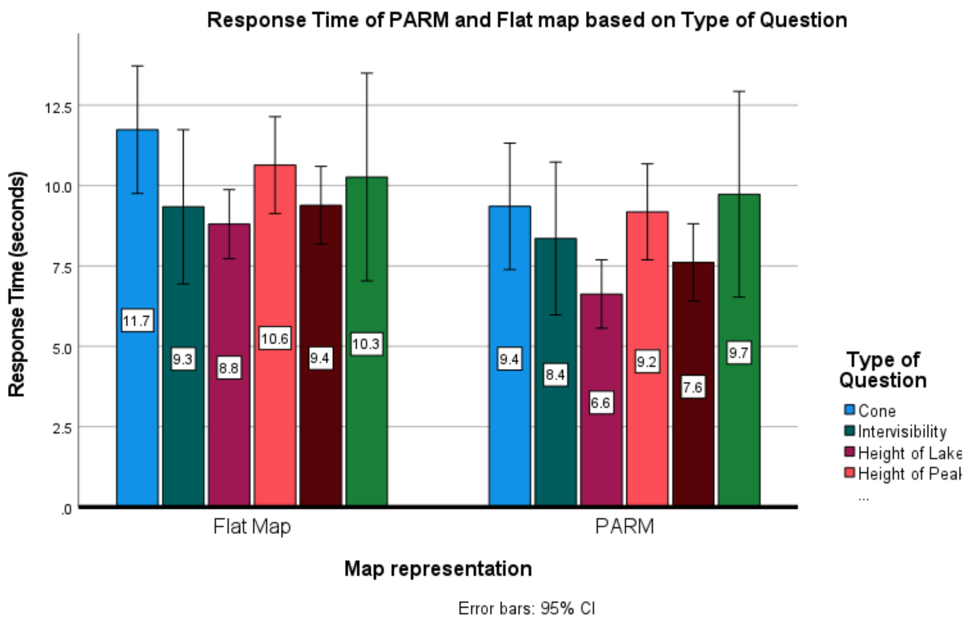


Figure 3.33b. Response Time of Map Representation and Question Types - Lake District Model

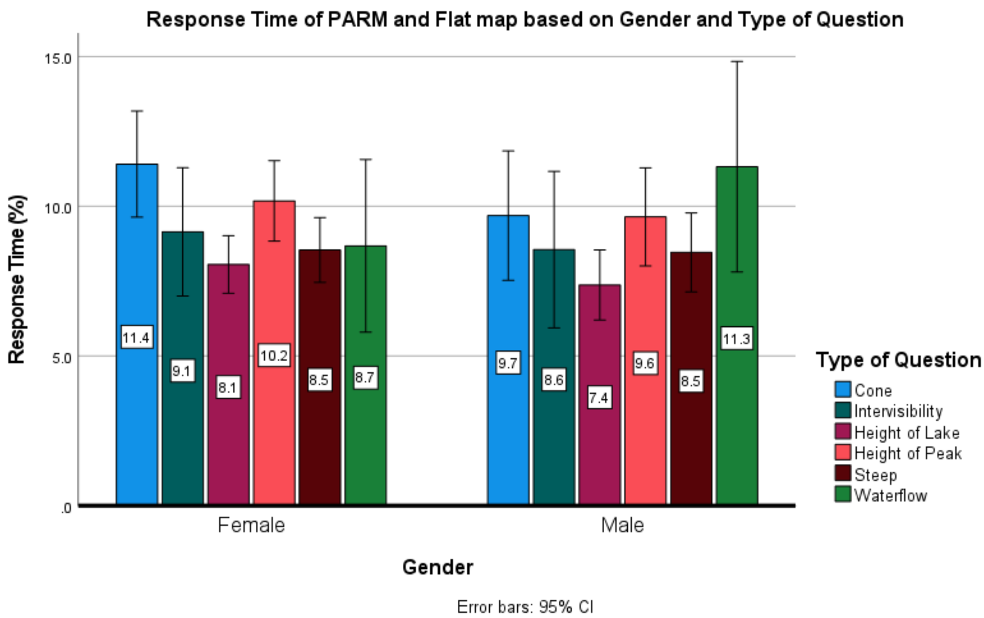


Figure 3.33c. Response Time of Gender and Question Types - Lake District Model

Table 3.51. Descriptive Statistics of Response Time of PARM and Flat Map Based on Type of Question and Gender - Lake District Model

Type of Question	MAP	Gender	Mean	Std. Deviation	N
Cone	Flat Map	Female	12.3	9.1	25
		Male	11.1	5.1	16
		Total	11.9	7.8	41
	PARM	Female	10.5	4.3	24
		Male	8.2	3.5	17
		Total	9.5	4.1	41
	Total	Female	11.4	7.2	49
		Male	9.6	4.5	33
		Total	10.7	6.3	82
Intervisibility	Flat Map	Female	8.6	4.1	25
		Male	10.1	4.2	16
		Total	9.2	4.2	41
	PARM	Female	9.7	12.6	24
		Male	7.0	2.4	17
		Total	8.6	9.8	41
	Total	Female	9.1	9.2	49
		Male	8.5	3.7	33
		Total	8.9	7.5	82
Height_of_Lake	Flat Map	Female	9.2	4.5	25
		Male	8.4	3.6	16
		Total	8.9	4.2	41
	PARM	Female	6.9	2.3	24
		Male	6.4	2.2	17
		Total	6.7	2.2	41
	Total	Female	8.1	3.8	49
		Male	7.3	3.1	33
		Total	7.8	3.5	82
Height_of_Peak	Flat Map	Female	10.7	4.4	25
		Male	10.6	5.6	16
		Total	10.6	4.8	41
	PARM	Female	9.7	4.8	24
		Male	8.7	4.2	17
		Total	9.3	4.5	41
	Total	Female	10.2	4.6	49
		Male	9.6	5.0	33
		Total	10.0	4.7	82

Type of Question	MAP	Gender	Mean	Std. Deviation	N
Steep	Flat Map	Female	9.0	4.1	25
		Male	9.8	4.6	16
		Total	9.3	4.3	41
	PARM	Female	8.1	3.5	24
		Male	7.1	2.8	17
		Total	7.7	3.2	41
	Total	Female	8.5	3.8	49
		Male	8.4	4.0	33
		Total	8.5	3.8	82
Waterflow	Flat Map	Female	9.7	5.3	25
		Male	10.8	5.7	16
		Total	10.2	5.4	41
	PARM	Female	7.6	2.8	24
		Male	11.8	20.5	17
		Total	9.4	13.3	41
	Total	Female	8.7	4.3	49
		Male	11.3	15.0	33
		Total	9.8	10.1	82

Table 3.52. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM and Flat Map Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	454.940	5	90.988	2.928	.013	.036
Type_of_Question*MAP	49.234	5	9.847	.317	.903	.004
Type_of_Question*Gender	214.577	5	42.915	1.381	.230	.017
Type_of_Question*MAP*Gender	152.028	5	30.406	.978	.431	.012
Error(Type_of_Question)	12119.808	390	31.076			

Table 3.53. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	40502.905	1	40502.905	442.701	.000	.850
MAP	284.728	1	284.728	3.112	.082	.038
Gender	3.060	1	3.060	.033	.855	.000
MAP * Gender	18.171	1	18.171	.199	.657	.003
Error	7136.251	78	91.490			

Response time on PARM (**Figure 3.34**) shows male participants had quicker results than female participants except for the waterflow question types where females responded much quicker than male participants. Statistical analysis (**Table 3.54-3.57**) shows for Flat Map, different gender resulted in a significant effect on response time at the 95% confidence level (sig <0.05). However, the interaction between different type of question and different gender for both PARM and Flat Map gave no significant effect statistically on response time.

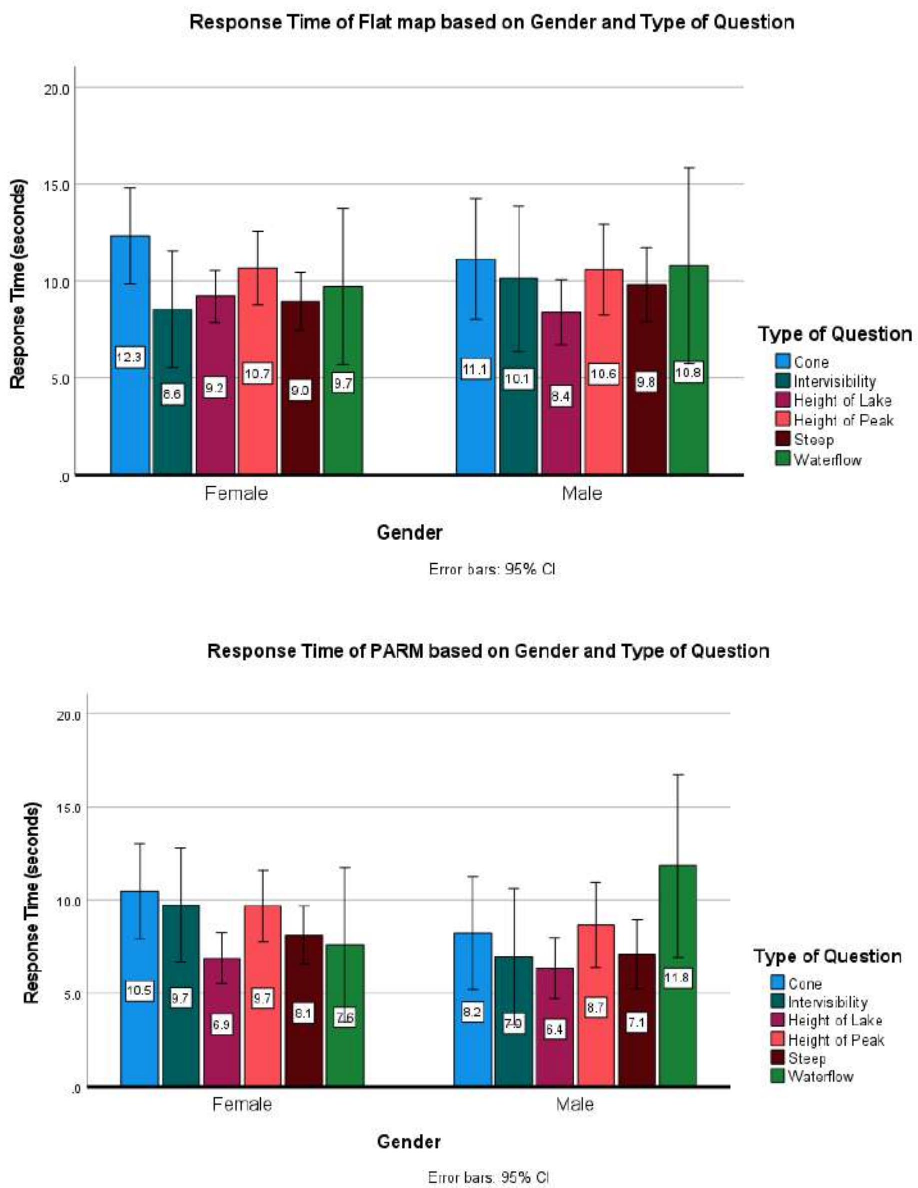


Figure 3.34. Response Time of Flat Map (top) and PARM (bottom) with Different Type of Question and Participant Gender - Lake District Model

Table 3.54. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	280.204	5	56.041	1.129	.346	.028
Type_of_Question*Gender	308.830	5	61.766	1.245	.290	.031
Error(Type_of_Question)	9677.217	195	49.627			

Table 3.55. Tests of Between-Subjects Effects of Response Time of PARM Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	17167.872	1	17167.872	222.750	.000	.851
Gender	18.252	1	18.252	.237	.629	.006
Error	3005.825	39	77.072			

Table 3.56. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of Flat Map Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	224.522	5	44.904	3.585	.004	.084
Type_of_Question*Gender	60.236	5	12.047	.962	.442	.024
Error(Type_of_Question)	2442.590	195	12.526			

Table 3.57. Tests of Between-Subjects Effects of Response Time of Flat Map Based on Type of Question and Gender - Lake District Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	23556.507	1	23556.507	222.423	.000	.851
Gender	3.128	1	3.128	.030	.864	.001
Error	4130.426	39	105.908			

3.5.10 Accuracy and Response Time of PARM and Flat Map Based on Object Distances on Model

Based on distance between features on the maps (**Figure 3.35**), PARM had a significantly better result compared to the Flat Map. Moreover, the accuracy result based on object distances (far, medium, near, same) on the Flat Map had similar results as on PARM. Statistical analysis (**Table 3.59** & **Table 3.60**) shows that different distances and interaction between different map (PARM and Flat Map) gave no significant effects on accuracy.

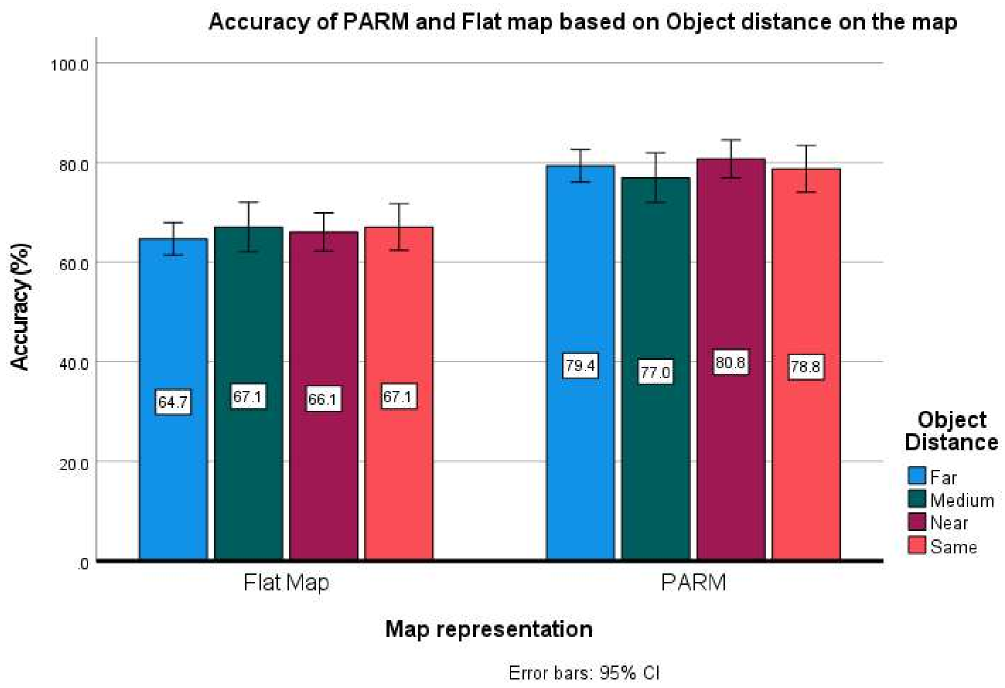


Figure 3.35. Accuracy of PARM and Flat Map Based on Object Distances on Model

Table 3.58. Descriptive Statistics of Accuracy of PARM and Flat Map Based on Object Distances on Model

Distance	MAP	Mean	Std. Deviation	N
Far	Flat Map	64.7	10.0	42
	PARM	79.4	11.2	42
	Total	72.0	12.9	84

Distance	MAP	Mean	Std. Deviation	N
Medium	Flat Map	67.2	16.0	42
	PARM	77.0	16.4	42
	Total	72.0	16.9	84
Near	Flat Map	66.1	13.7	42
	PARM	80.8	10.8	42
	Total	73.4	14.3	84
Same	Flat Map	67.1	15.1	42
	PARM	78.8	15.5	42
	Total	72.9	16.3	84

Table 3.59. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map Based on Object Distances on Model

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Distances	119.668	3	39.889	.267	.849	.003
Distances * MAP	347.842	3	115.947	.776	.508	.009
Error(Distances)	36737.351	246	149.339			

Table 3.60. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map Based on Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1770694.651	1	1770694.651	5610.383	.000	.986
MAP	13651.000	1	13651.000	43.253	.000	.345
Error	25880.043	82	315.610			

Response time measurements on PARM and Flat map based on object distances (far, medium, close and same) were better on PARM compared to Flat Map (**Figure 3.36**). Statistical analysis (**Table 3.62** & **Table 3.63**) shows that different object distance resulted in significant effects on response time at 95% confidence level (sig <0.05). Object distance on PARM, or object distance on Flat map only, gave statistically significant differences, but the comparison of object distance between PARM and Flat map showed no statistically significant difference.

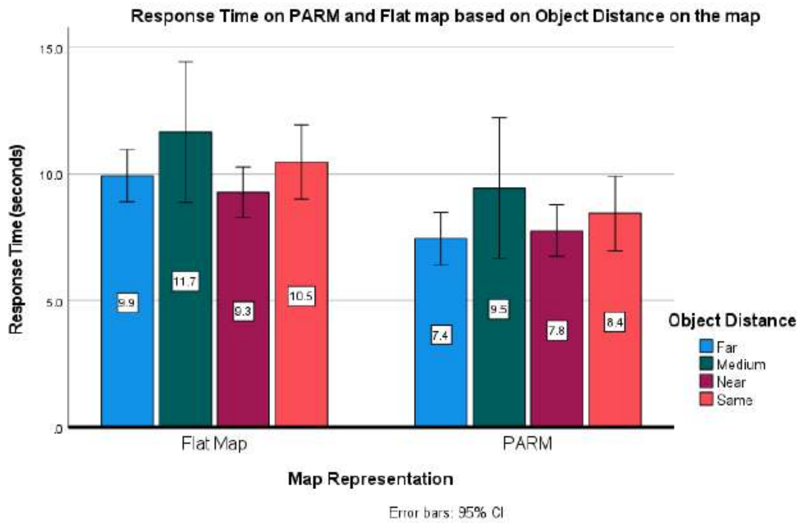


Figure 3.36. Response Time of PARM and Flat Map Based on Object Distances on Model

Table 3.61. Descriptive Statistics of Response Time of PARM and Flat Map Based on Object Distances on Model

Distance	MAP	Mean	Std. Deviation	N
Far	Flat Map	9.9	4.1	42
	PARM	7.4	2.4	42
	Total	8.7	3.6	84
Medium	Flat Map	11.7	8.9	42
	PARM	9.5	9.2	42
	Total	10.6	9.0	84
Near	Flat Map	9.3	3.7	42
	PARM	7.8	2.9	42
	Total	8.5	3.4	84
Same	Flat Map	10.5	4.8	42
	PARM	8.4	4.8	42
	Total	9.5	4.9	84

Table 3.62. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM and Flat Map Based on Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Distances	216.545	3	72.182	3.495	.016	.041
Distances*MAP	10.954	3	3.651	.177	.912	.002
Error(Distances)	5079.907	246	20.650			

Table 3.63. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map Based on Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	29112.548	1	29112.548	450.447	.000	.846
MAP	355.502	1	355.502	5.501	.021	.063
Error	5299.694	82	64.630			

3.5.11 Accuracy and Response Time of PARM Based on Type of Backdrop Map and Object Distances on Model

Figure 3.37 shows the variation on accuracy of participant answers on PARM with different types of backdrop map and object distances. Statistical analysis (**Table 3.65** & **Table 3.66**) shows that interaction between object distance resulted in significant effect on accuracy at the 95% confidence level (sig <0.05). However, comparison between object distance and different backdrop map, and object distance on PARM vs Flat map resulted in no significant effect.

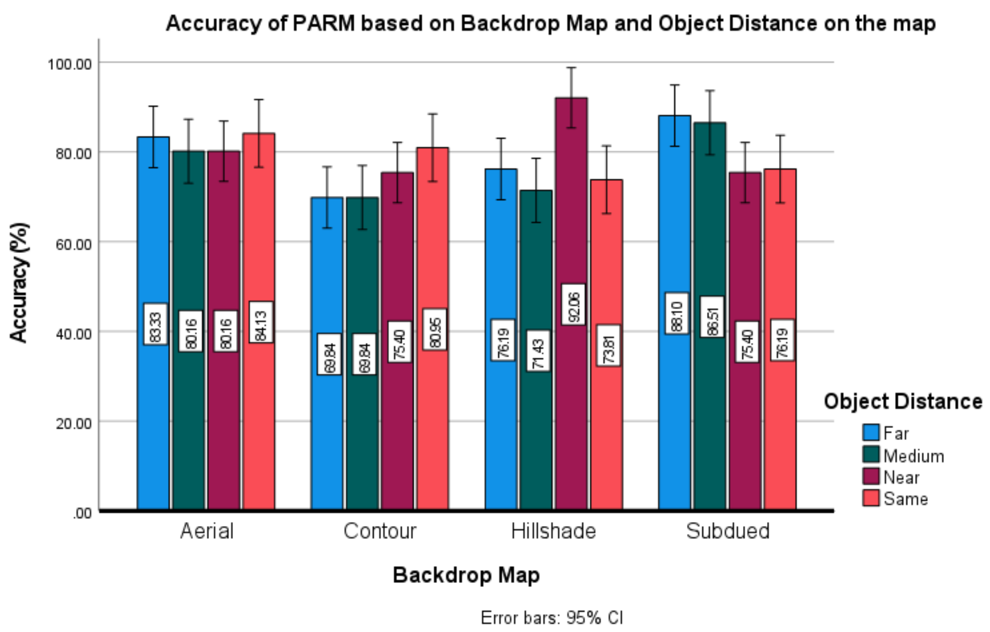


Figure 3.37. Accuracy of PARM with Different Type of Backdrop Map and Object Distances on Model

Table 3.64. Descriptive Statistics of Accuracy of PARM with Different Type of Backdrop Map and Object Distances on Model

Distance	Backdrop map	Mean	Std. Deviation	N
Far	Aerial	83.3	22.4	42
	Contour	69.8	23.1	42
	Hillshade	76.2	24.7	42
	Subdued	88.1	19.2	42
	Total	79.4	23.3	168
Medium	Aerial	80.2	20.9	42
	Contour	69.8	27.4	42
	Hillshade	71.4	21.6	42
	Subdued	86.5	23.4	42
	Total	77.0	24.2	168
Near	Aerial	80.6	22.2	42
	Contour	75.4	23.4	42
	Hillshade	92.1	16.1	42
	Subdued	75.4	25.6	42
	Total	80.6	22.9	168
Same	Aerial	84.1	22.4	42
	Contour	81.0	23.4	42
	Hillshade	73.8	23.9	42
	Subdued	76.2	28.8	42
	Total	78.8	24.9	168

Table 3.65. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM with Different Type of Backdrop Map and Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Distances	1230.159	3	410.053	.841	.472	.005
Distances * Backdrop_map	19484.127	9	2164.903	4.441	.000	.075
Error(Distances)	239841.270	492	487.482			

Table 3.66. Tests of Between-Subjects Effects of Accuracy of PARM with Different Type of Backdrop Map and Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	4190582.010	1	4190582.010	6072.524	.000	.974
Backdrop_map	6798.942	3	2266.314	3.284	.022	.057
Error	113174.603	164	690.089			

Figure 3.38 shows that medium object distance on Aerial map has a long response time compared to others. Statistical analysis (**Table 3.68** & **Table 3.69**) shows that different object distances, as well as the interaction between object distance and different backdrop maps on PARM, had no significant effect on response time.

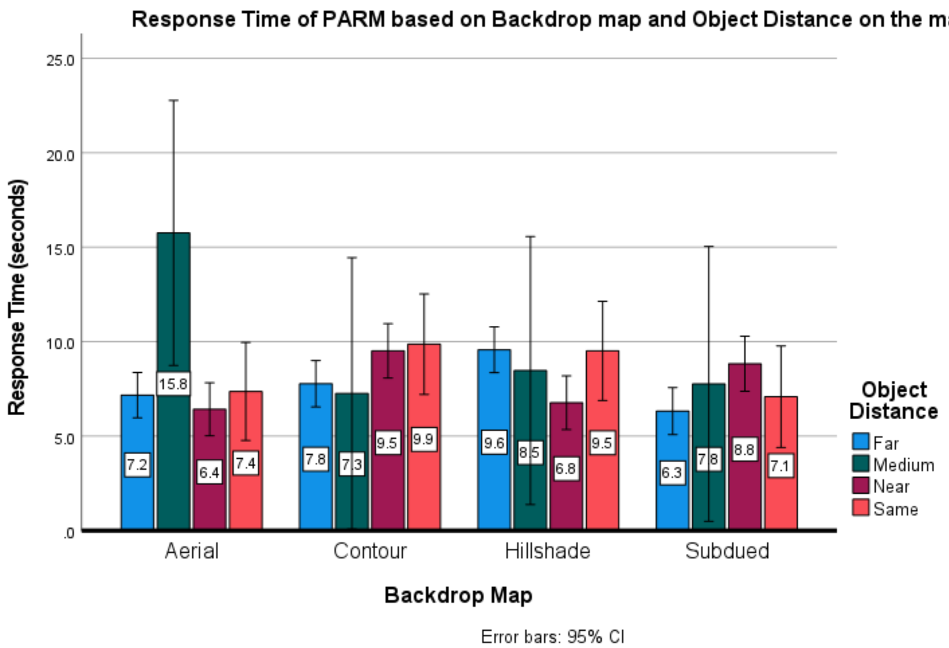


Figure 3.38. Response Time of PARM with Different Type of Backdrop Map and Object Distances on Model

Table 3.67. Descriptive Statistics of Response Time of PARM with Different Type of Backdrop Map and Object Distances on Model

Distance	Backdrop map	Mean	Std. Deviation	N
Far	Aerial	7.2	2.6	42
	Contour	7.8	4.6	40
	Hillshade	9.6	5.3	41
	Subdued	6.3	2.2	39
	Total	7.8	4.1	162
Medium	Aerial	8.9	4.5	42
	Contour	7.3	3.8	40
	Hillshade	8.4	4.4	41
	Subdued	7.7	4.5	39
	Total	8.1	4.3	162
Near	Aerial	6.4	3.3	42
	Contour	9.5	6.8	40

Distance	Backdrop map	Mean	Std. Deviation	N
	Hillshade	6.8	2.3	41
	Subdued	8.8	4.8	39
	Total	7.9	4.7	162
Same	Aerial	7.4	3.4	42
	Contour	9.9	4.4	40
	Hillshade	9.5	15.7	41
	Subdued	7.1	3.1	39
	Total	8.4	8.6	162

Table 3.68. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM with Different Type of Backdrop Map and Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Distances	441.267	3	147.089	.963	.410	.006
Distances*Backdrop map	2504.921	9	278.325	1.823	.062	.033
Error(Distances)	72363.477	474	152.666			

Table 3.69. Tests of Between-Subjects Effects of Response Time of PARM with Different Type of Backdrop Map and Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	46417.403	1	46417.403	257.130	.000	.619
Backdrop_map	235.901	3	78.634	.436	.728	.008

3.5.12 Accuracy and Response Time of Flat Map Based on Type of Backdrop Map and Object Distances on Model

Figure 3.39 shows that on the Flat Map, the accuracy of the same object distance on aerial map is higher than others. Statistical analysis (**Table 3.71** & **Table 3.72**) shows that different object distance on Flat Map as well as interaction between object distance and different backdrop map gave no significant effect on accuracy.

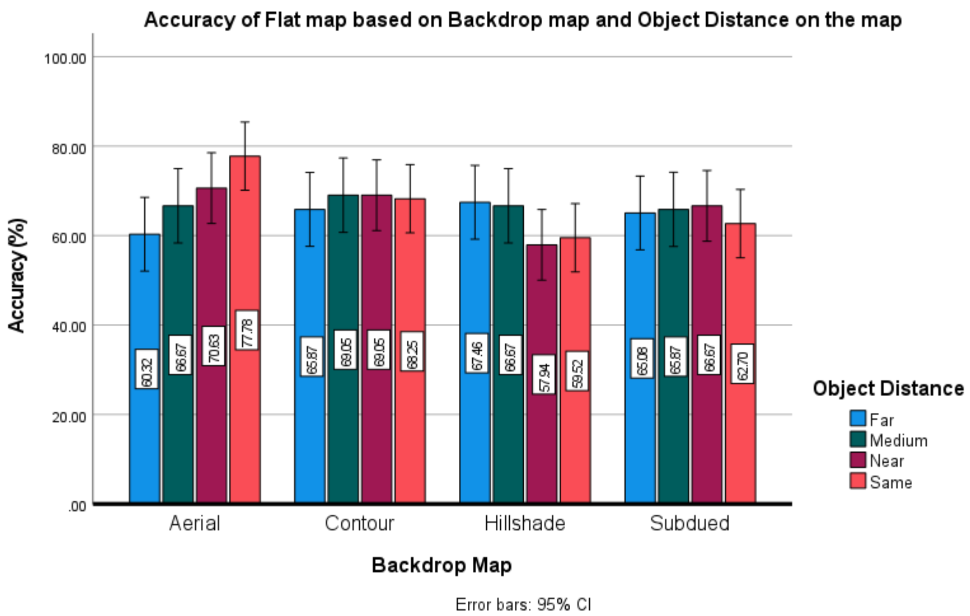


Figure 3.39. Accuracy of Flat Map with Different Type of Backdrop Map and Object Distances on Model

Table 3.70. Descriptive Statistics of Accuracy of Flat Map with Different Type of Backdrop Map and Object Distances on Model

Distance	Backdrop map	Mean	Std. Deviation	N
Far	Aerial	60.3	24.7	42
	Contour	65.9	27.0	42
	Hillshade	67.5	29.9	42
	Subdued	65.1	26.5	42
	Total	64.7	27.0	168
Medium	Aerial	66.7	26.5	42
	Contour	69.0	30.7	42
	Hillshade	66.7	25.5	42
	Subdued	65.9	26.0	42
	Total	67.1	27.1	168
Near	Aerial	70.6	23.5	42
	Contour	69.0	24.8	42
	Hillshade	57.9	24.5	42
	Subdued	66.7	30.4	42
	Total	66.1	26.2	168
Same	Aerial	77.8	25.1	42
	Contour	68.3	22.0	42
	Hillshade	59.5	21.5	42
	Subdued	62.7	30.5	42
	Total	67.1	25.8	168

Table 3.71. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of Flat Map with Different Type of Backdrop Map and Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Distances	639.881	3	213.294	.315	.815	.002
Distances*Backdrop map	9737.103	9	1081.900	1.597	.113	.028
Error(Distances)	333234.127	492	677.305			

Table 3.72. Tests of Between-Subjects Effects of Accuracy of Flat Map with Different Type of Backdrop Map and Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2946800.595	1	2946800.595	3946.596	.000	.960
Backdrop_map	3801.257	3	1267.086	1.697	.170	.030
Error	122453.704	164	746.669			

Figure 3.40 shows different response time of Flat Map with different type of Backdrop maps and Object Distances. Statistical analysis (**Table 3.74** & **Table 3.75**) shows that different object distance on Flat maps as well as interaction between object distance and different backdrop map had no significant effect statistically on response time.

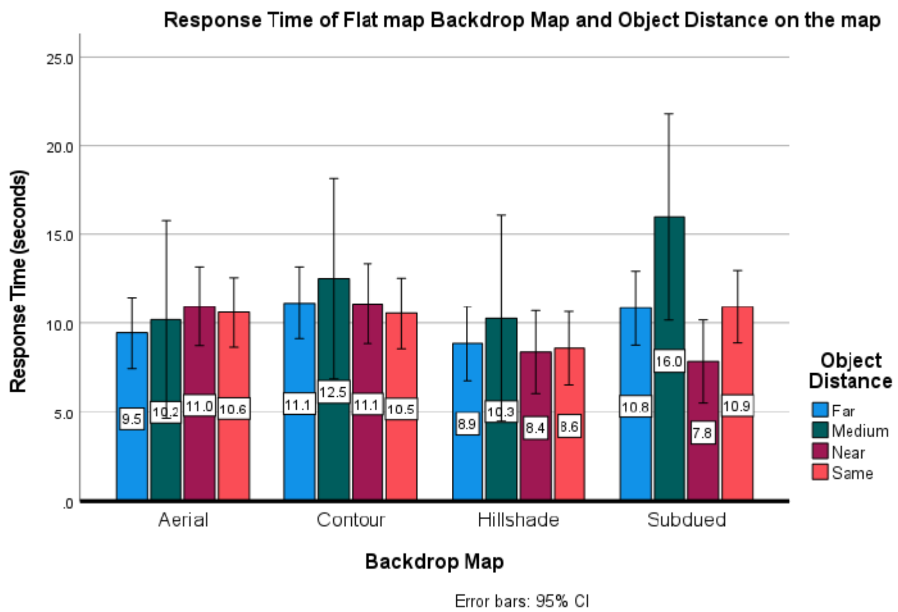


Figure 3.40. Response Time of Flat Map with Different Type of Backdrop Map and Object Distances on Model

Table 3.73. Descriptive Statistics of Response Time of Flat Map with Different Type of Backdrop Map and Object Distances on Model

Distance	Backdrop_map	Mean	Std. Deviation	N
Far	Aerial	9.5	5.4	38
	Contour	11.1	8.3	37
	Hillshade	8.6	4.9	35
	Subdued	10.8	5.7	35
	Total	10.1	6.3	145
Medium	Aerial	10.9	6.2	38
	Contour	12.5	6.8	37
	Hillshade	10.3	15.0	35
	Subdued	16.0	30.6	35
	Total	12.2	17.4	145
Near	Aerial	11.0	9.9	38
	Contour	11.1	7.4	37
	Hillshade	8.4	4.1	35
	Subdued	7.8	4.2	35
	Total	9.6	7.0	145
Same	Aerial	10.6	5.8	38
	Contour	10.6	7.0	37
	Hillshade	8.6	4.9	35
	Subdued	10.9	6.6	35
	Total	10.2	6.1	145

Table 3.74. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of Flat Map with Different Type of Backdrop Map and Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Distances	602.657	3	200.886	2.319	.075	.016
Distances * Backdrop_map	822.490	9	91.388	1.055	.395	.022
Error(Distances)	36635.693	423	86.609			

Table 3.75. Tests of Between-Subjects Effects of Response Time of Flat Map with Different Type of Backdrop Map and Object Distances on Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	64010.394	1	64010.394	383.499	.000	.731
Backdrop_map	528.285	3	176.095	1.055	.370	.022
Error	23534.534	141	166.912			

3.5.13 Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Participant Familiarity to Lake District

Figure 3.41 shows that there was better accuracy on PARM compared to Flat Map based on participants familiarity with the Lake District. Moreover, the trends of participants who have visited the Lake District had better results on all backdrop maps except the aerial map (**Figure 3.42**). However, it was also found that different representations (PARM/Flat Map) did not have a significant effect on the accuracy of participants who were familiar with the area on PARM or Flat map (**Table 3.77** & **Table 3.78**).

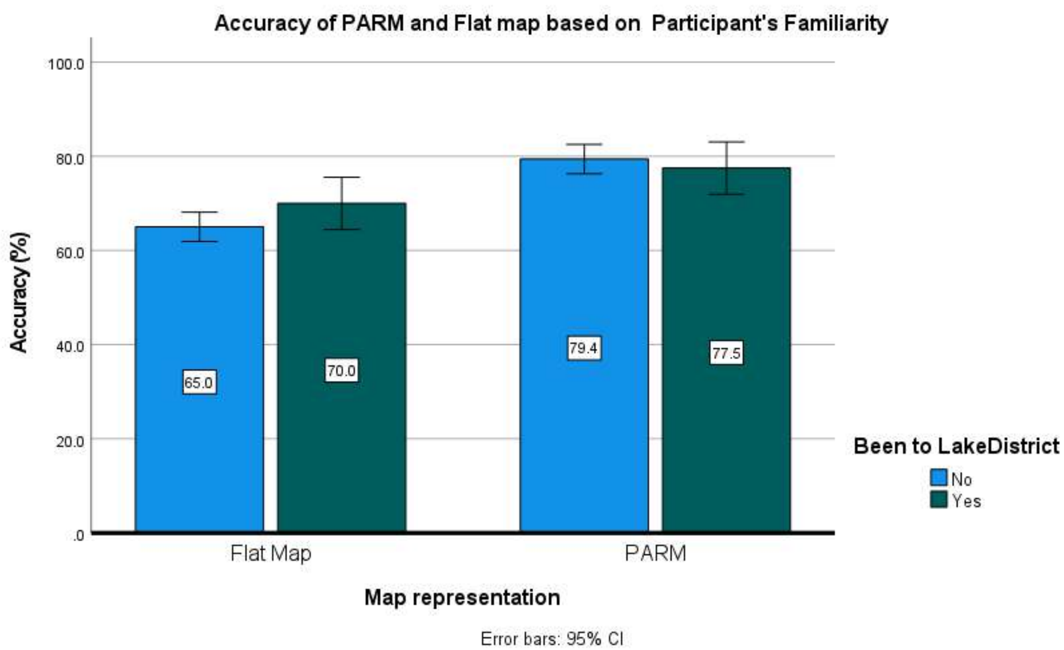


Figure 3.41. Accuracy of PARM and Flat Map for Participant who have or have not Visited Lake District

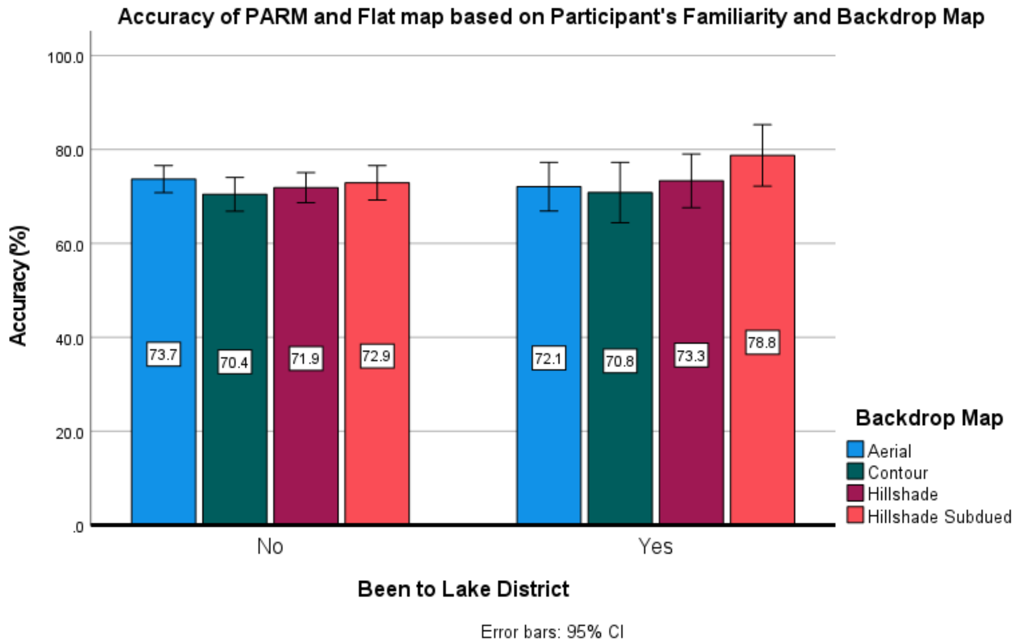


Figure 3.42. Accuracy of PARM and Flat Map with Different Type of Backdrop Map and Participant Familiarity to Lake District

Table 3.76. Descriptive Statistics Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Participant Familiarity to Lake District

Backdrop Map	MAP	Been to Lake District	Mean	Std. Deviation	N
Aerial	Flat Map	No	63.3	10.1	32
		Yes	69.2	8.8	10
		Total	64.7	10.0	42
	PARM	No	84.1	12.9	32
		Yes	75.0	14.2	10
		Total	81.9	13.6	42
	Total	No	73.7	15.6	64
		Yes	72.1	11.9	20
		Total	73.3	14.7	84
Contour	Flat Map	No	66.9	14.9	32
		Yes	67.5	20.2	10
		Total	67.1	16.0	42
	PARM	No	74.0	12.1	32
		Yes	74.2	13.3	10
		Total	74.0	12.2	42
	Total	No	70.4	13.9	64
		Yes	70.8	17.0	20
		Total	70.5	14.6	84
Hillshade	Flat Map	No	65.6	14.8	32
		Yes	67.5	10.0	10
		Total	66.1	13.7	42

	PARM	No	78.1	10.3	32
		Yes	79.2	15.8	10
		Total	78.4	11.6	42
	Total	No	71.9	14.1	64
		Yes	73.3	14.2	20
		Total	72.2	14.1	84
Hillshade_subdued	Flat Map	No	64.3	15.9	32
		Yes	75.8	7.3	10
		Total	67.1	15.1	42
	PARM	No	81.5	14.6	32
		Yes	81.7	16.1	10
		Total	81.5	14.8	42
	Total	No	72.9	17.4	64
		Yes	78.8	12.5	20
		Total	74.3	16.5	84

Table 3.77. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Participant Familiarity to Lake District

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop_Map	839.624	3	279.875	2.035	.110	.025
Backdrop_Map * MAP	367.195	3	122.398	.890	.447	.011
Backdrop_Map * Been to LakeDistrict	452.719	3	150.906	1.097	.351	.014
Backdrop_Map * MAP * Been_to_LakeDistrict	628.439	3	209.480	1.523	.209	.019
Error(Backdrop_Map)	33013.997	240	137.558			

Table 3.78. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Participant Familiarity to Lake District

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1298959.700	1	1298959.700	4153.877	.000	.981
MAP	7300.350	1	7300.350	23.345	.000	.226
Been to LakeDistrict	140.256	1	140.256	.449	.505	.006
MAP*Been to LakeDistrict	722.969	1	722.969	2.312	.132	.028
Error	25016.819	80	312.710			

3.5.14 Accuracy of PARM and Flat Map Based on Type of Question and Participant Familiarity to Lake District

Figure 3.43 shows that based on participants familiarity with the Lake District, all types of questions had a better or similar result on participants who were familiar compared to those unfamiliar with the Lake District except intervisibility question types. Moreover, statistical analysis (**Table 3.80** & **Table 3.81**) shows that familiarity with the Lake District, interaction between different representations (PARM and Flat map) gave no significant effect on accuracy.

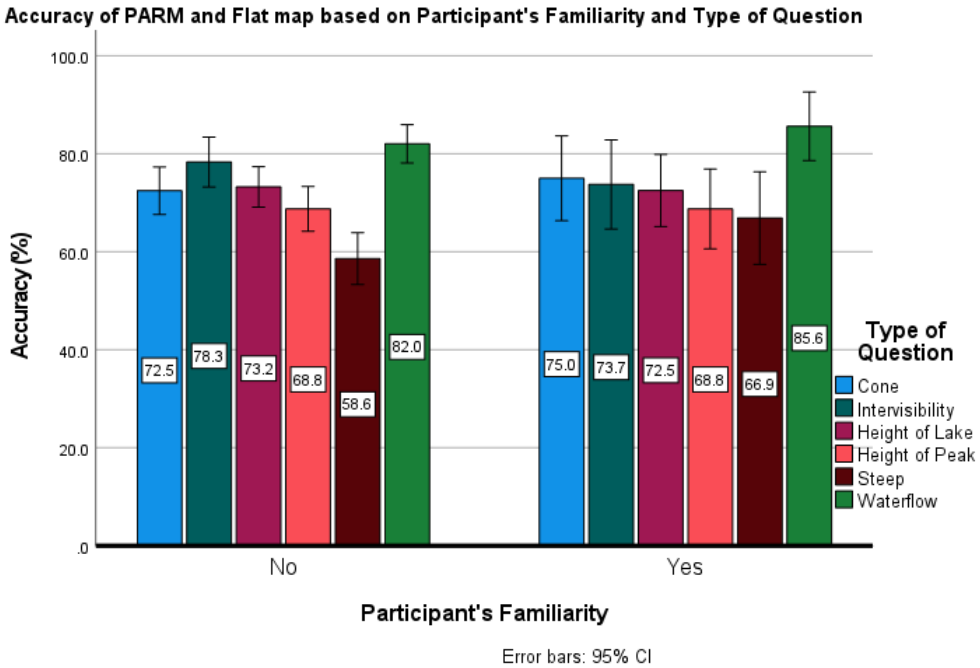


Figure 3.43. Accuracy of PARM and Flat Map with Different Type of Question and Participant Familiarity to Lake District

Table 3.79. Descriptive Statistics Accuracy of PARM and Flat Map Based on Type of Question and Participant Familiarity to Lake District

Type of Question	MAP	Been to Lake District	Mean	Std. Deviation	N
Cone	Flat Map	No	62.5	21.5	32
		Yes	71.2	13.2	10
		Total	64.6	20.1	42
	PARM	No	82.4	18.7	32
		Yes	78.8	19.6	10
		Total	81.5	18.8	42

Type of Question	MAP	Been to Lake District	Mean	Std. Deviation	N
	Total	No	72.5	22.4	64
		Yes	75.0	16.7	20
		Total	73.1	21.1	84
Intervisibility	Flat Map	No	75.0	21.1	32
		Yes	70.0	26.5	10
		Total	73.8	22.2	42
	PARM	No	81.6	16.2	32
		Yes	77.5	24.2	10
		Total	80.7	18.1	42
	Total	No	78.3	18.9	64
		Yes	73.8	25.0	20
		Total	77.2	20.5	84
Height_of_Lake	Flat Map	No	68.0	14.9	32
		Yes	66.3	19.6	10
		Total	67.6	15.9	42
	PARM	No	78.5	17.7	32
		Yes	78.8	14.5	10
		Total	78.6	16.9	42
	Total	No	73.2	17.1	64
		Yes	72.5	18.0	20
		Total	73.1	17.2	84
Height_of_Peak	Flat Map	No	60.9	11.8	32
		Yes	68.8	20.6	10
		Total	62.8	14.5	42
	PARM	No	76.6	19.8	32
		Yes	68.8	27.2	10
		Total	74.7	21.6	42
	Total	No	68.8	18.0	64
		Yes	68.8	23.5	20
		Total	68.8	19.3	84
Steep	Flat Map	No	52.3	20.4	32
		Yes	63.8	23.9	10
		Total	55.1	21.6	42
	PARM	No	64.8	21.6	32
		Yes	70.0	19.7	10
		Total	66.1	21.1	42
	Total	No	58.6	21.8	64
		Yes	66.9	21.6	20
		Total	60.6	21.9	84
Waterflow	Flat Map	No	71.5	20.1	32
		Yes	80.0	14.7	10
		Total	73.5	19.2	42

Type of Question	MAP	Been to Lake District	Mean	Std. Deviation	N
	PARM	No	92.6	10.0	32
		Yes	91.3	15.6	10
		Total	92.3	11.4	42
	Total	No	82.0	19.0	64
		Yes	85.6	15.9	20
		Total	82.9	18.3	84

Table 3.80. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Participant Familiarity to Lake District

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	15265.877	5	3053.175	9.327	.000	.104
Type_of_Question*MAP	953.842	5	190.768	.583	.713	.007
Type_of_Question* Been_to_LakeDistrict	1456.353	5	291.271	.890	.488	.011
Type_of_Question*MAP * Been_to_LakeDistrict	968.723	5	193.745	.592	.706	.007
Error(Type_of_Question)	130938.639	400	327.347			

Table 3.81. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Participant Familiarity to Lake District

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1948439.550	1	1948439.550	4153.877	.000	.981
MAP	10950.525	1	10950.525	23.345	.000	.226
Been_to_LakeDistrict	210.383	1	210.383	.449	.505	.006
MAP * Been_to_LakeDistrict	1084.453	1	1084.453	2.312	.132	.028
Error	37525.228	80	469.065			

3.5.15 Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Difficulties in Reading Map

Figure 3.44 shows that on both PARM and Flat Map, participants with no experience of having trouble reading maps had slightly better accuracies compared to those who experienced difficulties in reading maps. Participants who had difficulties in reading maps had lower accuracy on all backdrop maps except the aerial map (**Figure 3.45**). Statistical analysis (**Table 3.83** & **Table 3.84**) showed that difficulty in reading maps, interaction between different map (PARM and Flat Map), as well as interaction between different backdrop and difficulty reading map had no significant effect on response time.

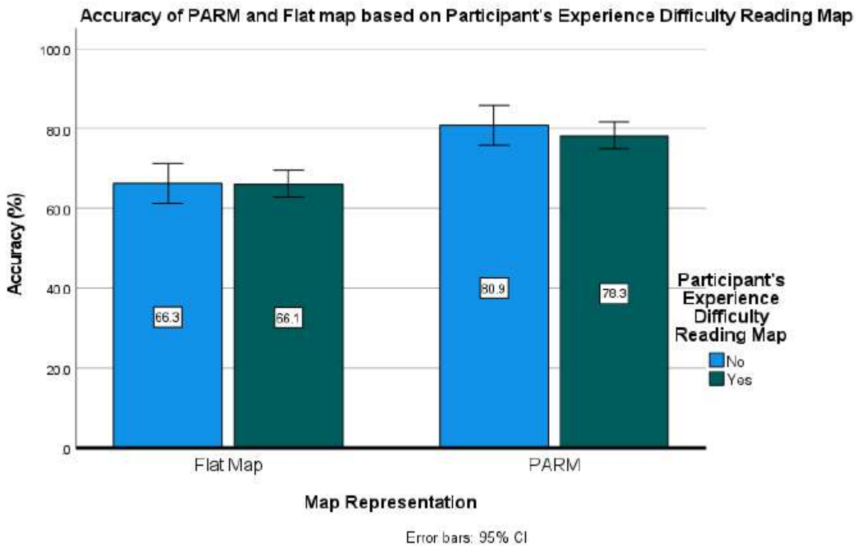


Figure 3.44. Accuracy of PARM and Flat Map for Participant Who Have or Do Not Have Trouble Reading Map

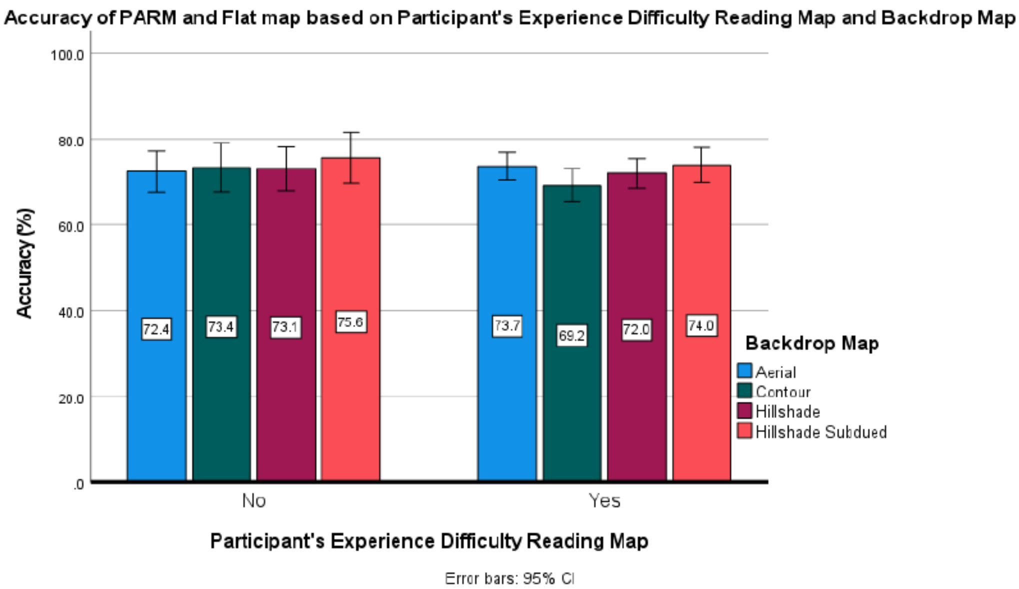


Figure 3.45. Accuracy of PARM and Flat Map with Different Type of Backdrop Map and Participant Difficulty in Reading Map

Table 3.82. Descriptive Statistics of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Difficulties in Reading Map

Backdrop Map	MAP	Experience Difficulties Reading Map	Mean	Std. Deviation	N
Aerial	Flat Map	No	60.9	8.6	13
		Yes	66.4	10.5	28
		Total	64.6	10.2	41
	PARM	No	84.0	13.4	13
		Yes	81.0	14.1	28
		Total	81.9	13.8	41
	Total	No	72.4	16.1	26
		Yes	73.7	14.4	56
		Total	73.3	14.9	82
Contour	Flat Map	No	70.5	12.6	13
		Yes	65.2	17.6	28
		Total	66.9	16.2	41
	PARM	No	76.3	10.7	13
		Yes	73.2	13.1	28
		Total	74.2	12.3	41
	Total	No	73.4	11.8	26
		Yes	69.2	15.9	56
		Total	70.5	14.8	82
Hillshade	Flat Map	No	64.7	11.9	13
		Yes	67.0	14.8	28
		Total	66.3	13.8	41
	PARM	No	81.4	6.9	13
		Yes	77.1	13.3	28
		Total	78.5	11.8	41
	Total	No	73.1	12.8	26
		Yes	72.0	14.9	56
		Total	72.4	14.2	82
Hillshade subdued	Flat Map	No	69.2	14.2	13
		Yes	66.1	15.9	28
		Total	67.1	15.2	41
	PARM	No	82.1	13.5	13
		Yes	81.8	15.6	28
		Total	81.9	14.8	41
	Total	No	75.6	15.1	26
		Yes	74.0	17.5	56
		Total	74.5	16.7	82

Table 3.83. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Difficulties in Reading Map

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Backdrop_Map	448.915	3	149.638	1.058	.368	.013
Backdrop_Map*MAP	1287.339	3	429.113	3.035	.030	.037
Backdrop_Map* Exp_diff_reading_map	265.141	3	88.380	.625	.600	.008
Backdrop_Map*MAP * Exp_diff_reading_map	465.015	3	155.005	1.096	.351	.014
Error(Backdrop_Map)	33090.135	234	141.411			

Table 3.84. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map Based on Type of Backdrop Map and Difficulties in Reading Map

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1510797.779	1	1510797.779	4625.384	.000	.983
MAP	12668.870	1	12668.870	38.786	.000	.332
Exp_diff_reading_map	144.832	1	144.832	.443	.507	.006
MAP * Exp_diff_reading_map	107.048	1	107.048	.328	.569	.004
Error	25477.287	78	326.632			

3.5.16 Accuracy of PARM and Flat Map Based on Type of Question and Difficulties in Reading Map

Figure 3.46 shows that based on types of questions, the accuracy of participants who have difficulties in reading maps is better on two question types (waterflow and steeper slope). Statistical analysis (**Table 3.86** & **Table 3.87**) shows that interaction between type of question and difficulty reading map had no significant effect statistically on response time.

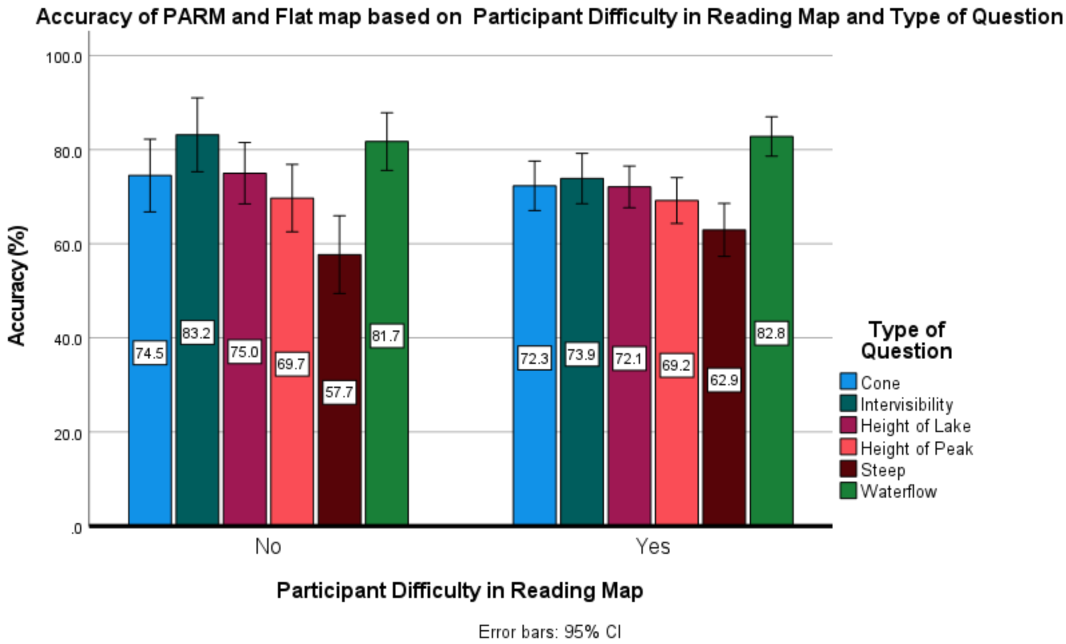


Figure 3.46. Accuracy of PARM and Flat Map with Different Type of Backdrop Map and Participant Difficulty in Reading Map

Table 3.85. Descriptive Statistics of Accuracy of PARM and Flat Map Based on Type of Question and Difficulties in Reading Map

Type of Question	MAP	Experience Difficulties Reading Map	Mean	Std. Deviation	N
Cone	Flat Map	No	63.5	13.9	13
		Yes	64.7	22.8	28
		Total	64.3	20.3	41
	PARM	No	85.6	13.4	13
		Yes	79.9	21.1	28
		Total	81.7	19.0	41
	Total	No	74.5	17.5	26
		Yes	72.3	23.1	56
		Total	73.0	21.4	82
Intervisibility	Flat Map	No	81.7	14.1	13
		Yes	69.6	24.6	28
		Total	73.5	22.4	41
	PARM	No	84.6	17.8	13
		Yes	78.1	18.2	28
		Total	80.2	18.1	41
	Total	No	83.2	15.8	26
		Yes	73.9	21.9	56

Type of Question	MAP	Experience Difficulties Reading Map	Mean	Std. Deviation	N
		Total	76.8	20.5	82
Height of Lake	Flat Map	No	69.2	12.1	13
		Yes	67.0	17.7	28
		Total	67.7	16.1	41
	PARM	No	80.8	15.0	13
		Yes	77.2	18.0	28
		Total	78.4	17.0	41
	Total	No	75.0	14.6	26
		Yes	72.1	18.5	56
		Total	73.0	17.3	82
Height of Peak	Flat Map	No	63.5	8.0	13
		Yes	62.9	16.8	28
		Total	63.1	14.5	41
	PARM	No	76.0	18.7	13
		Yes	75.4	22.4	28
		Total	75.6	21.1	41
	Total	No	69.7	15.5	26
		Yes	69.2	20.6	56
		Total	69.4	19.1	82
Steep	Flat Map	No	51.0	23.1	13
		Yes	58.0	20.5	28
		Total	55.8	21.3	41
	PARM	No	64.4	21.6	13
		Yes	67.9	20.8	28
		Total	66.8	20.8	41
	Total	No	57.7	22.9	26
		Yes	62.9	21.0	56
		Total	61.3	21.7	82
Waterflow	Flat Map	No	69.2	18.8	13
		Yes	74.6	19.1	28
		Total	72.9	18.9	41
	PARM	No	94.2	11.0	13
		Yes	91.1	11.7	28
		Total	92.1	11.4	41
	Total	No	81.7	19.8	26
		Yes	82.8	17.8	56
		Total	82.5	18.3	82

Table 3.86. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map Based on Type of Question and Difficulties in Reading Map

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	20621.476	5	4124.295	12.768	.000	.141
Type_of_Question * MAP	2687.486	5	537.497	1.664	.142	.021
Type_of_Question * Exp_diff_reading_map	2065.836	5	413.167	1.279	.272	.016
Type_of_Question * MAP * Exp_diff_reading_map	577.475	5	115.495	.358	.877	.005
Error(Type_of_Question)	125980.927	390	323.028			

Table 3.87. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map Based on Type of Question and Difficulties in Reading Map

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2266196.668	1	2266196.668	4625.384	.000	.983
MAP	19003.305	1	19003.305	38.786	.000	.332
Exp_diff_reading_map	217.247	1	217.247	.443	.507	.006
MAP* Exp_diff_reading_map	160.571	1	160.571	.328	.569	.004
Error	38215.931	78	489.948			

To summarize the key findings of the study in this chapter, based on the 4 types of backdrop maps, PARM showed higher accuracies and quicker response times than the flat maps. Thus, PARM gave a better portrayal than flat maps regarding for the types of questions asked, in terms of both accuracy and response time. Both females and males performed better on PARM in terms of accuracy, across all question types and backdrop maps. Participant familiarity with the area, and participants difficulties in reading maps, showed no significant difference between PARM and flat map.

4 Exploring the Capabilities of PARM for an Urban Terrain

The presence of landmarks is essential in map reading. They provide clues that help users to self-locate themselves on the actual location landscape. However, natural landmarks such as the kind of landmarks that exist in the Lake District region are sometimes not as recognisable as human-made landmarks. An urban terrain model usually has various kinds of features on the surface like buildings, trees, roads, railways, bridges, etc. Such landmarks can be used as reference points when interpreting landscapes. Therefore, in this part of the study, a PARM of University Park (UP Campus), University of Nottingham was explored and compared with the associated flat map. It was of interest to see if the 3-dimensional features of the physical model could provide more distinct landmarks to help participants with existing knowledge of the area interpret the representation more easily. The difference in this second experiment was the participant's awareness of the place. All participants were students or staff of the University of Nottingham who had University Park as their main place of study or work.

4.1 Aims

The aims of the UP Campus experiment are as follow:

1. To examine whether a physical model can help people who already know an area to orientate themselves, based on the recognition of landmarks, and so perform a you-are-here (YAH) style function
2. To examine whether the 3D representation (physical relief model) of the UP Campus map is more effective for orientation than the UP Campus flat map
3. To identify objects on PARM that affect people's knowledge from the model

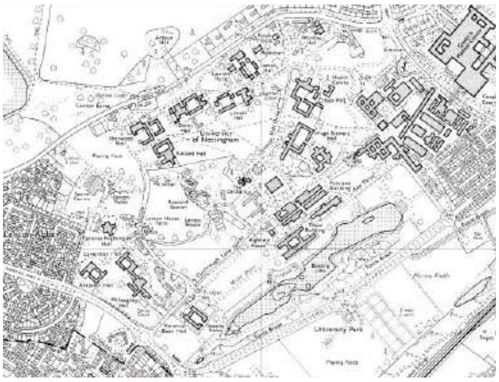
4.2 Experimental Setup

In general, the experimental setup for this experiment is similar to the experiment for the Lake District Model in chapter 3, including the tools and devices used, participants and recruitment process, the experimentation environment, and the experimentation procedures. However, in this experiment, all participants are either students or staff of the University of Nottingham who have some familiarity with the University Park area. The announcement of the experiment was put on the announcement billboard in buildings on the UP Campus.

The physical model used in this experiment is a PARM model of University Park, University of Nottingham, UK (developed by Dr. Gary Priestnall) (**Figure 4.1**). The model was 120 cm (l) x 80 cm (w) x 2.5 cm (min. h) in size and made of a lightweight, high-density foam board and white in colour. To obtain 2D terrain maps, a white flat wooden board with the dimensions of approximately 150x100 cm was used. Although the 3D physical model and flat board are different sizes, the size of the image from the projector onto the board was the same as the PARM model.

Figure 4.1. PARM Model of University Park

For the backdrop map, an aerial image of the University Park campus was used as can be seen in **Figure 4.2**. These images are the image that has been used in the Mayfest UoN open day which 6 types of map images were presented. The selected image (aerial) was used because of its clarity and natural view of the place.



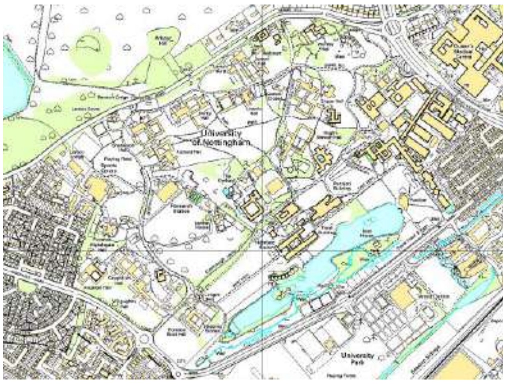
University Park (1985)

Aerial

Aerial Shade

Hybrid 1

Hybrid 2



OS 10k

Figure 4.2. Digital Image of University Park, University of Nottingham

The UP Campus area was selected because it has a good range of features on the area such as lakes, slopes, trees, buildings, roads, bridges and towers, and is suitable to explore the potential function of PARM as a you-are-here map to be explored.

4.3 Pilot Study: Refinement of Experimental Setup

4.3.1 Design of Questions: University Park Model

The experiment on the Lake District model gave a baseline for the subsequent experiments where the University Park model was used. However, a pilot study was still undertaken for the experiment on the University Park model to test the questions in terms of their clarity as well as their effectiveness in assessing the capability of PARM to assist users familiar with the area. The significant difference between upland rural (Lake District model) and urban areas (UP Campus model) is the 3D objects on the model reflect more human-made objects such as buildings. The UP-campus physical model was based on 1999 airborne laser-scanning data where buildings and roads are slightly different compared to the existing UP Campus. A new type of question could therefore be to identify the new objects/buildings around the UP Campus which do not exist on the UP campus map or 3D physical model

The main difference between the two experiments was that participants involved in the University Park experiment had some knowledge and familiarity with the location. Additionally, in contrast to objects on the Lake District model, objects on the University Park model were mostly human-made such as buildings, roads, and bridges. This reflected both the different types of landscape and the different scales of the model, with the UP Campus model showing local detail of an urban environment rather than a regional scale rural environment. Therefore, the types of questions asked were different to the previous experiment. The types of questions and the variables that might influence the participants are as follows:

(1) Determine the location of new objects

Since the map was based on late 1990s data, participants were required to estimate the location of present-day objects (buildings or roads) which were not represented on the model. This was considered part of the participants advanced 'calibrations' based on their knowledge. The calibration method worked by showing a picture of buildings or roads and asking them to show the location on the 3D physical model or 2D map which corresponds to where that object is.

(2) Determine the location from which a photo of an area was taken

A picture of an area was displayed, and the participant was required to show the location from which the picture was taken, based on their recognition of features in the scene.

(3) Higher point comparison

Participants needed to identify the highest of two objects, such as points on the ground surface, buildings, or trees. The variables were: (i) The difference in height between two points: similar height, medium height and obvious difference, (ii) The distance between two points: near, medium, far, (iii) Height of trees, and (iv) Height of buildings.

(4) Intervisibility

Participants needed to determine which of two alternative objects were visible from a particular point. Participants would answer the questions based on their recognition of the buildings, areas, landmarks on the picture, their knowledge of space, and their judgement based on the representations they were shown (model or flat map). The variables are: (i) The distance between two points: near, medium, far, (ii) uphill-downhill terrain, (iii) buildings, and (iv) trees.

(5) Cone viewpoints

There were two cones of vision shown on the map or model and participants needed to determine which one is similar to the picture provided based on their knowledge of space, terrain, buildings, and trees. The level of difficulties was similar, medium, and different viewpoints. Some variables that may influence their judgement are (i) uphill-downhill terrain, (ii) building on the left or right, (iii) trees on the left or right, (iv) lake on the left or right, (v) Road on the left or right.

(6) Who walks the steeper path

Participants were shown two animated walking paths on the slope and were asked to determine which declining path is the steepest. The variables are: (i) The angle difference of the two paths: similar, medium and different and (ii) The distance between two steps.

(7) Show Me the object (text only)

Participants were required to identify a certain object when only the name of the object was provided and not a picture. This could be considered another part of the participants 'calibrations' between the representation and their knowledge of the area. Participants were required to point at the building on the map.

(8) Show Me the object (with picture)

Participants were shown a picture of an object and were required to point to the location on the map.

Table 4.1. Examples of Questions from the pilot study (1st set) for the University Park Campus Model

Type of Questions	Number of Questions	Example of Question
Show me the object	9	**The Monitor:** Show Me the Lakeside Art Centre **The Projector:** UP Campus
New Object	9	**The Monitor:** Could you show the location of the bridge?  **The Projector:** UP Campus
Highest point	9	**The Monitor:** Notice both points, which one is highest? A or B **The Projector:** 
Inter-visibility	9	**The Monitor:** From which point is the red location visible? A or B

Type of Questions	Number of Questions	Example of Question
		The Projector: 
The picture was taken from	19	**The Monitor:** Where Was the Photo Taken from?  **The Projector:** UP Campus
Steepest Path	9	**The Monitor:** Which line follows the steepest path? A or B **The Projector:** 
View of the Buildings	9	**The Monitor:** Imagine that you are standing at the yellow dot. Which building(s) (building no. 1-6) can you see from the yellow dot?

Type of Questions	Number of Questions	Example of Question
		The Projector: 
Cone vision	8	**The Monitor:** Which viewpoint matches the picture below?  **The Projector:** 
Walking path	9	**The Monitor:** Imagine that you are the yellow or the red dot. Which walking path is declining? Red or Yellow **The Projector:** UP Campus + Walking path animation

In the first pilot study, 7 participants were involved consisting of 5 PhD students and 2 Masters students with various backgrounds of study. The participants had all lived in Nottingham for at least 6 months and based on self-assessment using a questionnaire given at the beginning of the study, the participants have Santa Barbara Sense of Direction Scale (SBSOD) scores (Hegarty et al., 2002) of between 34.3% and 83.8%. A total of 90 questions were given and were displayed on a monitor, while the model or flat map was projected with the aerial image of University Park Campus. Participants were asked to give the answers in 3 different ways i.e. A or B answers (Highest point, Steepest, Intervisibility, Cone Vision, Walking Path), Pointing-based answers (Show me, New Object, Picture taken from), and more than 1 answer question type (view of the buildings). An example of each type of question is given in **Table 4.1**.

In the pilot study, participants were able to move around freely and have more interaction with the model. They were asked to give and discuss the answer to help with the refinement of the questions. The result showed that participants could answer almost all the questions given (> 95% accuracy). Overall, the response times for A or B questions was faster than the pointing-based answers. Participants also discussed variables that help them determine the answer. Overall, for some types of questions such as Highest point, Intervisibility, Steepest path, and Walking Path, participants gave the answer mainly based on the geographical relief and elevation depicted on the model or map. For other types of questions, the answer was highly influenced by their knowledge and experiences that they then relate to the display of the map and model.

4.3.2 Initial Findings

According to the pilot study, several types of questions were eliminated due to the possibility of causing bias to the participant perceptions. The cone vision, intervisibility and high-low questions were considered less biased with the urban area 3D model. The deleted questions are as follows:

(1) Who walks the steeper path?

This type of question was excluded due to a similar reason to the 'who walks steeper slope' question in the Lake District pilot study.

(2) Show Me the object (text only or with picture)

These types of question were removed because it was too similar to the 'new object' question and not everyone knows the name of a particular building.

(3) View of the buildings

This question type was removed because there were too many options for the participant to judge and it was not suitable for the A/B question method so it was less suitable for analysis.

(4) Walking path

The problem with the walking path question was that the arrow of the path should very slim and clear, which would make bias of perception if not clear. Moreover, it was an issue with people's perceptions of how arduous a walking route might be.

(5) Picture was taken from

This was too dependent on the particular views of a building that people may have seen as it could be viewed from many different vantage points.

The second set of piloting questions involved 3 participants (1 PhD and 2 Masters students). There were 40 questions of 4 types, with 10 questions of each type, which are the same set of questions given in the main study. In the first part of the pilot study, all questions were given only on PARM and not on the flat board, so the second stage was designed to test the refined question set on both the PARM and the flat map. The result from the piloting study can be seen in **Table 4.2**. The table shows the new types of question (new objects) as a final result suggested that it can be used for this experiment in which each participant understand the question and answer it properly in terms of accuracy and response time.

Table 4.2. Result of Piloting Study (2nd set) of University Park Model

Type of Question	Participant 1		Participant 2		Participant 3	
	Accuracy (%)	RT *)	Accuracy (%)	RT *)	Accuracy (%)	RT *)
Cone	100	26.1	100	6.7	100	10.6
Height	80	15.6	70	5.8	80	8.8
Intervisibility	70	9.1	90	7.7	80	8
New Objects	90	8.8	70	9.1	60	36.7

*RT: Response Time (seconds)

4.4 Main Study

To achieve the aim of the experiment, 4 types of question were given to participants as follows:

1. Cone of Vision
2. High-Low
3. New Object
4. Inter-visibility

There were 40 questions in total of which 20 questions were projected onto a 3D physical model and the other 20 questions were displayed on a flat board. A complete list of questions is provided in Appendix 5. For all questions, an aerial image of University Park, University of Nottingham was used as the backdrop map (**Figure 4.3**) which had proved a successful backdrop in the first experiment.

Figure 4.3. Aerial Image of University Park on PARM

4.5 Results

4.5.1 Profile of Participants

Data for true answers and response times from 28 participants were analysed statistically using MS Excel and SPSS Statistics v24 using an ANOVA Repeated Measures of General Linear Model. Accuracy data are the percentage of true answers, while response time data was calculated based on response data of correct answers only. Data from participants involved in the pilot study were not included since the outcome of the pilot study was the refinement of the design of questions. Profiles of participants according to the information they provided can be seen in **Table 4.3** and **Figure 4.4**.

Table 4.3. General Profile of Participants – University Park Model

Details	Number (percentage)
Total participants	28
Female participants	17 (60.7%)
Male participants	11 (39.3%)
Participants who are students of the University of Nottingham	23 (82.1%)
Participants who are staff of University of Nottingham	5 (17.9%)

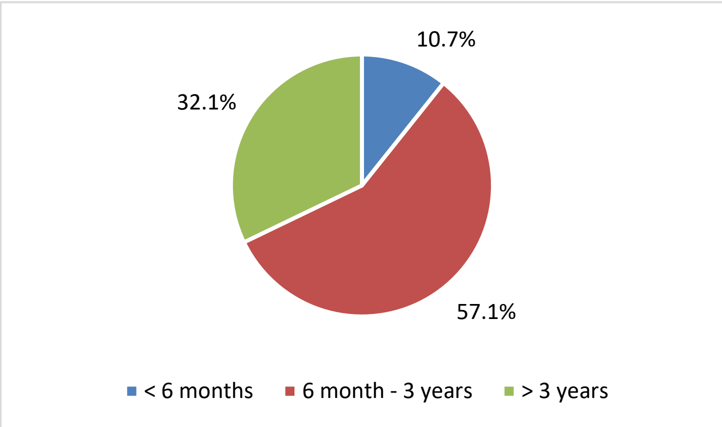


Figure 4.4. The proportion of Participants based on how long they have lived in Nottingham

At the end of the session, participants were asked to give any comments on the questions and about the model and flat map in general. Overall participants found PARM more helpful compared to the Flat Map. PARM provided more information on topographical features, making it possible for landmarks to become more noticeable e.g. Tower Building, which gives easier reference points. For the Flat Map, participants gave the answer mostly based on their knowledge and experiences, even for the 'Highest Point' type of question. In PARM they used a combination of their knowledge and details on the map such as the presence of buildings or trees and the landscape of the location (flat/slope etc). In terms of the type of question, participants found that the 'Show Me/New Object' type was more difficult to answer than other types of question, whereas the 'Cone Viewpoint' was easier than the other questions.

4.5.2 Accuracy and Response Time of PARM and Flat Map Based on Type of Question

Figure 4.5 shows that based on the type of questions, the accuracy of PARM and Flat map shows a similar result (maximum 2.9% differences). Statistical analysis (**Table 4.5** & **Table 4.6**) shows that different types of questions resulted in significant effects on accuracy at the 95% confidence level (sig <0.05). However, different representations (PARM and Flat Map) and interaction between different representations and types of question had no significant effect on accuracy.

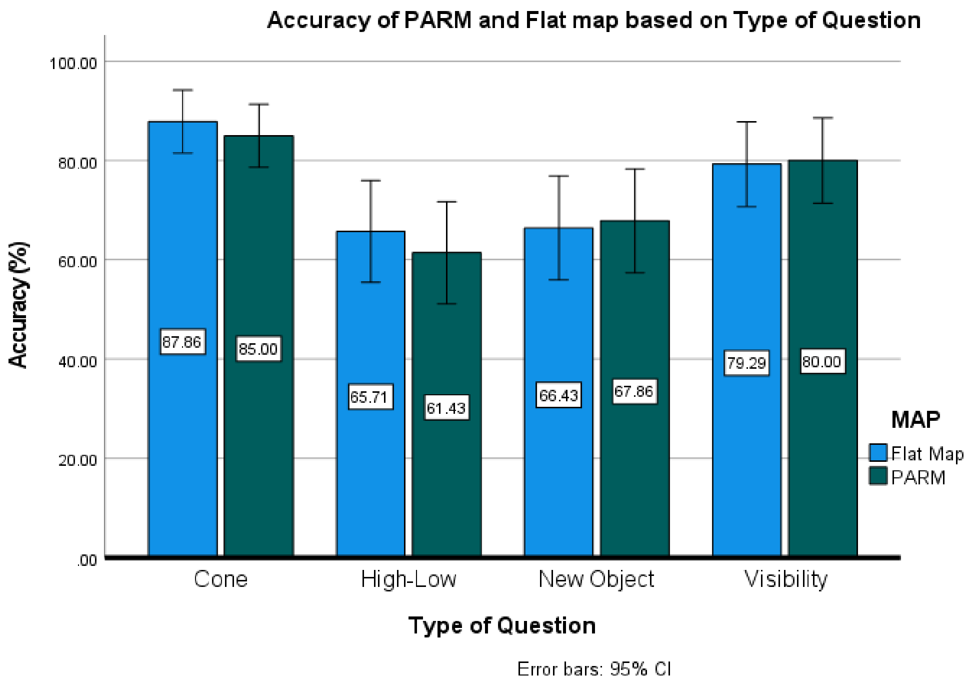


Figure 4.5. Accuracy of PARM and Flat Map Based on Type of Question – University Park Model

Table 4.4. Descriptive Statistics of Accuracy of PARM and Flat Map with Different Type of Question – University Park Model

Type of Question	MAP	Mean	Std. Deviation	N
Cone	Flat Map	87.9	13.7	28
	PARM	85.0	19.3	28
	Total	86.4	16.7	56
High-Low	Flat Map	65.7	28.2	28
	PARM	61.4	26.1	28
	Total	63.6	27.0	56
New Object	Flat Map	66.4	27.8	28
	PARM	67.9	27.4	28
	Total	67.1	27.4	56
Visibility	Flat Map	79.3	24.6	28
	PARM	80.0	20.4	28
	Total	79.6	22.4	56

Table 4.5. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map with Different Type of Question – University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	19148.214	3	6382.738	13.050	.000	.195
Type_of_Question * MAP	319.643	3	106.548	.218	.884	319.643
Error(Type_of_Question)	79232.143	162	489.087			

Table 4.6. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map with Different Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1233144.643	1	1233144.643	1497.482	.000	.965
MAP	87.500	1	87.500	.106	.746	.002
Error	44467.857	54	823.479			

Figure 4.6 shows that participants answered the New Object type of question faster on PARM than on the Flat Map. On the contrary, for the other types of questions slower response times were recorded on PARM. Statistical analysis (**Table 4.8** & **Table 4.9**) shows that the type of question resulted in significant effects on response time at the 95% confidence level (sig <0.05). However, the interaction between different representation (PARM and Flat Map) and types of question had no significant effect statistically on response time. On the other hand, 2D and 3D map interaction gave significant effects on response time.

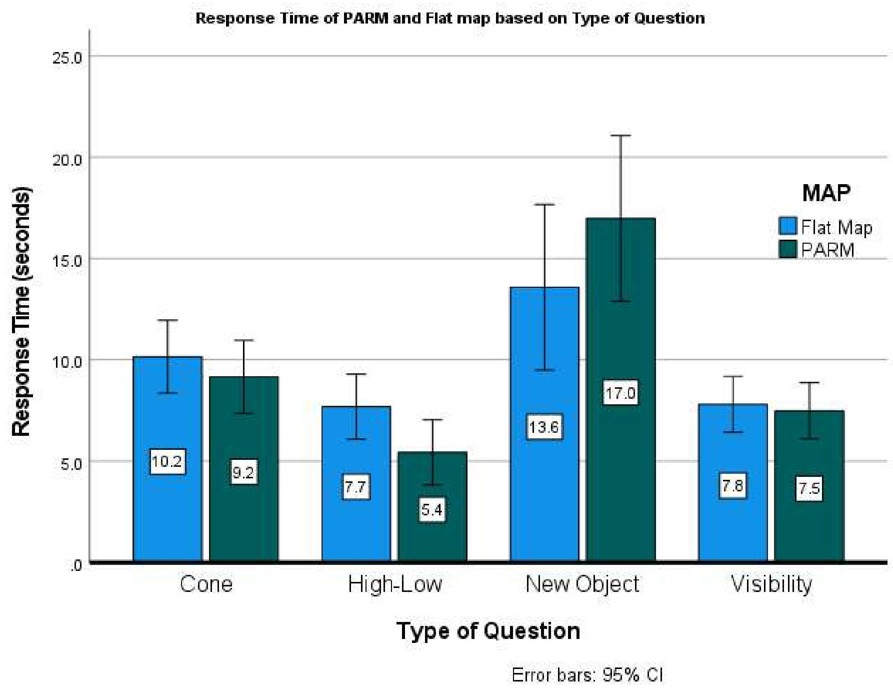


Figure 4.6. Response Time of PARM and Flat Map with Different Type of Question - University Park Model

Table 4.7. Descriptive Statistics of Response Time of PARM and Flat Map with Different Type of Question - University Park Model

Type of Question	MAP	Mean	Std. Deviation	N
Cone	Flat Map	10.2	5.1	28
	PARM	9.2	4.3	28
	Total	9.7	4.7	56
High-Low	Flat Map	7.7	5.0	28
	PARM	5.4	3.3	28
	Total	6.6	4.4	56

Type of Question	MAP	Mean	Std. Deviation	N
New Object	Flat Map	13.6	9.7	28
	PARM	17.0	11.8	28
	Total	15.3	10.8	56
Visibility	Flat Map	7.8	3.7	28
	PARM	7.5	3.6	28
	Total	7.7	3.6	56

Table 4.8. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM and Flat Map with Different Type of Question - University Park Model

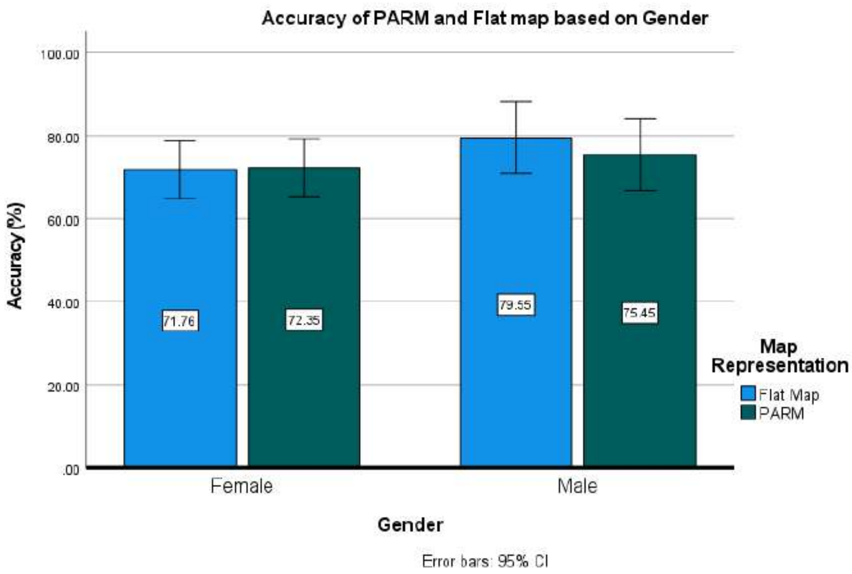
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	2532.739	3	844.246	24.936	.000	2532.739
Type_of_Question * MAP	247.812	3	82.604	2.440	.066	247.812
Error(Type_of_Question)	5484.809	162	33.857			

Table 4.9. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map with Different Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	21465.946	1	21465.946	311.398	.000	.852
MAP	.086	1	.086	.001	.972	.000
Error	3722.448	54	68.934			

4.5.3 Accuracy of PARM and Flat Map Based on Type of Question and Gender

Figure 4.7 shows that based on gender, males had better results on PARM than the Flat Map and whereas for females the results were similar on both representations. Based on the types of questions, male participants had better results (cone, highest point, new object) than females except for the visibility question. It was also found that the type of representation, question types, and gender give statistically no significant effect on the accuracy of participants as shown in **Table 4.11** & **Table 4.12**).



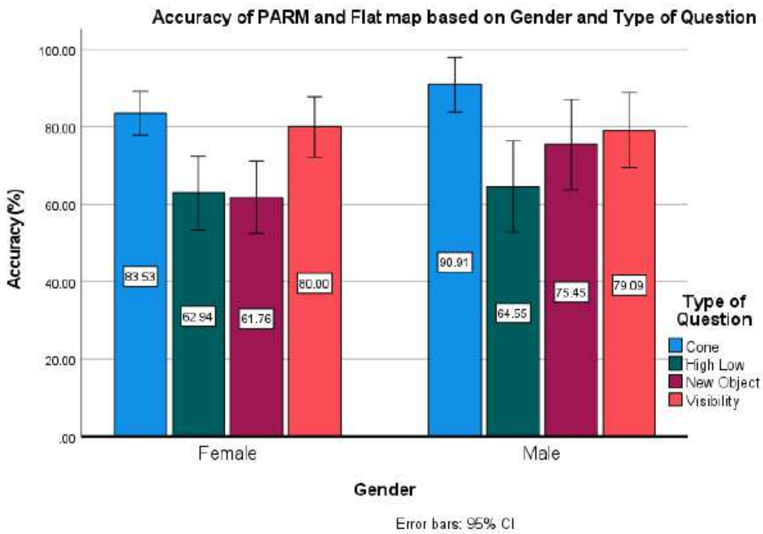


Figure 4.7. Accuracy of PARM and Flat Map with Different Gender and Type of Question - University Park Model

Table 4.10. Descriptive Statistics of Accuracy of PARM and Flat Map with Different Gender and Type of Question - University Park Model

Type of Question	MAP	Gender	Mean	Std. Deviation	N
Cone	Flat Map	Female	85.9	15.4	17
		Male	90.9	10.4	11
		Total	87.9	13.7	28

Type of Question	MAP	Gender	Mean	Std. Deviation	N
	PARM	Female	81.2	21.8	17
		Male	90.9	13.8	11
		Total	85.0	19.3	28
	Total	Female	83.5	18.7	34
		Male	90.9	11.9	22
		Total	86.4	16.7	56
High_Low	Flat Map	Female	64.7	24.0	17
		Male	67.3	35.0	11
		Total	65.7	28.2	28
	PARM	Female	61.2	26.0	17
		Male	61.8	27.5	11
		Total	61.4	26.1	28
	Total	Female	62.9	24.7	34
		Male	64.5	30.8	22
		Total	63.6	27.0	56
New_Object	Flat Map	Female	60.0	32.4	17
		Male	76.4	15.0	11
		Total	66.4	27.8	28
	PARM	Female	63.5	26.7	17
		Male	74.5	28.4	11
		Total	67.9	27.4	28
	Total	Female	61.8	29.3	34
		Male	75.5	22.2	22
		Total	67.1	27.4	56
Visibility	Flat Map	Female	76.5	24.7	17
		Male	83.6	25.0	11
		Total	79.3	24.6	28
	PARM	Female	83.5	19.0	17
		Male	74.5	22.1	11
		Total	80.0	20.4	28
	Total	Female	80.0	22.0	34
		Male	79.1	23.5	22
		Total	79.6	22.4	56

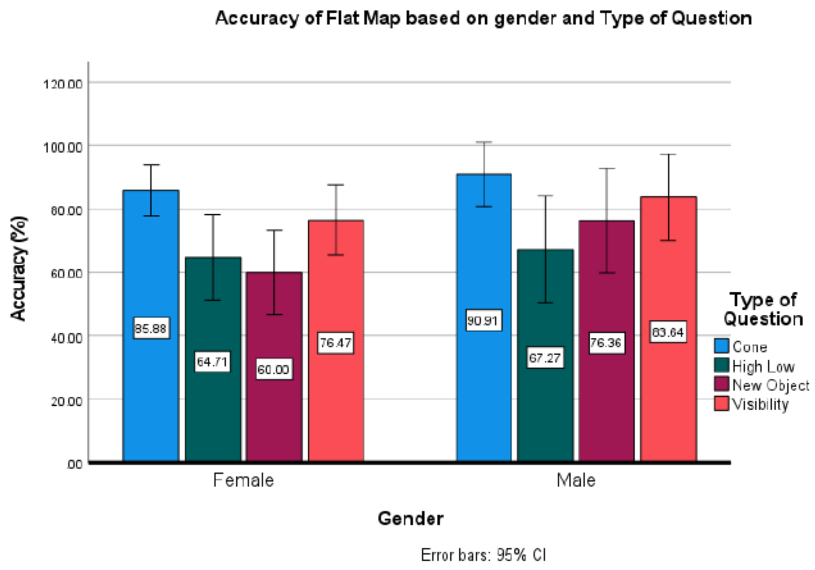
Table 4.11. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map with Different Gender and Type of Question-UP Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	18022.871	3	6007.624	12.207	.000	.190
Type_of_Question* MAP	203.161	3	67.720	.138	.937	.003
Type_of_Question* Gender	1694.299	3	564.766	1.148	.332	.022
Type_of_Question* MAP*Gender	760.304	3	253.435	.515	.673	.010
Error(Type_of_ Question)	76777.540	156	492.164			

Table 4.12. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1195081.828	1	1195081.828	1459.005	.000	.966
MAP	163.875	1	163.875	.200	.657	.004
Gender	1581.828	1	1581.828	1.931	.171	.036
MAP* Gender	292.447	1	292.447	.357	.553	.007
Error	42593.583	52	819.107			

Based on **Figure 4.8** males had better results on all question types on both Flat Map and PARM. However, females had better results than male participants on the cone of vision test on the PARM model. It was also found that type of question and gender had statistically insignificant effects on the accuracy of participants (**Table 4.13-4.16**).



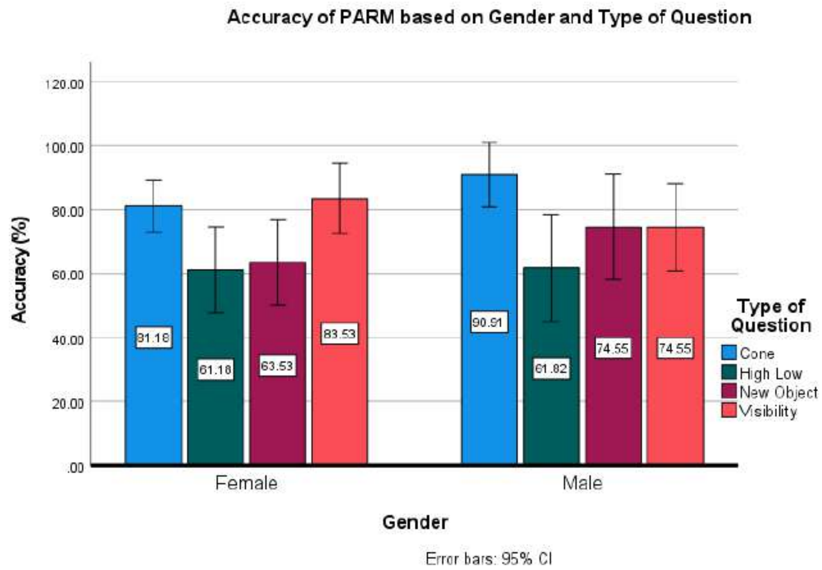


Figure 4.8. Accuracy of Flat map (top) and PARM (bottom) with Different Gender and Type of Question - University Park Model

Table 4.13. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	9385.027	3128.342	7.436	.000	.222
Type_of_Question*Gender	1727.884	575.961	1.369	.258	.050
Error(Type_of_Question)	32814.973	420.705			

Table 4.14. Tests of Between-Subjects Effects of Accuracy of PARM with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	583628.419	1	583628.419	604.208	.000	.959
Gender	256.990	1	256.990	.266	.610	.010
Error	25114.438	26	965.940			

Table 4.15. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of Flat Map with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	8841.005	3	2947.002	5.229	.002	8841.005
Type_of_Question*Gender	726.719	3	242.240	.430	.732	726.719
Error(Type_of_Question)	43962.567	78	563.623			

Table 4.16. Tests of Between-Subjects Effects of Accuracy of Flat Map with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	611617.284	1	611617.284	909.773	.000	.972
Gender	1617.284	1	1617.284	2.406	.133	.085
Error	17479.144	26	672.275			

4.5.4 Response Time of PARM and Flat Map Based on Type of Question and Gender

Figure 4.9 shows the overall results of response time for the UP Campus model based on participants' gender. Females had better response times compared to males on both PARM and Flat Map. The response time based on question type shows that females had better response times on all cases. In terms of the interaction of PARM/Flat Map, question types, and Gender there were statistically insignificant effects on the response time of participants (**Table 4.18** and **Table 4.19**).

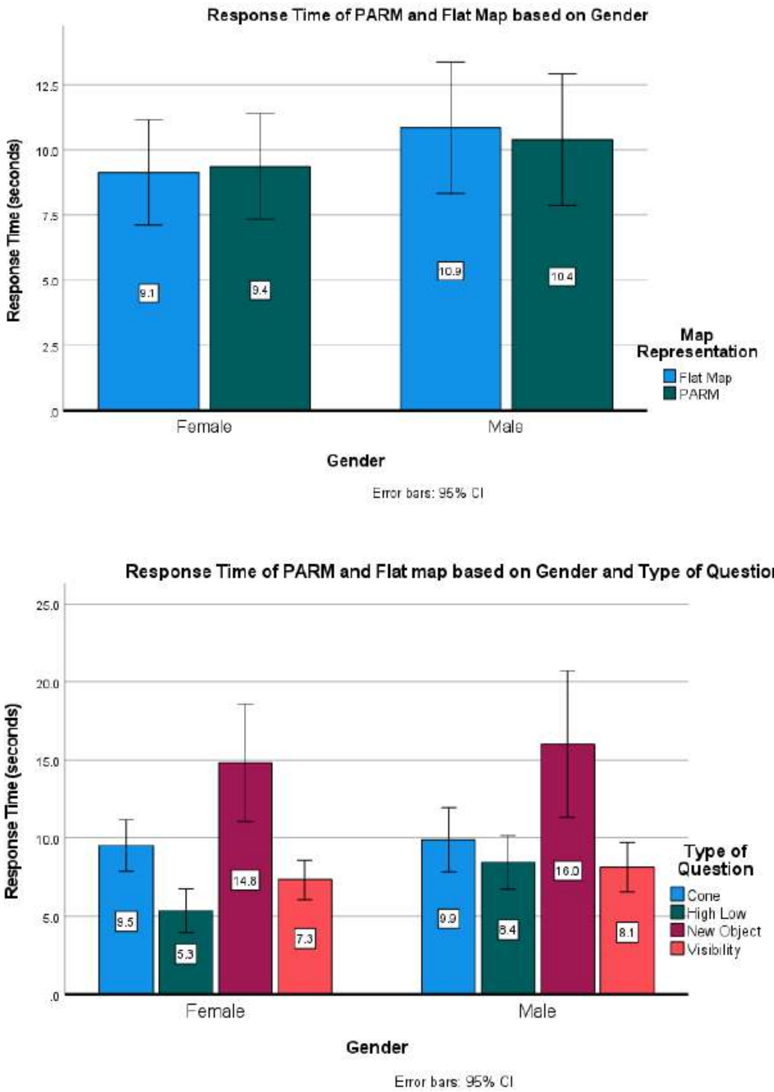


Figure 4.9. Response Time of PARM and Flat Map with Different Gender and Type of Question - University Park Model

Table 4.17. Descriptive Statistics of Response Time of PARM and Flat Map with Different Gender and Type of Question - University Park Model

Type of Question	MAP	Gender	Mean	Std. Deviation	N
Cone	Flat Map	Female	10.2	5.9	17
		Male	10.1	4.0	11
		Total	10.2	5.1	28
	PARM	Female	8.8	4.2	17
		Male	9.7	4.6	11
		Total	9.2	4.3	28
	Total	Female	9.5	5.1	34
		Male	9.9	4.2	22
		Total	9.7	4.7	56

Type of Question	MAP	Gender	Mean	Std. Deviation	N
High_Low	Flat Map	Female	6.4	2.7	17
		Male	9.7	7.0	11
		Total	7.7	5.0	28
	PARM	Female	4.3	2.0	17
		Male	7.2	4.2	11
		Total	5.4	3.3	28
	Total	Female	5.3	2.6	34
		Male	8.4	5.8	22
		Total	6.6	4.4	56
New_Object	Flat Map	Female	12.6	11.2	17
		Male	15.1	7.0	11
		Total	13.6	9.7	28
	PARM	Female	17.0	12.4	17
		Male	16.9	11.4	11
		Total	17.0	11.8	28
	Total	Female	14.8	11.9	34
		Male	16.0	9.3	22
		Total	15.3	10.8	56
Visibility	Flat Map	Female	7.4	4.1	17
		Male	8.5	3.0	11
		Total	7.8	3.7	28
	PARM	Female	7.3	3.7	17
		Male	7.8	3.8	11
		Total	7.5	3.6	28
	Total	Female	7.3	3.8	34
		Male	8.1	3.3	22
		Total	7.7	3.6	56

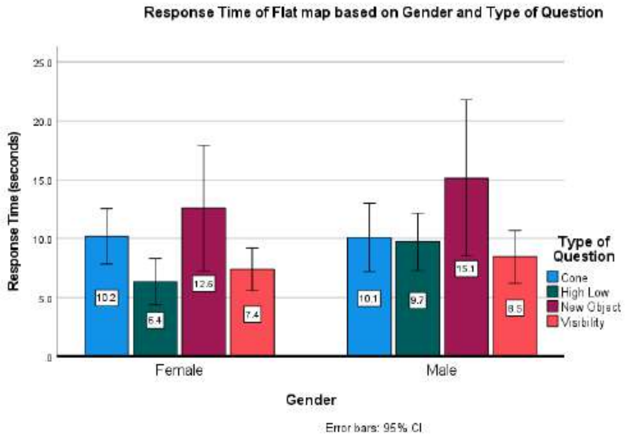
Table 4.18. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM and Flat Map with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	2360.697	3	786.899	22.712	.000	2360.697
Type_of_Question*MAP	212.571	3	70.857	2.045	.110	212.571
Type_of_Question*Gender	58.080	3	19.360	.559	.643	58.080
Type of Question*MAP*Gender	21.798	3	7.266	.210	.890	21.798
Error(Type_of_Question)	5404.932	156	34.647			

Table 4.19. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	21101.997	1	21101.997	303.533	.000	.854
MAP	.667	1	.667	.010	.922	.000
Gender	101.230	1	101.230	1.456	.233	.027
MAP*Gender	6.112	1	6.112	.088	.768	.002
Error	3615.106	52	69.521			

Response times for types of questions shown in **Figure 4.10** show that females had quicker response times than males except for cone vision on Flat Map and new object on PARM, which had similar results. It was also found that the types of questions and gender gave statistically insignificant effects on the response time of participants in both PARM and Flat Map (**Table 4.20-4.23**).



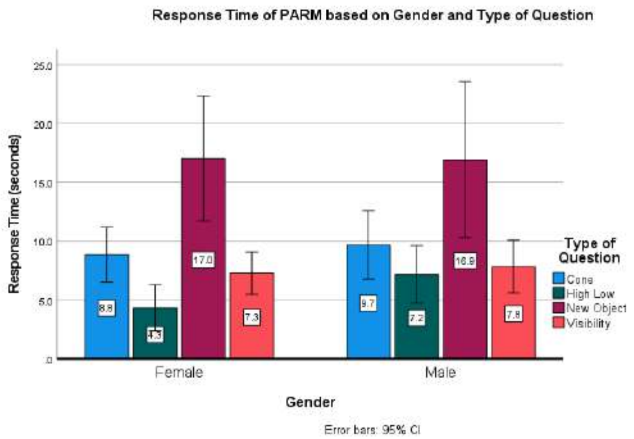


Figure 4.10 Response Time of Flat map (top) and PARM (bottom) with Different Gender and Type of Question - University Park Model

Table 4.20. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	1957.718	3	652.573	19.736	.000	1957.718
Type_of_Question*Gender	32.181	3	10.727	.324	.808	32.181
Error(Type_of_Question)	2579.073	78	33.065			

Table 4.21. Tests of Between-Subjects Effects of Response Time of PARM with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	10432.659	1	10432.659	118.380	.000	.820
Gender	28.796	1	28.796	.327	.572	.012
Error	2291.351	26	88.129			

Table 4.22. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of Flat Map with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	615.550	3	205.183	5.664	.001	615.550
Type_of_Question*Gender	47.696	3	15.899	.439	.726	47.696
Error(Type_of_Question)	2825.859	78	36.229			

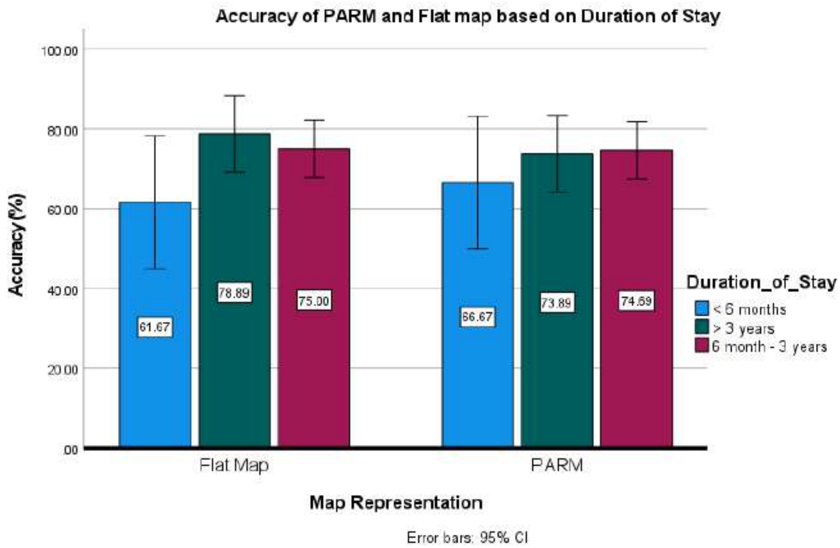
Table 4.23. Tests of Between-Subjects Effects of Response Time of Flat Map with Different Gender and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	10670.006	1	10670.006	209.571	.000	.890
Gender	78.546	1	78.546	1.543	.225	.056
Error	1323.755	26	50.914			

4.5.5 Accuracy of PARM and Flat Map Based on Length of Time Living in Nottingham and Type of Question

Figure 4.11 indicates that PARM was better for participants that had known the UP Campus for less than 6 months. However, for participants who had known the UP

Campus for more than 6 months, the Flat Map was better than PARM. All types of questions were better for all participants that had known UP Campus for more than 6 months except the visibility question. Statistical analysis (**Table 4.25** & **Table 4.26**) shows that the interaction between type of question and length of time living in Nottingham resulted in a significant effect on response time at the 95% confidence level (sig <0.05). However, the interaction between different representation (PARM and Flat Map) and duration of stay showed no significant effect statistically on response time.



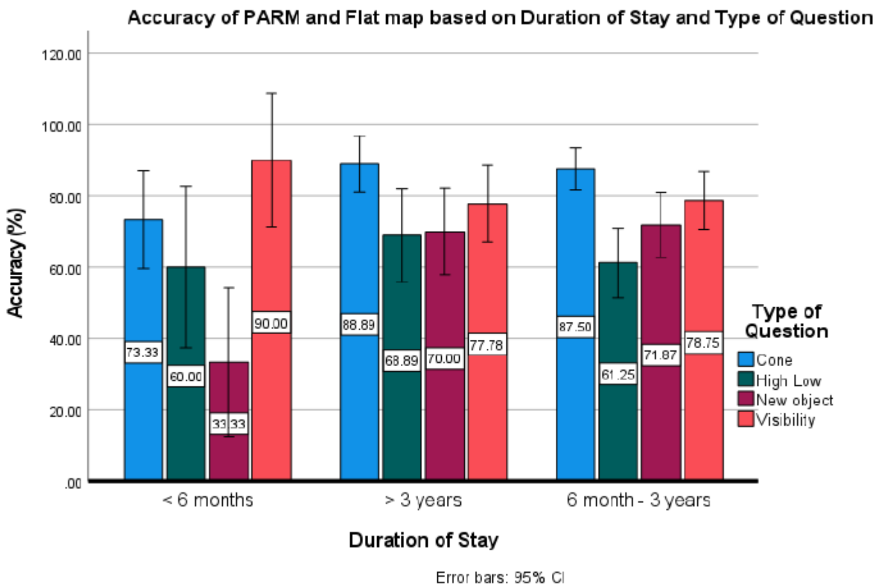


Figure 4.11. Accuracy of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model. Participants' duration of stay in UP Campus is 6 months, 6 months-3 years, and more than 3 years.

Table 4.24. Descriptive Statistics of Accuracy of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Type of Question	MAP	Duration_of_Stay	Mean	Std. Deviation	N
Cone	Flat Map	< 6 months	86.3	17.5	3
		> 3 years	85.0	19.3	9
		6 months - 3 years	73.3	20.7	16
		Total	88.9	15.7	28
	PARM	< 6 months	87.5	15.9	3
		> 3 years	86.4	16.7	9
		6 months - 3 years	53.3	41.6	16
		Total	77.8	18.6	28
	Total	< 6 months	61.3	29.6	6
		> 3 years	65.7	28.2	18
		6 months - 3 years	66.7	30.6	32
		Total	60.0	28.3	56
High_Low	Flat Map	< 6 months	61.3	25.8	3
		> 3 years	61.4	26.1	9
		6 months - 3 years	60.0	33.5	16
		Total	68.9	24.9	28
	PARM	< 6 months	61.3	27.3	3
		> 3 years	63.6	27.0	9
		6 months - 3 years	26.7	30.6	16
		Total	75.6	19.4	28
	Total	< 6 months	68.8	26.3	6
		> 3 years	66.4	27.8	18
		6 months - 3 years	40.0	20.0	32
		Total	64.4	26.0	56
New_Object	Flat Map	< 6 months	75.0	26.8	3
		> 3 years	67.9	27.4	9
		6 months - 3 years	33.3	24.2	16
		Total	70.0	23.0	28
	PARM	< 6 months	71.9	26.3	3
		> 3 years	67.1	27.4	9
		6 months - 3 years	93.3	11.5	16
		Total	71.1	24.7	28
	Total	< 6 months	81.3	25.8	6
		> 3 years	79.3	24.6	18
		6 months - 3 years	86.7	11.5	32
		Total	84.4	21.9	56
Visibility	Flat Map	< 6 months	76.3	20.9	3
		> 3 years	80.0	20.4	9

Type of Question	MAP	Duration_of_Stay	Mean	Std. Deviation	N
		6 months - 3 years	90.0	11.0	16
		Total	77.8	23.7	28
	PARM	< 6 months	78.8	23.2	3
		> 3 years	79.6	22.4	9
		6 months - 3 years	86.3	17.5	16
		Total	85.0	19.3	28
	Total	< 6 months	73.3	20.7	6
		> 3 years	88.9	15.7	18
		6 months - 3 years	87.5	15.9	32
		Total	86.4	16.7	56

Table 4.25. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	17360.669	3	5786.890	12.662	.000	.202
Type_of_Question*MAP	140.197	3	46.732	.102	.959	.002
Type_of_Question * Duration_of_Stay	7572.272	6	1262.045	2.761	.014	.099
Type_of_Question*MAP * Duration_of_Stay	3106.399	6	517.733	1.133	.346	.043
Error(Type_of_Question)	68553.472	150	457.023			

Table 4.26. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	732180.598	1	732180.598	889.904	.000	.947
MAP	.385	1	.385	.000	.983	.000
Duration_of_Stay	2814.038	2	1407.019	1.710	.191	.064
MAP * Duration_of_Stay	515.625	2	257.813	.313	.732	.012
Error	41138.194	50	822.764			

Figure 4.12 shows the accuracy of the visibility type of question (on PARM and Flat Map) and the highest point question (PARM) for participants living in Nottingham for less than 6 months was better on PARM and Flat Map compared to participants who had known UP Campus for more than 6 months. Statistical analysis (**Table 4.27-**

4.30) shows that interaction between type of question and duration of stay for Flat Map resulted in a significant effect on accuracy at the 95% confidence level (sig <0.05), while the interaction between type of question and duration of stay in PARM showed no significant effect on accuracy.

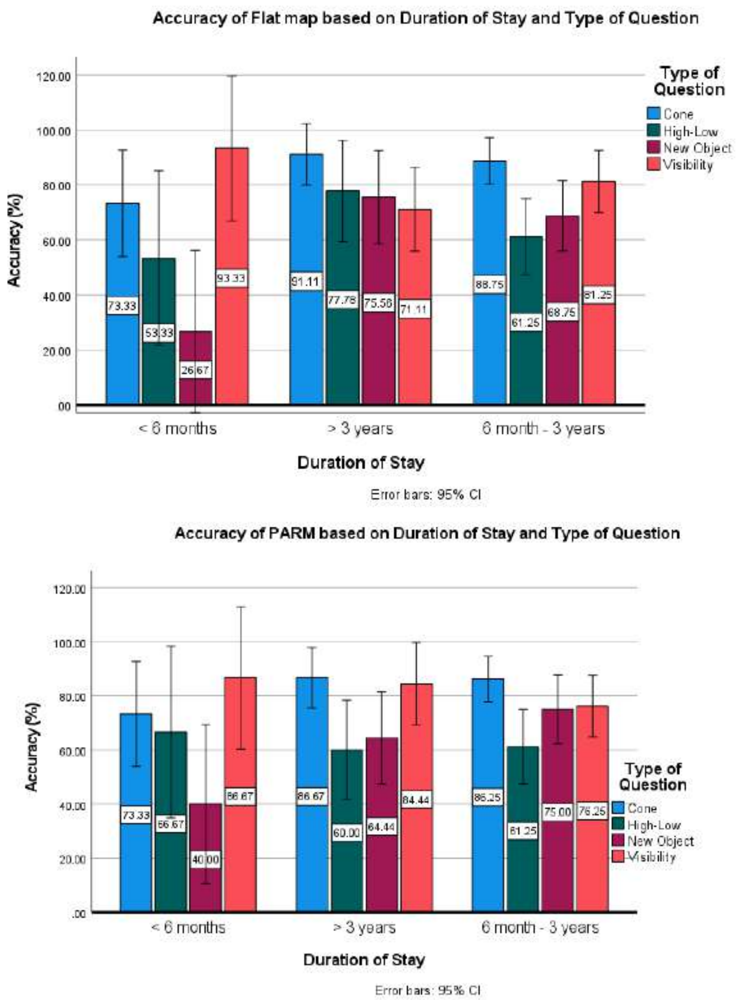


Figure 4.12. Accuracy of Flat map (top) and PARM (bottom) with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Table 4.27. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	7932.373	3	2644.124	6.427	.001	.205
Type_of_Question*Duration_of_Stay	3689.385	6	614.897	1.495	.192	.107
Error(Type_of_Question)	30853.472	75	411.380			

Table 4.28. Tests of Between-Subjects Effects of Accuracy of PARM with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	365559.370	1	365559.370	369.760	.000	.937
Duration_of_Stay	655.456	2	327.728	.331	.721	.026
Error	24715.972	25	988.639			

Table 4.29. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

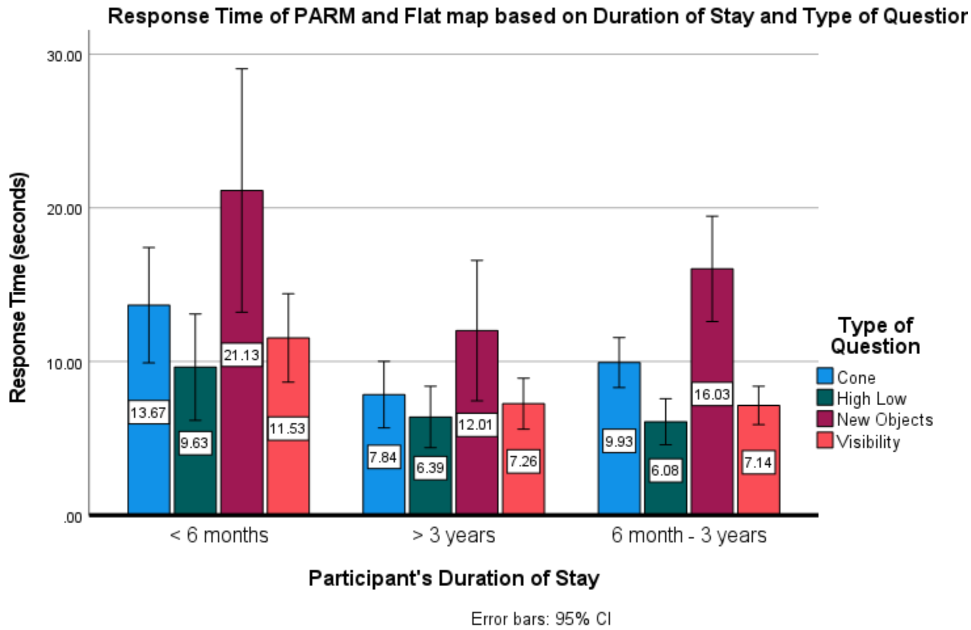
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	9568.493	3	3189.498	6.345	.001	9568.493
Type_of_Question*Duration_of_Stay	6989.286	6	1164.881	2.317	.042	6989.286
Error(Type_of_Question)	37700.000	75	502.667			

Table 4.30. Tests of Between-Subjects Effects of Accuracy of Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	366621.613	1	366621.613	558.118	.000	.957
Duration_of_Stay	2674.206	2	1337.103	2.036	.152	.140
Error	16422.222	25	656.889			

4.5.6 Response Time of PARM and Flat Map Based on Duration of Residence in Nottingham and Type of Question

Figure 4.13 shows the response time for participants who had known UP Campus for less than 6 months had better results on PARM. On the other hand, for participants living in Nottingham for over 3 years, the Flat Map showed better results than PARM. In terms of answering all of the questions, participants living in Nottingham for over 3 years had quicker response times. Moreover, the interaction between map and duration of stay, and the interaction between type of question and duration of stay had a statistically significant effect on the response times of participants (**Table 4.32** & **Table 4.33**). Post Hoc analysis (**Table 4.34**) categorizes participants who have stayed less than 6 months in one group and those who have lived in Nottingham for between 6 months and 3 years or over 3 years under another group.



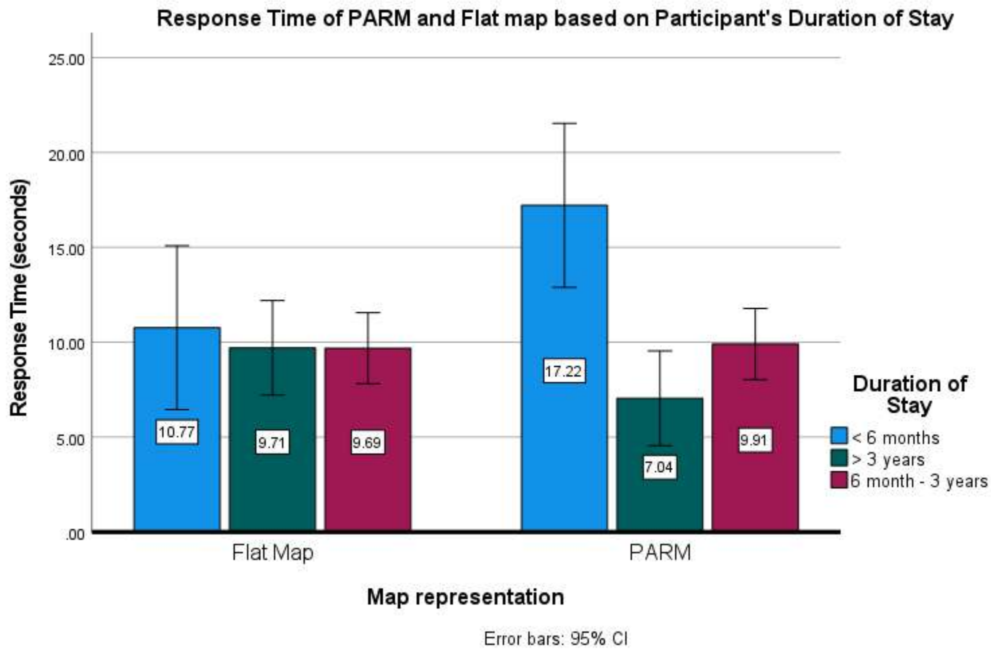


Figure 4.13. Response Time of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Table 4.31. Descriptive Statistics of Response Time of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Type of Question	MAP	Duration_of_Stay	Mean	Std. Deviation	N
Cone	Flat Map	< 6 months	13.5	3.4	3
		> 3 years	9.0	2.5	9
		6 months - 3 years	10.2	6.3	16
		Total	10.2	5.1	28
	PARM	< 6 months	13.9	5.5	3
		> 3 years	6.7	4.2	9
		6 months - 3 years	9.7	3.5	16
		Total	9.2	4.3	28
	Total	< 6 months	13.7	4.1	6
		> 3 years	7.8	3.5	18
		6 months - 3 years	9.9	5.0	32
		Total	9.7	4.7	56
High_Low	Flat Map	< 6 months	10.9	11.5	3
		> 3 years	8.4	4.8	9
		6 months - 3 years	6.7	3.5	16
		Total	7.7	5.0	28
	PARM	< 6 months	8.3	6.0	3
		> 3 years	4.4	2.0	9
		6 months - 3 years	5.5	3.3	16
		Total	5.4	3.3	28
	Total	< 6 months	9.6	8.3	6
		> 3 years	6.4	4.1	18
		6 months - 3 years	6.1	3.4	32
		Total	6.6	4.4	56
New_Object	Flat Map	< 6 months	6.7	6.9	3
		> 3 years	13.9	6.6	9
		6 months - 3 years	14.7	11.3	16
		Total	13.6	9.7	28
	PARM	< 6 months	35.6	25.2	3
		> 3 years	10.1	4.8	9

Type of Question	MAP	Duration_of_Stay	Mean	Std. Deviation	N
		6 months - 3 years	17.4	7.5	16
		Total	17.0	11.8	28
	Total	< 6 months	21.1	22.9	6
		> 3 years	12.0	5.9	18
		6 months - 3 years	16.0	9.5	32
		Total	15.3	10.8	56
Visibility	Flat Map	< 6 months	12.0	2.5	3
		> 3 years	7.6	3.2	9
		6 months - 3 years	7.1	3.7	16
		Total	7.8	3.7	28
	PARM	< 6 months	11.1	3.4	3
		> 3 years	6.9	4.0	9
		6 months - 3 years	7.2	3.3	16
		Total	7.5	3.6	28
	Total	< 6 months	11.5	2.7	6
		> 3 years	7.3	3.6	18
		6 months - 3 years	7.1	3.4	32
		Total	7.7	3.6	56

Table 4.32. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	1696.291	3	565.430	19.091	.000	1696.291
Type_of_Question*MAP	767.748	3	255.916	8.640	.000	767.748
Type_of_Question* Duration_of_Stay	172.131	6	28.688	.969	.449	172.131
Type_of_Question*MAP * Duration_of_Stay	869.942	6	144.990	4.895	.000	869.942
Error(Type_of_Question)	4442.737	150	29.618			

Table 4.33. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

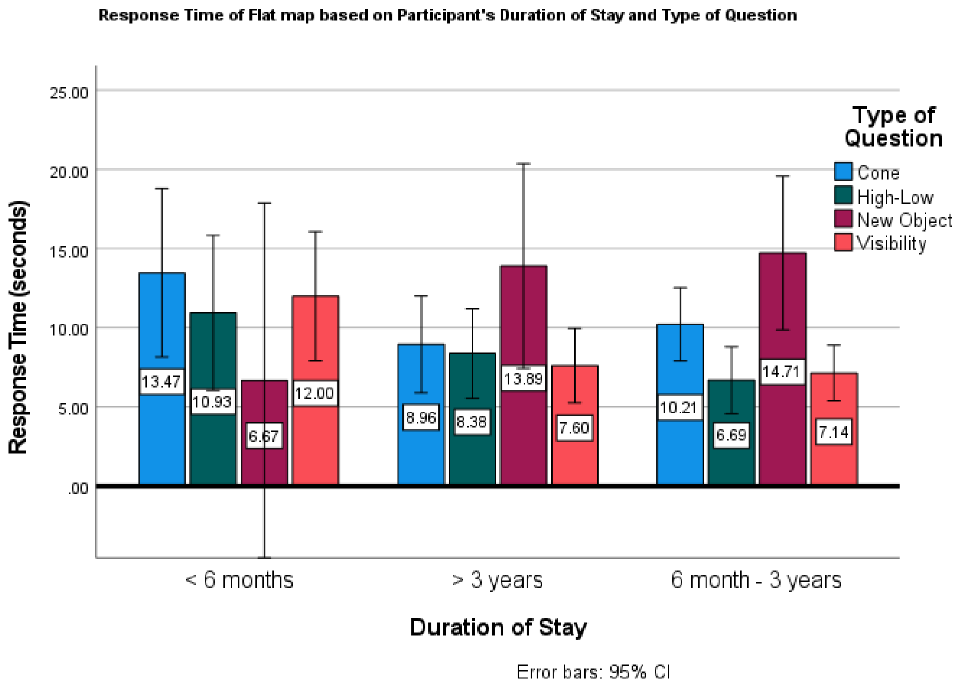
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	16325.156	1	16325.156	294.035	.000	.855
MAP	63.365	1	63.365	1.141	.291	.022
Duration_of_Stay	567.862	2	283.931	5.114	.010	.170
MAP * Duration_of_Stay	378.527	2	189.264	3.409	.041	.120
Error	2776.059	50	55.521			

Table 4.34. Post Hoc Test of Response Time of PARM and Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Test	Duration_of_Stay	N	Subset	
			1	2
Ryan-Einot-Gabriel-Welsch F	> 3 years	18	8.3750	
	6 months - 3 years	32	9.7969	
	< 6 months	6		13.9917
	Sig.		.201	1.000
Ryan-Einot-Gabriel-Welsch Range	> 3 years	18	8.3750	
	6 months - 3 years	32	9.7969	9.7969
	< 6 months	6		13.9917
	Sig.		.258	.057

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 13.880.
Alpha = .05.

Figure 4.14 shows the new object question type showed significant differences for both PARM and Flat Map for participants with different durations of stay in Nottingham. Participants who had known UP Campus for less than 6 months had the slowest response time on PARM and the fastest response time on the Flat Map. Statistical analysis (**Table 4.35** & **Table 4.36**) showed that for PARM, duration of stay, as well as the interaction between duration of stay and the type of question, had a significant effect on response times at the 95% confidence level (sig <0.05). Post Hoc analysis (**Table 4.37**) classifies participants who have stayed less than 6 months in one group and those who have lived in Nottingham for between 6 months and 3 years or more than 3 years under another group. In contrast, the duration of stay as well as the interaction between duration of stay and type of question showed no statistically significant effect on response time for Flat Map (**Table 4.38** & **Table 4.39**).



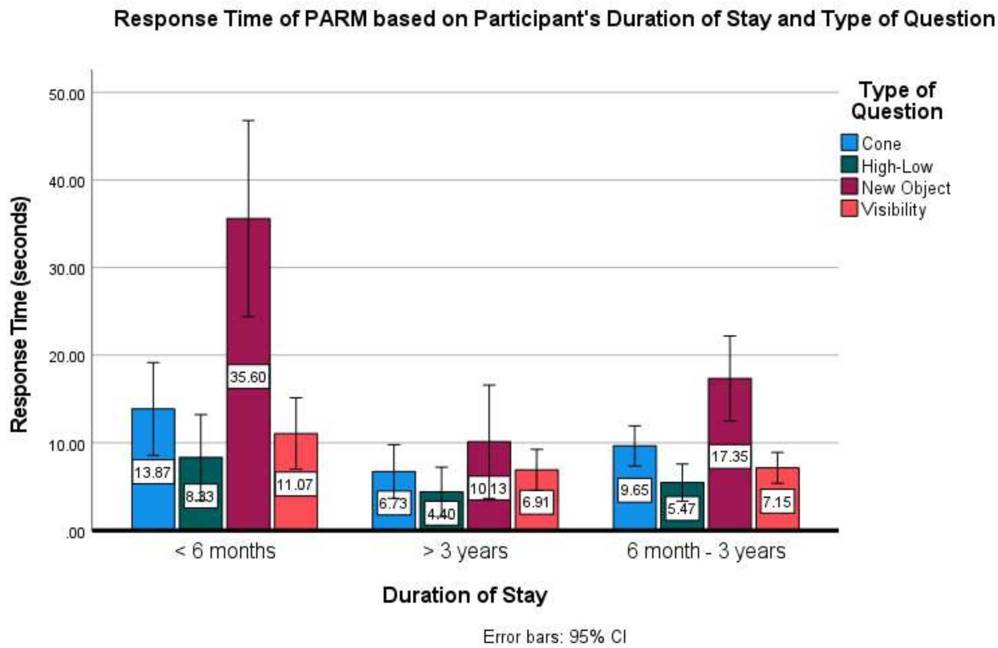


Figure 4.14. Response time of Flat map (top) and PARM (bottom) with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Table 4.35. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of PARM with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_Question	2343.223	3	781.074	31.165	.000	2343.223
Type_of_Question*Duration_of_Stay	731.549	6	121.925	4.865	.000	731.549
Error(Type_of_Question)	1879.706	75	25.063			

Table 4.36. Tests of Between-Subjects Effects of Response Time of PARM with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	9211.333	1	9211.333	166.138	.000	.869
Duration_of_Stay	934.054	2	467.027	8.423	.002	.403
Error	1386.093	25	55.444			

Table 4.37. Post Hoc Test of Response Time of PARM with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Tests	Duration_of_Stay	N	Subset	
			1	2
Ryan-Einot-Gabriel-Welsch F	> 3 years	9	7.0444	
	6 months - 3 years	16	9.9063	
	< 6 months	3		17.2167
	Sig.		.077	1.000
Ryan-Einot-Gabriel-Welsch Range	> 3 years	9	7.0444	
	6 months - 3 years	16	9.9063	
	< 6 months	3		17.2167
	Sig.		.116	1.000

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 13.861.
Alpha = .05.

Table 4.38. Tests of Within-Subjects Effects (Sphericity Assumed) of Response Time of Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Type_of_ Question	120.816	3	40.272	1.178	.324	120.816
Type_of_ Question*Duration_of_Stay	310.524	6	51.754	1.514	.185	310.524
Error(Type_of_ Question)	2563.031	75	34.174			

Table 4.39. Tests of Between-Subjects Effects of Response Time of Flat Map with Different Duration of Stay in Nottingham and Type of Question - University Park Model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	7177.188	1	7177.188	129.089	.000	.838
Duration_of_Stay	12.336	2	6.168	.111	.895	.009
Error	1389.966	25	55.599			

4.5.7 Accuracy and Response Time of PARM and Flat Map on the Lake District and University Park Models

To draw together results from both studies **Figure 4.15** shows that the accuracy of PARM was considerably higher than the accuracy of the Flat Map for the Lake District Model. On the contrary, for the UP Campus model, the accuracy of the Flat Map was slightly better than the accuracy of PARM. Statistical analysis (**Table 4.41** & **Table 4.42**) showed that the interaction between different representations (3D model and flat map) and area (Lake District and UP Campus) had a significant effect on accuracy at the 95% confidence level (sig <0.05).

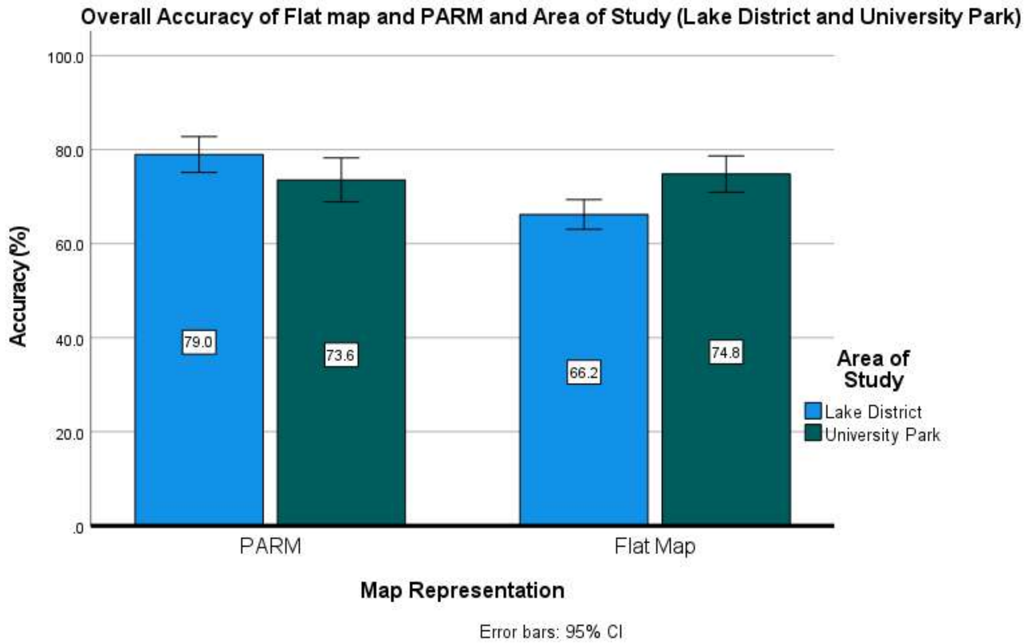


Figure 4.15. The Overall accuracy of PARM and Flat Map of Lake District and University Park Campus

Table 4.40. Descriptive Statistics of Accuracy of PARM and Flat Map of Lake District and University Park Campus

Maps	Area	Mean	Std. Deviation	N
PARM	Lake District	79.0	10.0	42
	University Park	73.6	15.3	28
	Total	76.8	12.6	70
Flat_Map	Lake District	66.2	7.6	42
	University Park	74.8	13.3	28
	Total	69.7	11.0	70

Table 4.41. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map of Lake District and University Park Campus

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MAP	1111.360	1	1111.360	12.241	.001	.153
MAP * Area	1646.960	1	1646.960	18.141	.000	.211
Error(MAP)	6173.477	68	90.786			

Table 4.42. Tests of Between-Subjects Effects of Accuracy of PARM and Flat Map of Lake District and University Park Campus

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	724099.808	1	724099.808	4314.568	.000	.984
Area	85.122	1	85.122	.507	.479	.007
Error	11412.217	68	167.827			

Figure 4.16 shows that participants gave correct answers in a shorter time on PARM compared to the Flat Map for the Lake District model. However, the response time of both PARM and Flat Map appeared similar for the UP Campus model. Statistical analysis (**Table 4.44** & **Table 4.45**) showed that the interaction between different representations (3D model and flat map) and area (lake District and UP Campus) had no significant effect on response times at the 95% confidence level (sig <0.05).

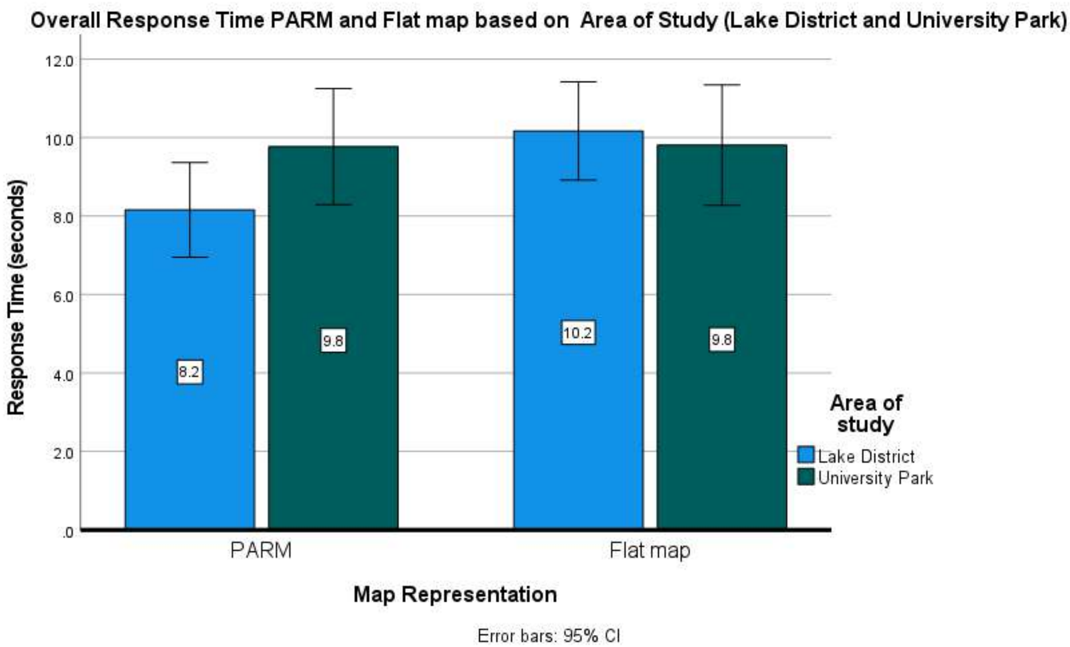


Figure 4.16. The Overall Response Time of PARM and Flat Map of Lake District and University Park Campus

Table 4.43. Descriptive Statistics of Response Time of PARM and Flat Map of Lake District and University Park Campus

Maps	Area	Mean	Std. Deviation	N
PARM	Lake District	8.2	3.4	42
	University Park	9.8	4.6	28
	Total	8.8	4.0	70
Flat_Map	Lake District	10.2	4.3	42
	University Park	9.8	3.6	28
	Total	10.0	4.0	70

Table 4.44. Tests of Within-Subjects Effects (Sphericity Assumed) of Accuracy of PARM and Flat Map of Lake District and University Park Campus

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
MAP	35.327	1	35.327	2.934	.091	.041
MAP * Area	32.672	1	32.672	2.714	.104	.038
Error(MAP)	818.633	68	12.039			

Table 4.45. Tests of Between-Subjects Effects of Response Time of PARM and Flat Map of Lake District and University Park Campus

Source	Type III Sum of Squares	Mean Square	F	Sig.	Partial Eta Squared
Intercept	12069.365	12069.365	606.545	.000	.899
Area	13.159	13.159	.661	.419	.010
Error	1353.102	19.899			

To summarize the findings of this chapter for the UP Campus model, based on the type of question, the accuracy for the Cone of Vision and High-low questions were slightly lower on PARM than the Flat Map by 2-4%. On the other hand, for the New Object and Visibility questions they were slightly higher on PARM by 0.7-1.5%. The response times for the Cone of Vision, High-Low and Visibility questions were quicker on PARM by 0.3-2.3 seconds compared to the Flat Map. Nevertheless, the New Object was 3.4 seconds slower than the Flat Map. In terms of gender and type of question, PARM accuracy was slightly better for male participants compared to the Flat Map, with similar results for female participants between PARM and Flat map. Overall, male participants had better accuracies than females on both PARM and Flat Map. In terms of response time, female participants answered questions quicker than male participants for both map representation, PARM and Flat map.

The length of time living in Nottingham had a significant impact on the urban terrain study. For participants living in Nottingham for less than 6 months, PARM was better than the Flat Map in terms of accuracy. However, for those who have known the UP Campus for more than 6 months, the Flat Map was slightly better than PARM. This variable also affected the participant's judgement on the New Object question type, where participants with a duration of stay less than 6 months had lower accuracies compared to others. This is because the new objects such as buildings, bridges or roads do not exist on the map yet, which is a challenging question compared to Cone Vision, Visibility and High-low question type. At the same time, response times showed similar results to accuracies. The New Object question took longer to answer for participants who had known UP Campus for less than 6 months.

Overall, the comparison between PARM and the Flat map of the Lake District and UP Campus models showed that PARM had better accuracies for upland rural areas and the Flat map showed better results for the urban terrain area. In terms of response time, participants were quicker to answer on PARM compared to the Flat Map for the upland rural area but had a similar result with the Flat map for the urban terrain area.

In conclusion, overall PARM showed better results for the upland rural area and for people who were less familiar with the area in the urban case study.

The experiments have explored PARM as a tangible display rather than an interface that might provide feedback to user interaction. The next chapter will explore the potential for detecting the user's touch, which would allow PARM to be considered a tangible interface capable of letting users query locations on the surface of the model.

5 Finger Point Interaction using Kinect Sensor on PARM

5.1 Introduction

Human-computer interaction (HCI) introduces the communication between people and computers, and how interactions are interpreted. There are many ways to communicate with computers based on human anatomy and physiology such as speech, human body movement, or combinations of those modes. These can be considered input tools through which the computer interprets the natural interactions (Preece et al, 2002).

Observations of PARM displays at a community open day event called Mayfest, held at the University of Nottingham in May 2011 (Priestnall et al, 2012), and at the Wordsworth Trust (Priestnall et al, 2017) suggested many people pointed out objects with their fingers on the physical model. More recently an ‘in-the-wild’ study attempted to observe visitor behaviour at a PARM display in Langdale, Cumbria to see if there was a desire for interaction (Priestnall and Cheverst, 2019). During the 3-day observation study which involved 221 visitors, there was a clear expectation from visitors to have ‘tangible interaction’ with the PARM display. In other words, the PARM display provided a physical form through which people thought they could directly control digital information (Ulmer and Ishii, 2000). This kind of interaction would offer great possibilities for interactive education as well as ‘you-are-here’ style visitor displays.

A related development in touchable displays was the Augmented Reality (AR) Sandbox developed by Dr. Kreylos and his team at UC Davis by utilizing a sandbox, projector and Kinect sensor to undertake simulations (Kreylos, 2021). This study uses interactive 3-dimensional visualization as a tool for earth science learning concepts, like geological landforms and topographic maps (Theodossiou et al, 2018). The display allows users to create hills and valleys with the sand, and the projector and Kinect sensor collaborate to detect the manipulated sand surface and project a relief representation back onto the surface, using contour lines and colours. In addition, rain effects and flood flow can be triggered by holding a hand over the sand with the fingers spread out. The hand is detected by the Kinect Sensor as a 'button' to create 'rain' which in turn generates water flow over the surface to the lower terrain.

Hand and finger recognition is considered a natural gesture in Human-computer Interaction (Pantera et al, 2020) in many applications such as games and digital object manipulation. Therefore, the proposed natural communication between a human and PARM was to use fingertip interaction, where the Kinect sensor might allow the finger to become the input device for tangible interaction through the PARM display surface.

The first experiment on the Lake District model and the second experiment on the UP Campus model had been undertaken without interaction, by design, as the emphasis was on the visual power of the 3D model compared to a flat representation. To explore the potential for touch-based interaction, it was decided to use the available and customisable solution offered by the Kinect sensor to develop a way to detect when the user's finger touched the PARM surface.

5.2 Aims

The aims of the finger point interaction experiment are:

1. To develop a finger recognition application that can detect when and where the finger touches the PARM model surface
2. To measure the accuracy of finger touch and to assess its wider potential

5.3 Pilot study: Interactive Projecting Map on Sandbox

Based on the previous experiments of upland rural and urban terrain studies, the PARM project used several tools to project images onto uneven surfaces that were similar to the Augmented Reality (AR) Sandbox approach. The generalised setup of the AR Sandbox is shown in Figure 5.1, requiring a sandbox, a Microsoft Kinect sensor, a projector and a computer. Sandbox is not a flat surface which is similar to PARM.

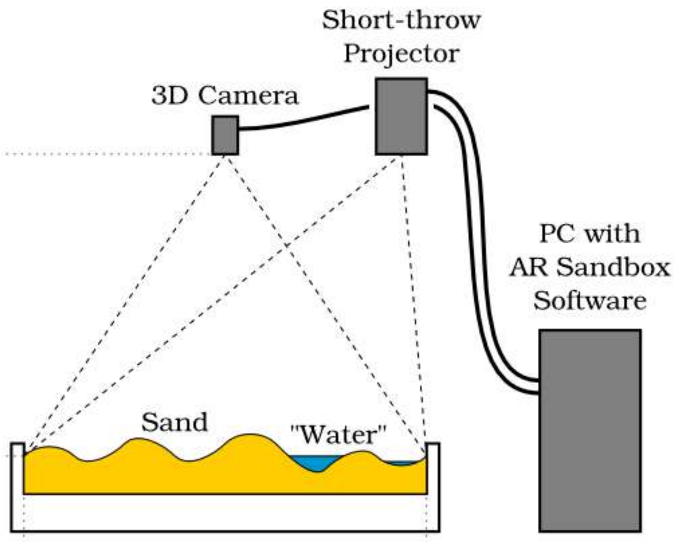


Figure 5.1. The typical arrangement of AR Sandbox (Kreylos, O., 2021)

Using the online documentation for AR sandbox installation from UC Davis (https://web.cs.ucdavis.edu/~okreylos/ResDev/SARndbox/Instructions) an AR sandbox was created at the University of Nottingham to undertake the finger-pointing experiment. The sandbox size was 120cm (length) x 70 cm (width) x 20cm (height), filled with sand to a depth of between 12 and 15cm. The sand used was white play sand which could be slightly moistened to make it mouldable. The projector resolution was 1024x768 pixels and was set 160cm above the centre of the sand surface along with a Microsoft Kinect sensor. The configuration of the computer was an AMD FX™-6100 six-core processor 3.30 GHz, with 16 GB memory and a GeForce GTX 970 graphics card. This was installed with Linux Mate with the Vrui Development Kit, Kinect 3D software and AR Sandbox program (**Figure 5.2a**).

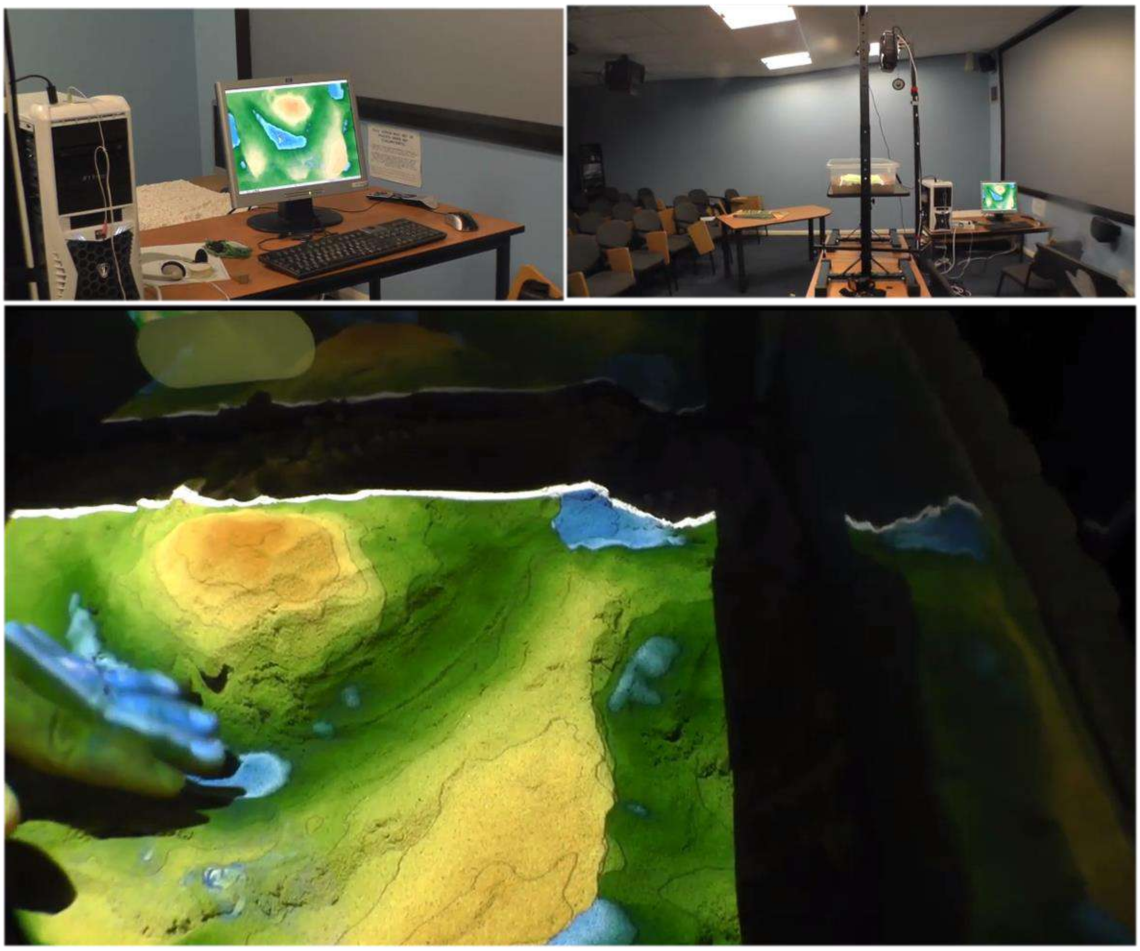


Figure 5.2 Augmented Reality Sandbox Settings (Arss, N., 2019)

The next step was to connect and configure the Kinect with the AR Sandbox software (link: https://web.cs.ucdavis.edu/~okreylos/ResDev/SARndbox/). This involved complex alignment of the Kinect which modelled the base plane of the sandbox through equations that helped to calibrate the projector and Kinect sensors together.

Once built many landscape simulations can be created on the AR sandbox like lakes, peaks, making a dam, lava or rain. To make rain, the program detects the hand shape between the Kinect sensor and the sandbox. All five fingers should be spread out to initiate a rainfall event (**Figure 5.2b**). One component of the hand detection algorithm is the detection of the individual finger, so this suggested that there was potential to detect the index finger for pointing purposes, so users could identify specific objects or places on a surface.

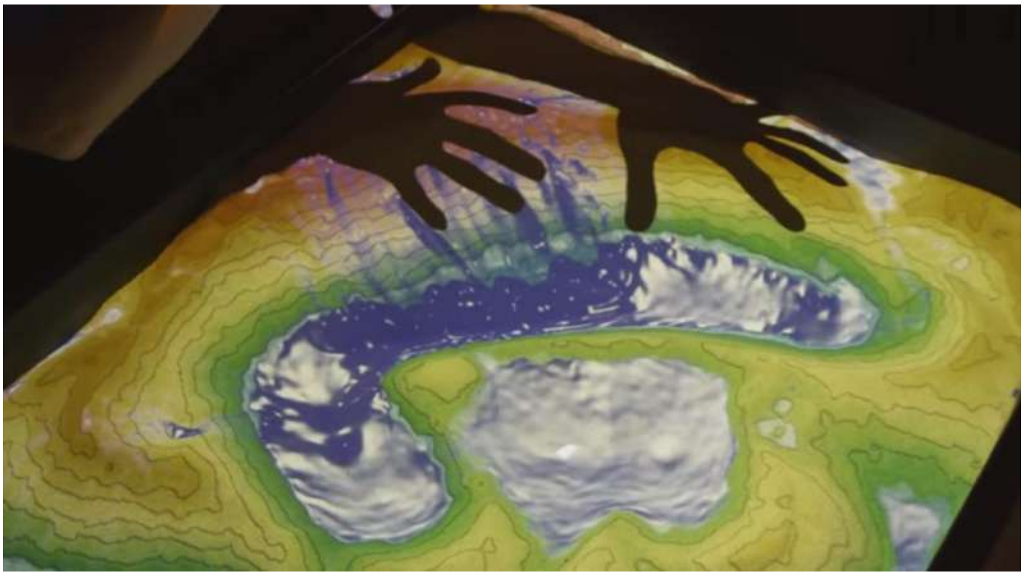


Figure 5.3. Rain simulation on AR Sandbox using a Hand Detection

A pilot experiment was undertaken to establish whether the hand detection algorithms could be modified for fingertip detection near the sand surface, using the AR Sandbox program and the sandbox itself. The results showed that the AR Sandbox program could not detect the hand shape within a range of 0 to 19 cm above the sand surface (**Table 5.1**). The AR Sandbox was therefore considered not suitable as a tool for finger-pointing interaction. The initial purpose of hand detection on the AR Sandbox was to create rain only and the position of the hand was far above the surface, making it unsuitable to apply to PARM in terms of the existing logical programming (Table 5.1).

Table 5.1. Hand detection experiment to measure how far the distance of the hand from the surface in AR Sandbox

Attempts Number	Distance between hand and sand surfaces (in cm)	Result: Detected / Undetected
1	25-24	Detected
2	24-23	Detected
3	23-22	Detected
4	22-21	Detected
5	21-19	Detected
6	20-19	Detected
7	19-18	Undetected
8	18-17	Undetected
9	17-16	Undetected
10	16-15	Undetected
11	15-14	Undetected
12	14-13	Undetected
13	13-12	Undetected
14	12-11	Undetected
15	11-10	Undetected
16	10-9	Undetected
17	9-8	Undetected
18	8-7	Undetected
19	7-6	Undetected
30	6-5	Undetected
21	5-4	Undetected
22	4-3	Undetected
23	3-2	Undetected
24	2-1	Undetected
25	1-0	Undetected

5.4 Finger Tracking Program using C# and Kinect sensor

Finger detection is also part of the Microsoft Kinect Sensor toolkit for Windows (https://developer.microsoft.com/en-us/windows/kinect) within an overall software environment comprising: Windows 7 operating system, Microsoft Visual Studio Express 2013 for Desktop (https://visualstudio.microsoft.com/#d-2012-express), Kinect Sensor Microsoft Library Kinect SDK 1.5 (https://www.microsoft.com/en-us/download/details.aspx?id=29866), DirectX (https://docs.microsoft.com/enus/windows/win32/DirectX?redirectedfrom=MSDN), C# and Library for Kinect development. Real-time finger detection will be captured in a txt file (coordinate X and Y) and exported to an MS. Excel file.

To explore whether this toolkit could be used to detect the point at which the finger touched the model, it was important to understand how hand and finger tracking worked.

There are several steps that must be followed to locate the centre of the hand and the fingertips. The stages of the procedure are as follows:

1. Produce a collection of pixels representing an object closest to the Kinect sensor
2. Reduce noise by increasing and decreasing the depth at which the hand shape is extracted, sharpening the edge curve image of the hand and finger shapes.
3. Categorize pixels representing the hand curve (hand outline including fingers) and hand parts
4. Compute the overall hand curve shape, including the individual fingers.
5. Identify the centre of the palm.
6. Identify the fingertips.

The following section describes how to assign a matrix of points in 3D space and on a bump to accomplish these objectives, and some modifications of the main algorithm to increase the efficiency of the code.

Producing a collection of pixels matrix

The Xbox games console uses a Kinect sensor as a body shape detector for many games. Typically, the distance between the sensor and gamer is 1.2-3.5 M (3.9-11.5ft). The Kinect sensor can be used for other purposes such as research in human body recognition by using the Microsoft Kinect library Software Development Kit (SDK) which can detect 25 human body joints and their coordinates. This library helps the sensor to detect the body movements with a range between 0.7-6M(2.3-19.7feet)

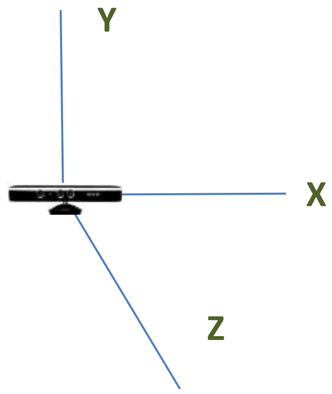


Figure 5.4. Kinect sensor coordinate detection

The Kinect combines an infrared sensor camera with a depth processor. Every single object detected by the Kinect sensor has 3 values: X, Y and Z projected in a cartesian coordinate system with X the horizontal axis, Y the vertical axis and Z is the depth axis. Each value detected by the Kinect sensor corresponds to (0,0) which was the sensor position. The distance between objects and the Kinect sensor can be represented by a mathematical vector with the formula below:

$$\sqrt{X^2 + Y^2 + Z^2}$$

Using this formula, the Kinect sensor can determine the closest objects within its optimal range detection. Due to the nature of this research being the detection of hands and fingers rather than the whole human body, the optimum distance range is smaller, being between 30cm and 50 cm (minimum and maximum distance) (**Figure 5.4**).

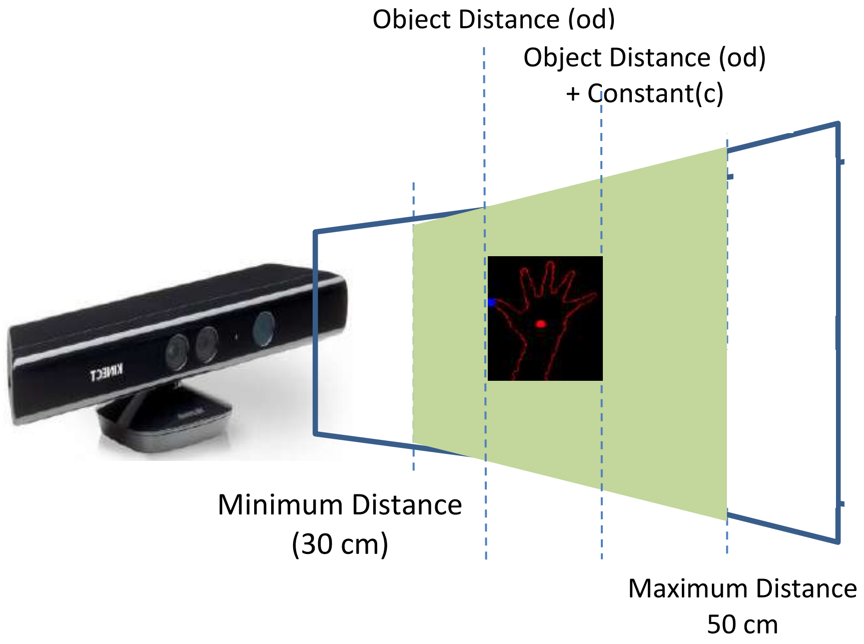


Figure 5.5. Range Detection of Kinect

The Kinect sensor can detect an object(od) with its length(c) as long as the object is within the minimum-maximum (optimum) detection range of the Kinect sensor. For example, if a mobile phone is detected by a Kinect sensor, it will detect the mobile phone as od and the length and width of the mobile phone as c.

Based on the initial experiment with the AR sandbox, to determine the object (hand) clearly, a resolution 320x240 was the optimum for distinguishing the hand curve by changing the pixel unit, whereas a greater resolution would be better but would lead to slower graphic rendering. This method reduces the number of operations and increases effectiveness consequently. Furthermore, by determining the edge of the minimum and maximum distance, the algorithm would not have to do additional steps to check if the object was inside or outside the optimum hand and finger distance detection range.

Reducing noise by increasing and decreasing the hand-shape position

One technique to reduce noise and image blurriness is to use dilation or erosion (Marcos, 2006) that increases the object image curve (finger web and fingertips) when it is less complete and decreases the curve when it is larger than expected. This is achieved through curve prediction based on the tip of the fingers. The technique uses a masking method which establishes a circle around the object/hand based on the minimum and maximum distance of the object/hand (**Figure 5.5**). As the increasing and decreasing noise technique is computationally intensive the method is only used when the Kinect sensor could not detect finger positions.

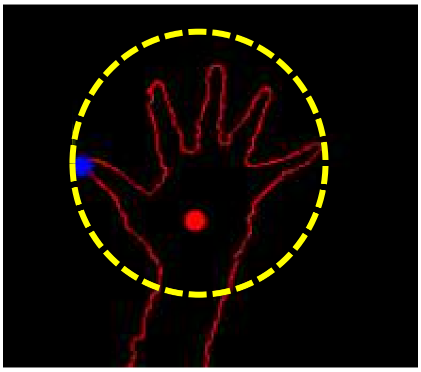


Figure 5.6. Masking of the hand

Categorizing the hand curve and hand-parts pixels

Based on sections 5.3 and 5.4 above, the hand contour can be detected by determining which pixels are part of the hand or not. Those pixels must be categorized as hand curves or hand-part pixels. Pixels that are part of the hand must be surrounded by other similar pixels but those which are not are considered to be on the edge, or part of the hand curve (**Figure 5.6**).

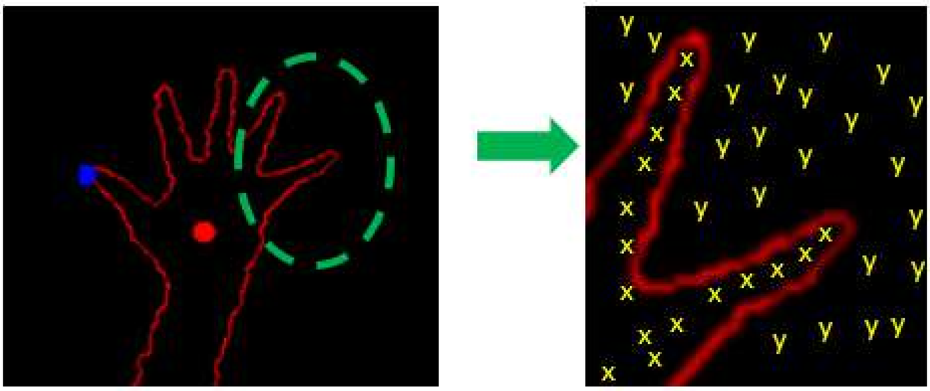


Figure 5.7. Hand Curve and Hand-parts Pixels

Computing the hand curve

In the real-time calculation of the hand curve, pixels come and go very quickly due to hand movements. This event causes an additional step to mark a pixel as checked and build a set of points representing the hand curve or hand-part pixels (**Figure 5.7**). This set of points creates an efficient way to allow fingertips and the centre of the palm to be identified. The data would be stored differently than hand-part pixel data. The outline of a hand as detected by the Kinect sensor uses the Turtle algorithm method. A detected pixel of a hand curve will be set as an initial pixel point. The Turtle algorithm will try to find neighbouring points on the left, right, above or below the initial point pixel.

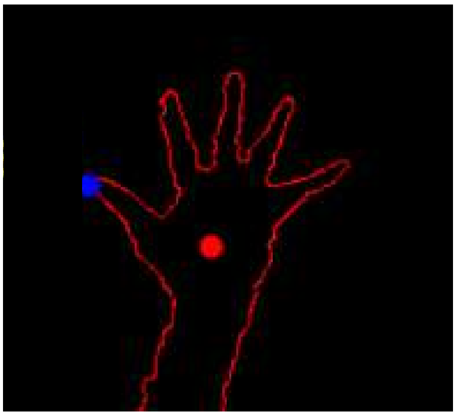


Figure 5.8. Red lines: sets of points creating a hand curve

Discover the centre of the palm

The centre of the palm plays an important role in defining the hand position and fingertips as well. Normally, the centre of the palm is the biggest circle in the hand curve. The centre point of the palm can be identified by computing the maximum consecutive distance of the hand-part pixel points which are adjacent to the hand curve points (**Figure 5.8**). Based on the algorithm training, finding the centre of the palm can be effective depending on the outline detection of the hand and fingers. The dashed circle on the palm shows the biggest circle and is considered to be the centre of the palm and therefore the position of the hand for hand gesture recognition.

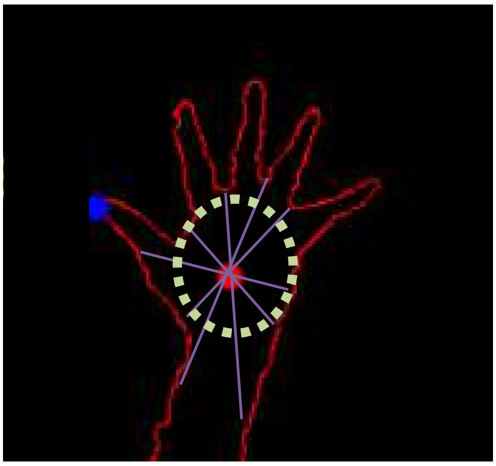
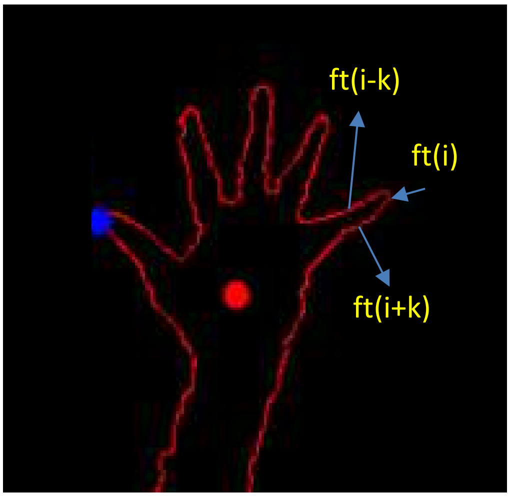


Figure 5.9. Consecutive points to calculate the centre of the palm

Determine the fingertips

The K-curvature algorithm is a common method to determine the angle of an object (**Figure 5.9**). The fingertip ft(i) is determined by calculating the ft(i-k) and ft(i+k) which generates two vectors and their angle. If the angle is smaller than a certain predefined value (less than 90 degrees), it is considered as a fingertip.



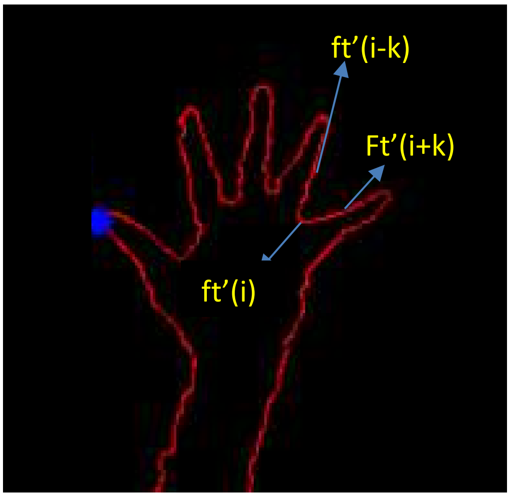


Figure 5.10. The k-curvature algorithm (left) and the false-positive result (right)

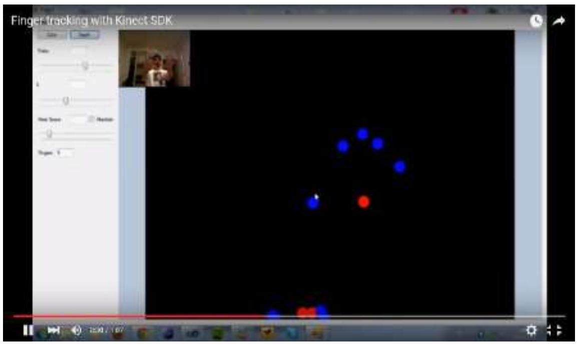
The false-positive of fingertips (**Figure 5.9**) is where a finger-web is detected. It happens because the fingertip and finger-web have similar shapes, although the angle of finger-web (**Figure 5.9 – right**) is typically larger than the actual finger-tip.

5.5 Finger Pointing Interaction on PARM

To explore the fidelity of finger point interaction on PARM, it was necessary to modify the existing finger detection program. This would act as a proof of concept using the real-time finger movement data which represented a string of coordinates of the fingertip as it moves through space towards the model. A workflow was developed to identify individual sequences of coordinates when a finger was moved towards the model surface, with the last coordinate representing the point at which the finger became one with the model. This was taken as the coordinate where the finger had touched the model.

The program Finger Tracking with Kinect SDK is a finger tracking program based on C# and the Kinect Software Development Kit (SDK). The complete algorithm for the program consists of the following algorithms: Main Window, Hand Detection, Vector 3FT Detection, Finger point Detection, Kinect Tracker, Kinect Setting, and Initial Program. To enhance the accuracy of the finger-pointing, some modifications to the algorithm were made to have a closer distance between the finger and a bumpy surface before the fingertip disappeared when it merged into the model.

The original Kinect program was designed to detect several fingers. To detect finger-pointing interaction on a PARM model, the Kinect sensor must be able to detect the position of a single fingertip when a hand enters the view angle of the Kinect sensor. Modifications were required to allow recognition or detection of fingertip coordinates suitable for finger-pointing interaction on a surface (**Figure 5.10**). Modification of the algorithm is shown in Appendix 6 using the red font.



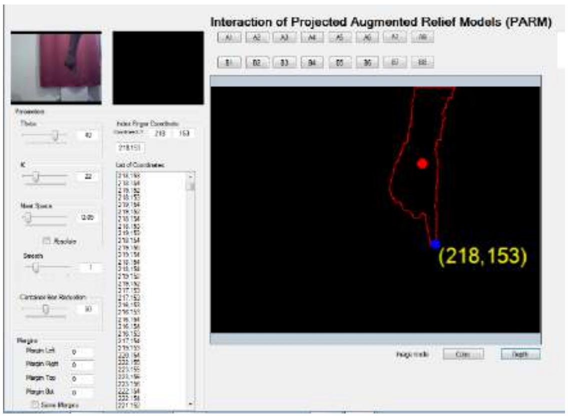


Figure 5.11. Finger detection using original Program (top) and Modified program: showing finger's coordinate (bottom)

An experiment was undertaken using the modified finger tracking program and a PARM display. A user was asked to move their hand towards the surface of the model. The Kinect captured the movement of the finger to between 0cm and 5cm from the model surface before it disappeared, with the typical distance of the finger from the surface being 4-5cm. The result of this study is shown in **Table 5.2** and **Figure 5.11** which suggested that the K-value (number of points in the viewing area) and the Theta value (the horizontal field of view angle of the Kinect sensor) could be modified to allow the fingers to be detected closer to the model, in fact to within 1cm of the model.

Figure 5.11 shows an experiment to explore hand detection using the Kinect sensor at various distances from the model surface, along with respective histograms. This study was to find out how close to a surface finger movement could be detected by the Kinect sensor. Several trials of hand detection using the Kinect Sensor were undertaken with various distances between the hand and the Kinect sensor. Down to within 3cm of the model the hand is still clear but within 2cm it is less clear and finally below 1cm it disappears and cannot be detected.

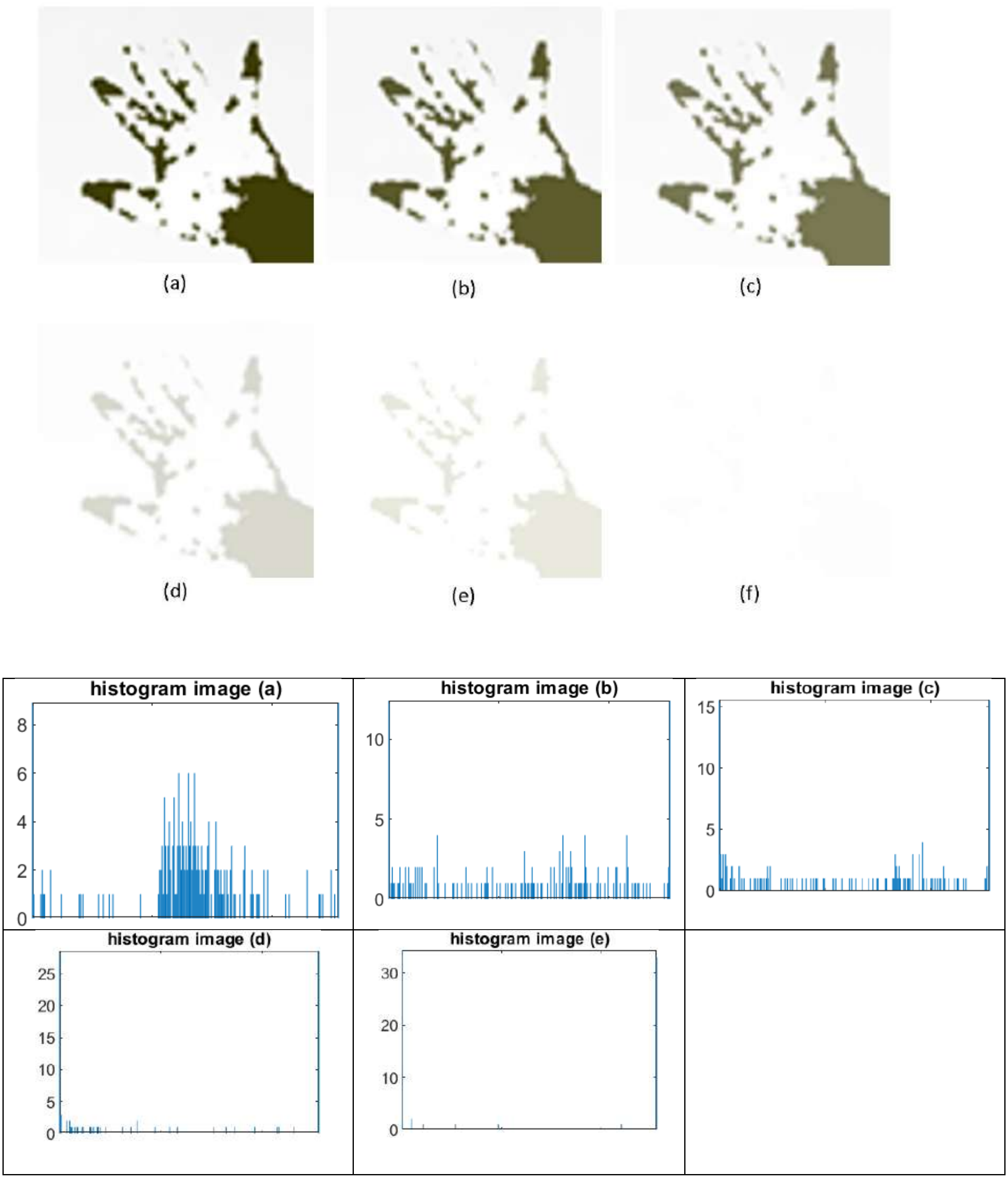


Figure 5.12. The hand detection above model and the histogram graph of the hand detection: (a) 5cm above the surface; (b) 4cm; (c) 3cm; (d) 2cm; (e) 1cm; and (f) 0cm (no hand detected by sensor and no histogram)

The challenging issue of the program is how to modify the K-curvature and Theta values (**Figure 5.12**) and display them as inputs on the main window for the user to do manipulation by increasing and decreasing the K-value and Theta value to get the optimum result (**Figure 5.13**). This dynamic value can be used by the user to set a value based on the distance of the hand from the Kinect sensor or to change the size of the hand image. The fingertip detection program has been made to have complete information about the coordinate movements of the finger as it approaches the model. Moreover, the modification also created an additional tool to catch the last finger position when the Kinect was tracking the finger towards the model surface. The fingertip coordinates were tracked and output to screen and could be stored in txt files when participants pointed to places the model by pressing one of the stored buttons (**Figure 5.13**).

Table 5.2. Determining Hand Position against Surface Model

Finger distance position from the surface (cm)	Hand Detection (Detected / Undetected)	Hand Detection with K value and theta modification			
		K Value (pixel)	Handshape Detection (Detected / Undetected)	Theta θ (degrees)	Fingertips Detection (Detected / Undetected)
3	Undetected	19	Undetected	39	Undetected
3		20	Undetected	40	Undetected
3		21	Undetected	41	Undetected
3		22	Undetected	42	Undetected
4	Undetected	19	Detected	39	Detected
4		19	Detected	40	Detected
4		19	Undetected	41	Detected
4		19	Undetected	42	Detected
4		20	Detected	39	Detected
4		20	Detected	40	Detected
4		20	Undetected	41	Undetected
4		20	Undetected	42	Undetected
4		21	Undetected	39	Undetected
4		21	Undetected	40	Undetected
4		21	Undetected	41	Undetected
4		21	Undetected	42	Undetected

Finger distance position from the surface (cm)	Hand Detection (Detected / Undetected)	Hand Detection with K value and theta modification			
		K Value (pixel)	Handshape Detection (Detected / Undetected)	Theta θ (degrees)	Fingertips Detection (Detected / Undetected)
4		22	Undetected	39	Undetected
4		22	Undetected	40	Undetected
4		22	Undetected	41	Undetected
4		22	Undetected	42	Undetected
5	Detected	19	Detected	39	Detected
5		19	Detected	40	Detected
5		19	Detected	41	Detected
5		19	Detected	42	Detected
5		20	Detected	39	Detected
5		20	Detected	40	Detected
5		20	Detected	41	Detected
5		20	Detected	42	Detected
5		21	Detected	39	Detected
5		21	Detected	40	Detected
5		21	Detected	41	Detected
5		21	Detected	42	Detected
5		22	Detected	39	Detected
5		22	Detected	40	Detected
5		22	Detected	41	Detected
5		22	Detected	42	Detected

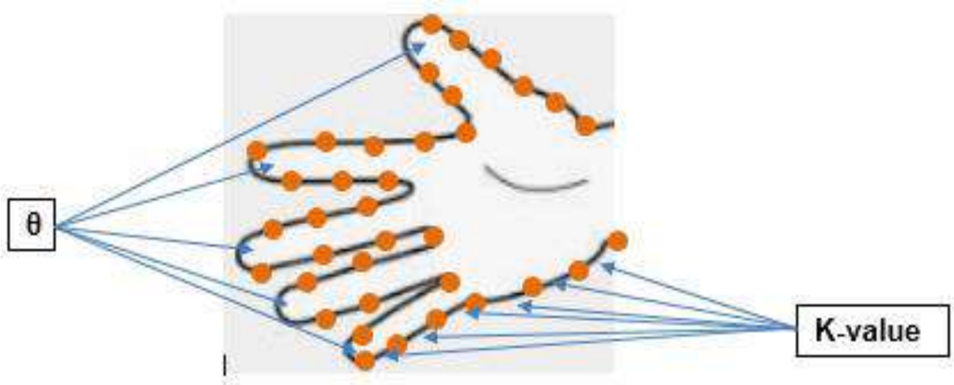


Figure 5.13. K-curvature algorithm with Theta(**θ**) and K value

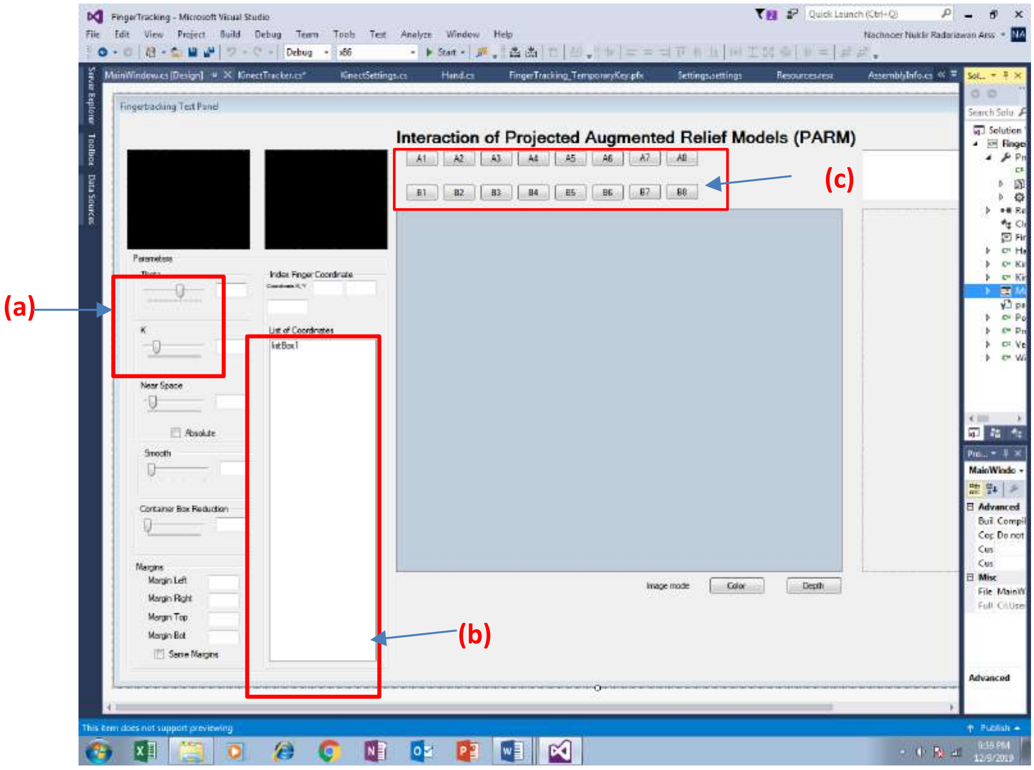


Figure 5.14. Modified User Interface of Kinect Program, (a) Theta and K-Value modification; (b) List of detected finger's coordinates; (c) Coordinates capture buttons for point A1-A4 and B1-B4

5.6 Accuracy of Finger Pointing on Peaks and Low Surfaces

5.6.1 Experimental Setup

An experiment was designed whereby 8 points were defined on each model surface to measure the accuracy of the finger touch on the physical model. On the UP Campus model, the 8 points are set on two types of surface, high surfaces (buildings) and low surfaces (car park, road, park etc). The same configuration is used on the Lake District model, 4 points on high surfaces (peaks) and 4 points on low surfaces (lake, valley etc) (**Figure 5.14**). The coordinates of each point are presented in **Table 5.3**. The Kinect sensor detection algorithm for this study had an optimum detection on the physical model for an area sized 60 cm x 30 cm, therefore all 8 points were positioned in this area of the model (**Figure 5.15**).

Figure 5.15. Finger Kinect Detection on UP Campus Model (left) and Lake District Model (right). Red points represent high surface, green points represent low surface

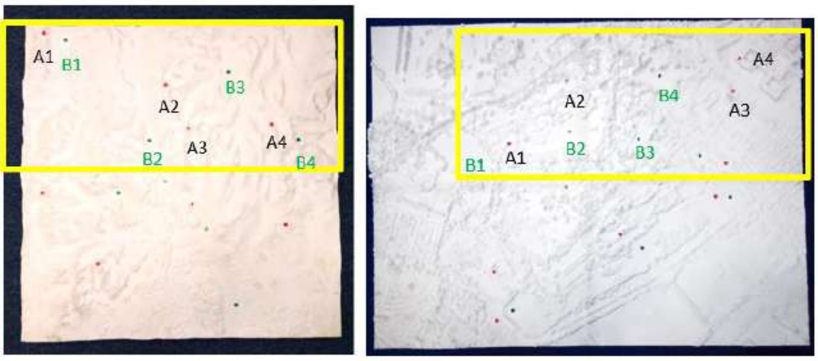


Figure 5.16. Kinect detection area

Figure 5.15 The areas of Kinect detection are shown by the yellow areas measuring 60cm x 30cm on both Lake District (left) and UP Campus (right) models. The points outside the yellow box were not used due to the Kinect sensor detection limitation. A1, A2, A3 and A4 represent the target points on higher surface/object, and B1, B2, B3 and B4 represent the target points on lower surfaces on both the Lake District and UP Campus models.

Table 5.3. Target Coordinate Data on Lake District Model and UP Campus

Points	Lake District		UP Campus	
	Coordinate x	Coordinate y	Coordinate x	Coordinate y
A1	205	51	220	175
A2	149	45	210	155
A3	134	74	182	127
A4	52	119	87	172
B1	226	39	183	104
B2	178	85	156	167
B3	120	39	140	124
B4	68	111	83	132

Fifty people participated in the experiments. They were students or staff of the University of Nottingham and know about the study from the announcement letter on billboards in the buildings on the UP Campus. They were asked to point to each spot on the Lake District and UP Campus model consecutively, starting from point 1 to 4 for the high surfaces and point 1 to 4 for low surfaces. The program recorded data of fingertip coordinates which represented the movement of the fingertips towards the model ending with where the finger was estimated to touch the model. The experimental environment setup can be seen in **Figure 5.16**. Coordinate data obtained from the participants were then analysed to determine the accuracy of finger tracking on the physical model.

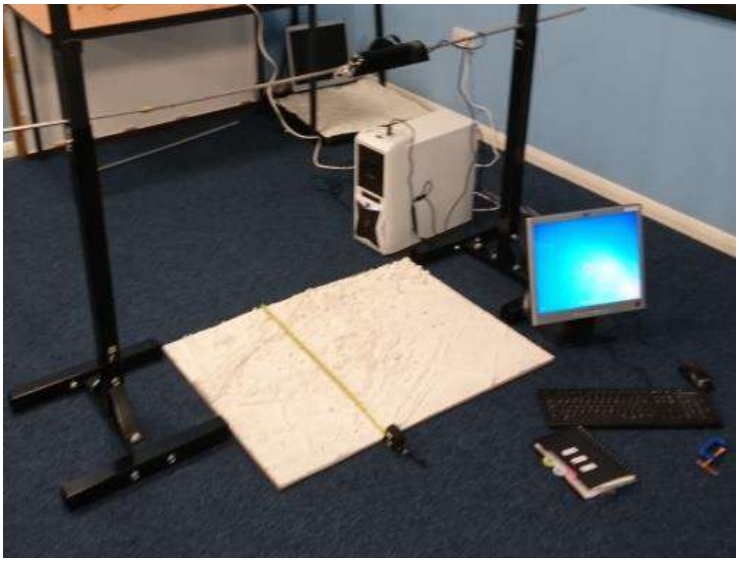


Figure 5.17. Experimentation Setup of Finger Tracking Accuracy on PARM

5.6.2 Results

Overall, based on the data for finger-point detection (**Appendix 7**), the accuracy of attempted coordinates varied between 1.75cm and 3.08 cm for higher surfaces and 1.70 and 3.39 cm for lower surfaces relative to the target points on the Lake District model (**Figure 5.17**). For the UP Campus model, the accuracy of attempted coordinates ranged from 1.71 to 4.29 cm for higher surfaces and 1.54cm to 3.36 cm for lower surfaces (**Figure 5.18**)

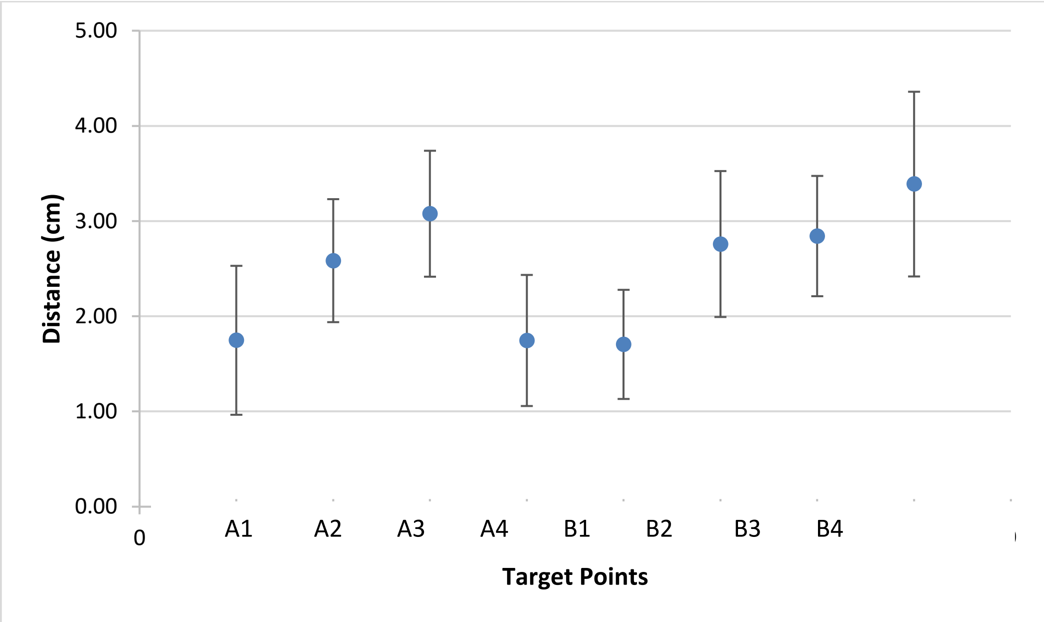


Figure 5.18. Accuracy of Finger Tracking on Lake District Model (average value from 50 attempts)

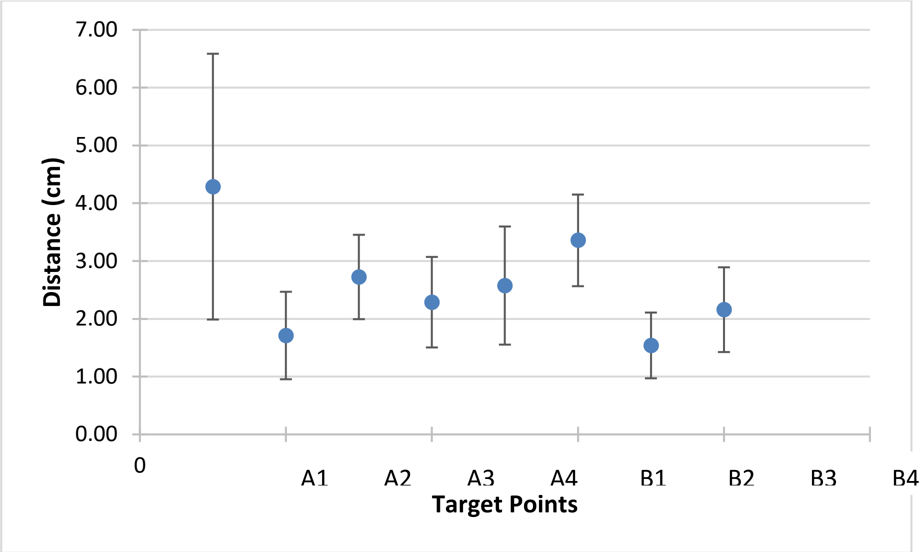


Figure 5.19. Accuracy of Finger Tracking on University Park Campus Model

These results suggest that the accuracy of finger point detection using this technique may not be satisfactory for many purposes because even 1cm away from the target point on the UP Campus model is equivalent to 40m in the real environment. This may be the distance between adjacent buildings so if the technique was used to give the user feedback about what building it was it may lead to confusing results. The finger-touch experiment also showed that the accuracy of the finger-point detection program depends on the location of the target relative to the Kinect sensor.

6 Discussion

6.1 Assessing PARM against a Flat Map

Two experiments were undertaken to determine the capabilities of PARM in depicting geographical information for users when compared to flat representations. Despite both experiments having some similarities in testing procedures (relative height test, cone of vision and intervisibility test for example), the models used in each experiment had relatively different features. In the first experiment, the model of the Lake District represented a large area of natural landscape including lakes, valleys and mountain peaks. The presence of landmarks is essential in providing clues that help users to relate information on a map with the real world and allow accurate reading of the map. However, natural landmarks are sometimes not as clearly defined as human-made landmarks. Therefore, in the second experiment, the PARM model of the University Park Campus was used, consisting mainly of human-made objects like buildings, roads, and bridges. Moreover, in the second experiment participants were required to have knowledge or familiarity with University Park Campus. To address these differences, different approaches to designing the questions were taken. Some types of questions given in the first experiment were not applicable in the second experiment, and vice versa.

Three-dimensional maps have been used to help people understand geographic information for a certain area. In general, the representation of 3D maps can be categorized as digital models, virtual models and physical models. Digital models are often used for people representing map data using XY coordinate and adding elevation information on the map data, to create a digital terrain model that can give an impression of 3D. Virtual models could be considered more immersive representations using special tools like the Oculus Rift, allowing people to experience a *virtual reality* of landscape and objects within it. This method allows people to walk through into the realm of space and move freely to anywhere. Although it sounds like a powerful tool, it has some drawbacks such as using uncommon and complex devices like special goggles which can make some people dizzy when using them. Physical models have been proven to be simple but powerful methods to portray 3D map data throughout history, such as for strategic simulation, educational or exhibition purposes. Despite the extensive development of 3D virtual models, physical models are still used in various fields. Sun et al. (2013) comparing 3D virtual models and physical models for architectural purposes, suggesting that physical models gave more accurate and faster response times when comparing building heights.

The work in this thesis has attempted to investigate some of the power of physical models that make them attractive and engaging to people. People engage with physical models, feel their surface and objects on the surface like buildings, mountains, and trees, and by doing so can estimate the scale of the landscape and the relative positions of features.

One capability of physical models is to explore them from multiple angles as illustrated by Ryselis et. al. (2020). The ability of participants to see and examine the models from different angles gives viewers the opportunity to spot more geographical information on the models such as elevation and slope. In the current study using the Lake District and University Park models however this method was not used. Instead, the participants were asked to observe the models from a fixed position and point of view. Observation from a fixed position using a view board in this study was deemed essential to get objective results to avoid great variations in viewing angles used and movements made around the model. Based on observations made during the pilot study, it was decided that the participants' head and body movement should be restricted and so a view board was used in the main experiments.

Through the experiments into the capabilities of PARM, some new and interesting findings of user engagement with PARM compared to 2D maps was obtained. Most participants found that PARM was better at portraying geographical information for an upland area. Due to the lack of knowledge regarding the area, participants used geographical features and the nature of 3D shapes on the model to answer the given questions. However, the results for the familiar urban landscape showed a non-significant effect between PARM and 2D maps since participants tend to use more of their knowledge of the terrain and spaces of the area when interpreting the model or flat map. This result was not consistent with comments from participants who suggested that the PARM model offers a better portrayal method of relief and terrain compared to a 2D map. According to participants' judgement, PARM could show terrain and relief clearer than traditional maps and give better information about height distinctions that is helpful especially when determining answers for the 'highest point' type of question.

An effect of familiarity on the accuracy was also suggested by the University Park model experiment. It was found that participants who had known the area for less than 6 months had better results with PARM, while those who have known the area for a long time showed no significant difference of accuracy for both PARM and Flat Map. However, participants familiarity with the Lake District area showed no effect on the accuracy due to most participants being unfamiliar with that landscape. The findings supported the use of PARM for people who were less familiar with a landscape, whether that was rural upland or urban.

Lobben (2004) explained that some basic factors affect one's ability to read a map. These include environmental mapping, object rotation, symbol identification, map/environment interaction, visualization, and self-location. Environmental mapping is a process where a cognitive map is created through repeated exposure to the environment, rather than from a map. The process of environmental mapping is known to significantly influence someone's ability to navigate with a map and is helpful to develop a 'sense of direction' or a sense of 'where they are'. Repeated exposure to University Park Campus by the participants through weeks, months, or years of having activities within the campus area would have allowed them to create a cognitive map which is helpful for them to interpret the University Park Campus on both PARM and Flat Map. Additionally, self-location refers to how a person can effectively associate the landmarks on the map with the real-world features and so help to position themselves on the map based on the position of landmarks. This correlates with the experimental result on the UP Campus where a person's duration of stay in an area affected their ability to correctly locate themselves through logical reasoning.

For unfamiliar areas such as the Lake District for most participants, the process of visualization and symbol identification would be more influential in interpreting a map given the lack of a cognitive map. The visualization variable is seen as important for people to navigate themselves in unfamiliar areas (Lobben, 2004). The process involves a mental transformation of a two-dimensional map into three-dimensional form, interpreting features on a map as real-world conditions (Crampton, 1992). The ability of participants to decode symbols available on different backdrop maps would also be a factor for participants to be able to accurately read the geographical information on a map or model such as the height of the peak, the height of the lake, steepest path, etc.

For both models, different types of questions were identified as potential variables which could impact a participant's ability to accurately interpret a map or a model. The types of questions given in the experiments were varied in terms of the geographical features being tested such as relative height and slope or the characteristics of the terrain of the area as represented by visibility and cone of vision type questions. For the Lake District model, PARM was found to be more helpful than the Flat Map for participants to accurately interpret the landscape for all types of question. Furthermore, the response time was quicker for the 'height comparison' (relative heights of peaks and lakes) and the 'steepest' type of question than other types of questions. This suggests that the 3D physical PARM model showed elevation in a very natural way through its physical representation on the model. The 'Height comparison' question was answered more quickly than other types of questions for the UP Campus model, even though the accuracy of this kind of question was the lowest. This may suggest that physical models can sometimes lead to overconfidence in interpreting a landscape due to their very engaging nature.

The experiment with the Lake District model showed that different backdrop maps affected participants judgement on PARM but had no effect on the Flat Map. Post-Hoc statistical analysis for participants' accuracy on PARM categorized Aerial and Hillshade subdued as more helpful for participants, while Contour map gave the lowest accuracy. In particular, for the Steep and Peak type of questions on PARM, the accuracy of participants' answers was considerably lower for the Contour map (44% and 64.3% for Steep and Peak question, respectively) compared to other types of backdrop map which were 60.7%-86.9% for the Steep question and 72.6%-86.9% for the Peak type of question. One important characteristic of the Contour map is the presence of contour lines that convey the elevation of the area that makes it possible to estimate the height of mountains, depth of sea or lakes or the steepness of slopes. However, a study by Rapp et al. (2007) has found that maps with three-dimensional cues such as stereo visualization and shading are found to be preferable and since the contour lines are flat cues, it can be difficult to visualize them as relief in three dimensions, especially for those with limited experience with maps. There is potential for using physical models for training or educational purposes where people need to become aware of the landscape but have traditionally had to use contour maps for this.

Other variables i.e. gender of participants, object distances, and participants' difficulty in map reading showed no significant effects on either accuracy or response time. Differences in spatial ability and the ability to read maps between males and females have been studied extensively with various results. One of the most recent studies showed that the ability of students to read maps was not influenced by gender (Rapp et al., 2007). Another study, however, by Gold et al. (2018) found there were significant differences in spatial skills, particularly for mental rotation, of male and female students. Disparities between gender on spatial ability were also found to be age-related, where differences became apparent in emerging adulthood (Muffato et al., 2021).

There are several implications of these findings in the PARM experiment, such as in the visibility test, where people tended not to be quicker but were more accurate when it comes to complex interpretation. This may suggest PARM could be useful for environmental visualisation where people need to understand a complex pattern like the spreading of a flood, the impact of a volcanic hazard from lava flows and ashfalls, or bathymetric maps showing shallow or dangerous waters during ship navigation. PARM could provide a strong frame of reference so people can gain a greater understanding of impact.

6.2 Finger Pointing Interaction with PARM

The 3-dimensional features of PARM have been known to attract people's interest to displays, particularly by touching the PARM with their fingers. Many technologies are available and could potentially be applied to allow users to engage in more interactive ways with PARM. However, for geographic applications such as on PARM more accurate interaction is desirable so that accurate geographical information can be obtained, for example, to determine the properties at a certain location.

In this study, two applications, the AR Sandbox and the Kinect Sensor software itself have been explored to gain an understanding of whether these techniques could be applied to PARM in a useful way. A pilot experiment on the AR Sandbox showed that while engaging interaction was allowed through physical touch, the finger detection scope was too wide (more than 19 cm) so that more accurate interaction was not likely to be obtained. The Kinect sensor software, however, showed more potential to fit the purpose of finger-pointing application on PARM, due to greater control over the software.

The Kinect sensor detected the natural gesture of finger-pointing. To get the best accuracy possible, several variables were explored and optimised such as the Kinect position, the distance of target points and finger from the Kinect sensor (the Kinect detection range), and the distance of the finger from the target point (finger detection scope). Additionally, another factor that has been identified through experimentation that might also affect the accuracy is the orientation and angular position of the finger relative to the Kinect sensor.

The Kinect sensor (version 1 as used in the AR Sandbox) was developed by Microsoft originally for gaming purposes which allowed a wide range of detection by design. The recommended effective depth range is 0.8 to 4 meters, but it can still detect from up to 8 meters away from the sensor. The depth of a surface is calculated based on the distortion of infrared dots emitted by the Kinect v1 sensor. A study by Wassenmüller & Stricker (2017) compared the depth camera of the Kinect v1 to the Kinect v2 and found that when the distance increases, the Kinect v1 has less accuracy and precision when detecting depth. The accuracy of Kinect v1 was off by less than 10 mm at 0.5 m away from the sensor, but at 1.8 m distance, the offset was more than 40 mm. So although the Kinect v1 sensor had been improved upon, it still had the potential to have good close-range accuracies that may allow finger point detection close to a model surface.

In developing a finger pointing interaction on the PARM model, the Kinect sensor must be able to detect the position of fingertips when a hand enters the view angle of the Kinect sensor over the PARM model. The Finger Tracking Algorithm uses hand curve segmentation and hand-part pixel identification for the detection of the hand and fingers. The hand image that is captured by the Kinect sensor is influenced greatly by the distance from the sensor. The purpose of hand detection in this research is to explore the accuracy of finger detection close to another object, the physical model, so was very different to detecting a finger in an open space. The finger detection scope which is the finger distance from the surface had to be optimised to get the best accuracy for finger-pointing. If the fingertip can be detected touching the surface when pointing to the target points (finger detection scope = 0), then that coordinate could be used to generate a query. The smaller the finger detection scope, the higher the likelihood of achieving better accuracy. However, it was found to be challenging to narrow down the finger detection scope. This is because the Kinect sensor could not detect the hand if it is too close to the surface model where the hand or finger is detected as part of the surface itself.

Overall, it was found that a certain distance of hand or finger toward the surface is required to allow proper detection by the Kinect sensor (between 1-5 cm above the surface) and that at a closer distance, the Kinect sensor is not able to detect the hand (0-1 cm above the surface). The question was whether the last coordinate of the fingertip detected would be close enough to the point on the model that was being touched to be useful.

Various methods have been developed to increase the accuracy of finger detection, such as using a Depth-Skin-Background Mixture-Model (Fernandez-Sanchez et al., 2013), RGB-D and SVM Classifier (Otiniano and Chavez, 2013) and K-curvature method (Abu et al. 2015). However, those methods were used in open-air finger recognition rather than near a bumpy surface. In this study, a K-curvature algorithm was used which is better at tracking fingertips compared to the other two methods. This method counts the neighbourhood pixels to get a simultaneous hand curve line, using a fixed K-curvature (22 pixels) to detect the hand. When the distance of the hand changed when the hand approached the surface model the hand image would be smaller as would the number of pixels. Modifications could be made to the K-curvature value and also the theta degree of the finger due to the changes of the hand position (distance). To reduce the finger detection scope, these modifications were made to the algorithm before applying the program for the finger-pointing accuracy experiment.

The finger tracking program used in this study had a default finger detection range of between 1-5 cm above the surface. The modified algorithm was found to slightly decrease the finger detection scope to 4 cm which is better than the previous algorithm which can detect the hand 5 cm above the surface. The program was also modified so that the coordinate position of fingertips can be recorded. It was more accurate than before when detecting only 1 fingertip than 5 fingertips at the same time on a bumpy surface. The graphic user interface (GUI) was also reformed to suit the experimental requirements using the C# programming language within visual studio. This included the addition of lists of fingertip coordinates and buttons to record fingertip movement when reaching a target point. The detection of fingertips touching a model surface is a breakthrough in Kinect research.

The modified algorithm of finger tracking was tested for its accuracy to pinpoint certain locations on PARM. The study involved 50 participants who each attempted to locate 8 target points on the Lake District and UP Campus models using their fingertips. The study showed similar offsets (average error between detected coordinate and real coordinate) for both models i.e. 2.48 cm for Lake District and 2.58 cm for the UP Campus model. These errors imply that the detected coordinate would often fall on a neighbouring peak or valley for the Lake District model, or an adjacent building in the case of the UP Campus model, and so would be unlikely to give a satisfactory user experience.

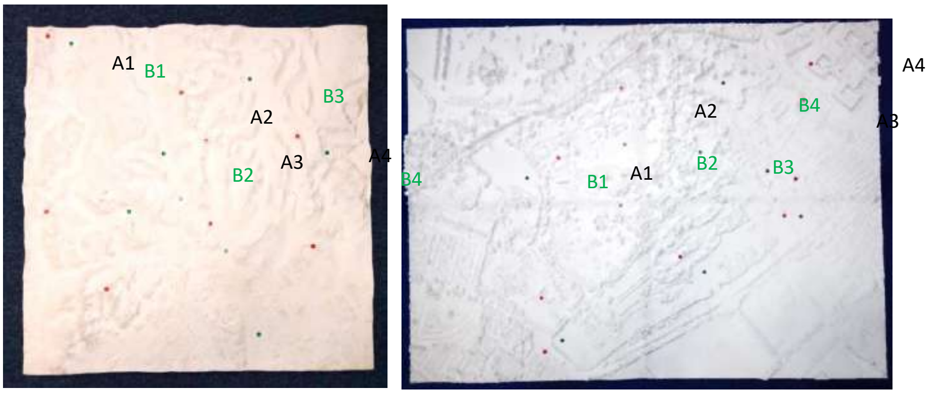


Figure 6.1. Point Labels on Lake District(left) and UP Campus (right). Red labels were points on the higher ground (A1, A2, A3, A4) and green labels were points on the lower grounds (B1, B2, B3, B4). The centre blue line is the Kinect position

It was also found that the position of the target relative to the position of the Kinect sensor affected accuracy. In the experiment, the Kinect sensor position was above the centre of the model, while the target points were scattered at the half top of the model. This means each target point might have a different angle toward the Kinect sensor (**Figure 6.1**). A previous study by Gonzalez-Jorge et al. (2013) found that different angles (45°, 90° and 135°) of the objects toward the version 1 Kinect sensor did not affect the accuracy and precision of the sensor. However, Yang et al. (2015) reported that the accuracy of the version 2 Kinect sensor depends on the viewpoint of the sensor. Accuracy was better when the object was positioned directly in front of the sensor and decreases when the object was positioned sideways. The findings in this thesis found a similar issue using the version 1 sensor so are at odds with the Gonzalez-Jorge et al. (2013) study.

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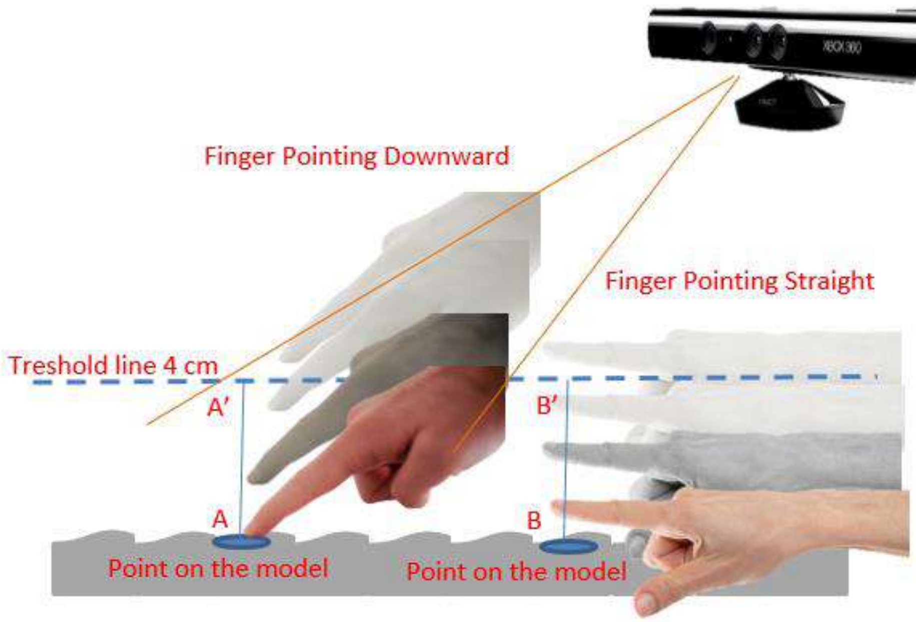


Figure 6.2. The difference in finger-pointing position

The problem is illustrated in **Figure 6.3** and **Figure 6.4** for the Lake District data which showed many fingertip accuracy issues in the study. Based on the variables mentioned earlier it can be seen that the attempted finger-pointing consistently failed to hit the target point. Most of the attempts were positioned to the north of the target point due to the Kinect position being 'to the south' of the finger.

The attempted points which lie relatively close to the centre of the model had more similar positions to the target points, i.e.: lower error. Although they are further positioned from the target point, the position was scattered from the right to the left of the target point respectively, such as points on the Lake District model (A2, A3, B2 and B3). For the A4 and B4 points which were positioned on the upper left of the model, the scattering of the attempted points tended to be in the region to the upper left of the target point. Points A2, A3 and B3 had the largest distance from the attempted points compared to the target points on average. When positioned close to the centre the Kinect was able to detect the fingertips for longer, to within 4 cm of the surface.

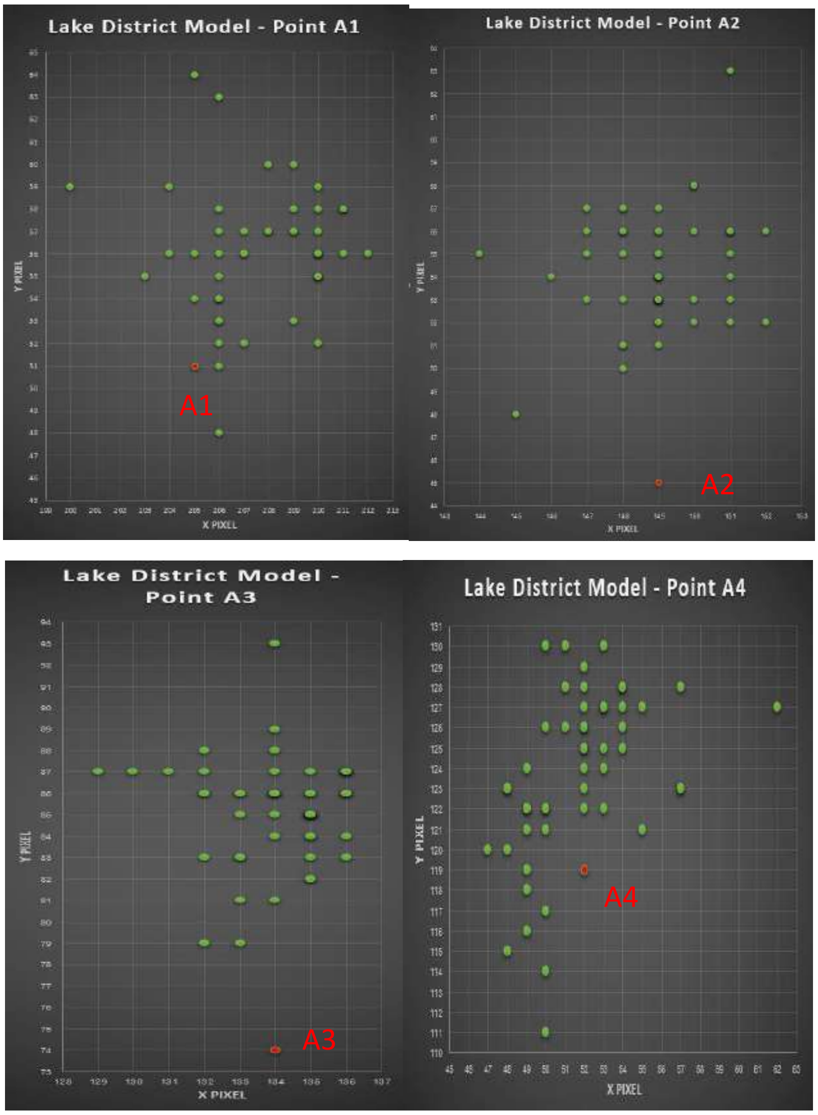


Figure 6.3. Lake District Model – Points on the higher grounds (A1, A2, A3, A4)

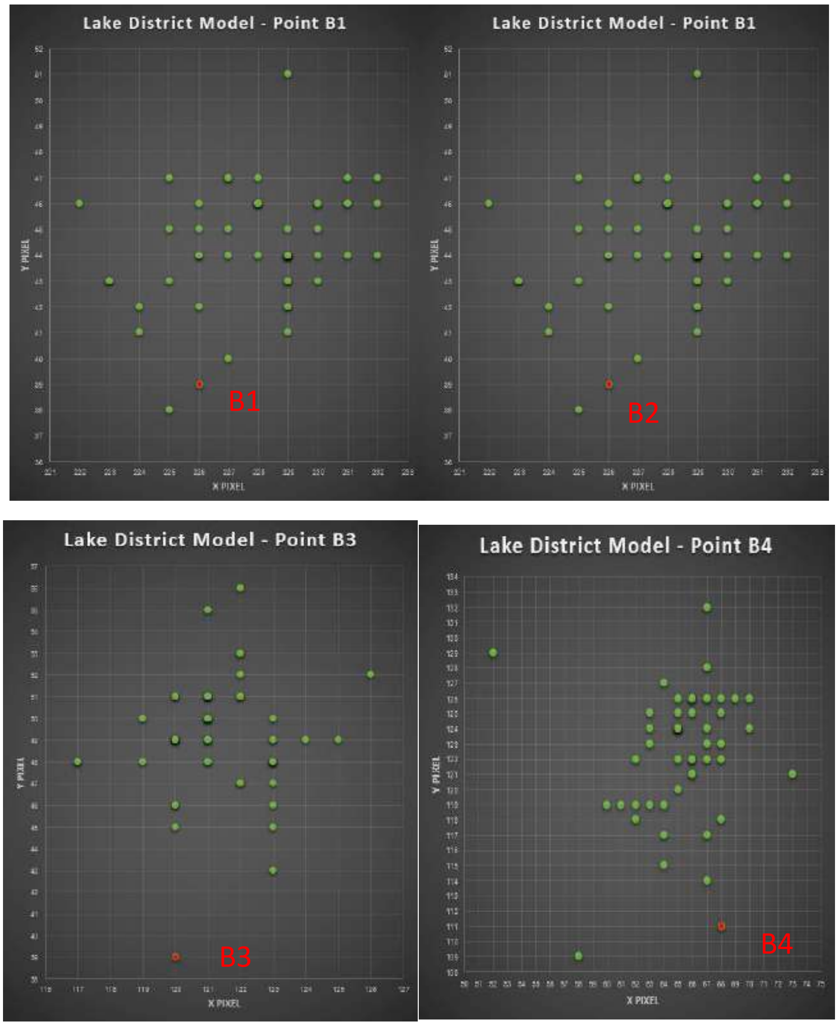


Figure 6.4. Lake District Model – Points on the lower grounds (B1, B2, B3, B4)

For the UP Campus model, **Figures 6.5** and **6.6** show even greater issues partly due to the tall nature of the building objects, for example, A1 represents the tower building which is 2cm above the surrounding model surface. The nature of the model meant that there were many objects like buildings, trees, bridges, roads and many more. Some target points on the UP Campus model were surrounded by tall objects which could affect the accuracy of the finger-pointing where the Kinect sensor detected the nearest object detected.

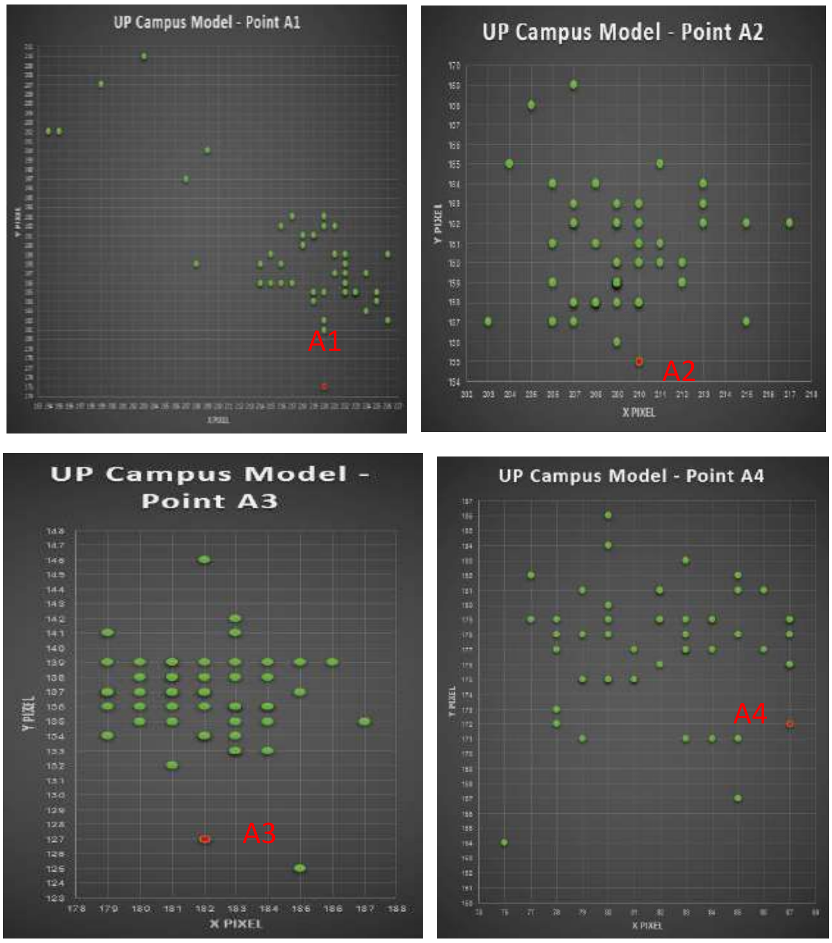


Figure 6.5. UP Campus Model – Points on the buildings (A1, A2, A3, A4)

For Point A1 (Tower building) the attempted points were scattered widely compared to other tall objects (A2, A3 and A4). This was because the tower building on the object was the tallest object on the model where on the finger-pointing experiment, people tended to position their finger against the A1 object not on their fingertips but on their distal phalanx. The results for lower points were affected by the surrounding objects, for example, B1 with buildings and trees, B2 with trees on the north, B3 with surrounding buildings and trees on the west and south side of the target point and B4 with the trees on the north.

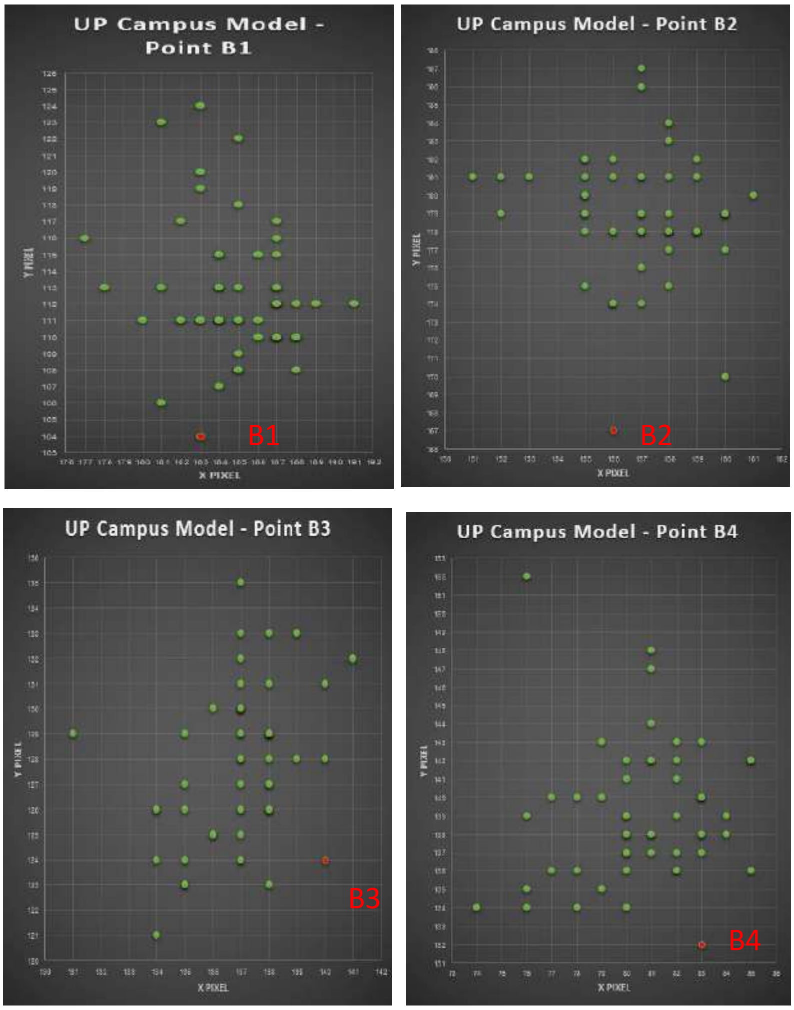


Figure 6.6. UP Campus Model – Points on the lower grounds (B1, B2, B3, B4)

To summarize, the accuracy of finger touch detection showed potential in a few limited cases but overall was disrupted by several factors including the relative position of the finger to the sensor and the nature of objects on the model itself. It could be concluded therefore that the level of accuracy of this method was unsatisfactory for spatial queries relating to features on the models. Larger areas on the models could perhaps be touched successfully but the users may have better expectations and think that each peak or building could be queried. Improvement of the accuracy of the finger tracking program should be further explored in particular to narrow down the distance between the fingertip and the surface. There is also the potential to explore the later version of the Kinect sensor or different technologies such as the Leap Motion.

7 Conclusion and Future Work

7.1 Conclusion

Overall results showed that PARM had better outcomes than flat maps for the Lake District model (statistically significant effects). On the contrary, despite participants comments that PARM was easier to read, the results showed that there was no significant benefit of PARM over the flat map for the University Park case study.

In the Lake District case study, the experiment showed that the type of backdrop map and type of question resulted in statistically significant effects on both accuracy and response time for both PARM and Flat Map. According to statistical analysis, the accuracy of PARM was significantly higher (by 7-17%) and the response time was significantly faster (by 1.1-3 seconds) than the Flat Map for all types of backdrop maps. Moreover, based on the type of question, PARM was also found to have better accuracy (6.9-18.8%) and response time (1.58-3.45 seconds faster) compared to the Flat Map. It was also found that gender, object distance in the model, the familiarity of participants with the Lake District, and participant difficulty in reading maps resulted in no statistically significant effects on the accuracy and response time of PARM and Flat Map. However, different gender of participants (in both PARM and Flat Map) and object distance to the model (in PARM) gave statistically significant effects on accuracy for different types of the backdrop.

The case study using the UP Campus model showed that different types of questions significantly affected the accuracy and response time for both PARM and Flat Map. The 'Cone of Vision' type of question had the highest accuracy i.e. 85.0% for PARM and 87.9% for Flat Map, while the 'Height comparison' type of question had the lowest accuracy which is 61.4% for PARM and 65.7% for Flat Map. In terms of response time, participants answered the 'Height comparison' type of question in the shortest time, 5.5 seconds for PARM and 7.7 seconds for Flat Map, whereas the 'New Object' type of question resulted in the longest answers, averaging 17.0

seconds for PARM and 13.6 seconds for Flat Map. The results also suggested that the accuracy of PARM was greater for participants that had known UP Campus for less than 6 months. In contrast, the accuracy of the Flat Map was greater than PARM for participants who had known UP Campus for more than 6 months. The accuracy of both PARM and Flat Map was greater for all types of question for participants that had known UP Campus for more than 6 months, except for the 'visibility' type of question. Moreover, it was found that gender had no significant effects on the accuracy and response time.

A novel approach to finger-pointing interaction on PARM was developed by modifying an existing finger tracking program using the Kinect v1 sensor and C#. The results showed that the modified algorithm, in particular the modification of the K-value and Theta value, allowed distinct detections of the fingertips when placed as closed as 4 cm above a bumpy surface. The modifications also included additional tools to capture and record the finger coordinates in real-time, allowing the last coordinate captured to be considered the point at which the finger came closest to touching the model. This could then be compared to the coordinate of the target point which the finger was intending to touch. Tests of accuracy for the finger tracking program involving 50 participants (50 attempts each) showed that the accuracy of attempted coordinates deviated by 1.75 – 3.08 cm for higher surface points and 1.70 – 3.39 cm for lower surface points from the target points on the Lake District model. For the UP Campus model, the accuracy of attempted coordinates was 1.71 - 4.29 cm for higher surface points and 1.54 – 3.36 cm for lower surface points.

In general, the results from the finger-pointing accuracy experiment were affected by the Kinect sensor position, the target point position and the features around the target points on the surface model. The Lake District model had no objects that could affect the accuracy, whereas the UP Campus had many features on the surface like buildings and trees which compromised the accuracy of finger tracking.

The results of the experiments suggested that the accuracy of finger-pointing on PARM using the method developed would not be high enough to allow objects to be distinguished. For the Lake District model, this meant peaks and valleys, for the UP Campus model it meant buildings. An error of 2cm would equate to the neighbouring feature and so would result in an unsatisfactory user experience.

If a reliable finger touch system could be developed then it could have applications for 'you-are-there' style tourist displays to allow visitors to query objects, landmarks, and points on the terrain. Another application would be as an educational tool for people to learn about earth science, for example, flood risk, where people could query water depths or the names of landmarks, as they might in a Geographical Information System (GIS).

7.2 Possible Applications of PARM

According to results obtained in the experiment, PARM is better for places that users are not familiar with. The Lake District is prominent as one of the most attractive tourist destinations in the UK. The display of PARM, for instance in a Tourist Information Centre, could be beneficial for visitors to familiarise themselves with area landscape before exploring the area. University Park Campus is part of an international university that always welcomes visitors and new students and a PARM model would be useful to provide information about the area for new students or visitors. This might be useful as well in managing disasterevents such as a fire in the Campus area. To explore more possibilities of PARM, general guidance for installing a PARM would be to set the objective of the PARM display, whether it was for tourism, education, military, entertainment, or any other special purposes, and then prepare a suitable type and scale of terrain data from which to build the model, which represented appropriate features to provide a frame of reference for the particular application.

7.3 Future Work

The capabilities of PARM in portraying graphical information can be enhanced by an interaction between humans and the model. It would be easier and fun if people do not have to press a keyboard, mouse or button to manipulate projected maps and imagery on a 3D model. By using natural gestures, using finger-pointing, they could interact with the model for example to change the backdrop map, or to query the details of a peak, a lake or a building. Moreover, the other benefits of an interactive PARM would be to query the elevation of a surface, to undertake waterflow simulations like the AR Sandbox but for real places, or to create interactive paths for wayfinding. Future work could generate simulations (flood, fire, ecological systems, etc) on urban and upland rural models and explore people's judgements and reactions. The addition of a finger pointing feature on simulations would be interesting, for example by touching one point on the surface model to create a start point water flow or to interactively simulate the starting points of forest fires to visualise what might happen.

Although a novel method of finger-pointing on 3D models has been developed, some limitations could be improved upon to make the above applications a reality. The limited levels of accuracy (1-4 cm) suggest that future work could explore newer versions of the Kinect sensor or other sensor devices to refine the algorithm or to develop entirely new approaches to detecting finger-pointing on bumpy surfaces more accurately. The probability of newer finger detection devices with greater accuracy than the existing Kinect sensors would be a game-changer. The limitations of the sensor device position towards the model, the surroundings of the target points, and exact finger-touch detection on the surface of the model will be removed and make PARM as a device like a touchscreen on a mobile phone, which is easy to install, use, and develop applications for. A touchable 3D physical model would be an attractive and stimulating display for tourism and educational purposes and would develop PARM from being a tangible display into a tangible interface.

Bibliography

ANGESLEVA, J., OAKLEY, I., HUGHES, S. & O'MODHRAIN, S. (2003) Body Mnemonics: Portable Device Interaction Design Concept', UIST'03, Vancouver, Canada.

ARSS, N. Augmented Reality Sandbox Project University of Nottingham, Youtube. [Accessed: 9 December 2021], available: https://www.youtube.com/watch?v=l9Fy9BMaiqA&t=8s

AZUMA, R., BAILLOT, Y., BEHRINGER, R., FEINER, S., JULIER, S. and MACINTYRE, B. (2001) Recent Advances in Augmented Reality. IEEE 0272-1716/01.

BACK, M., et al. (2001) Listen Reader: an electronically augmented paper-based book. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'01). 31 March – 5 April 2001. New York: Association for Computing Machinery (ACM). p. 23-29.

BARFIELD, W., MANN, S., BAIRD, K., GEMPERLE, F., KASABACH, C., STIVORIC, J., BAUER, M., MARTIN, R. & CHO, G. (2001) Computational Clothing and Accessories. W. Barfield & T. Caudell (eds), Fundamentals of Wearable Computers and Augmented Reality, Lawrence Erlbaum Associates, Mahwah, New Jersey, p. 471-509.

BELLOTTI, V., BACK, M., EDWARDS, W.K., E., G.R., HENDERSON, A. & LOPES, C. (2002) Making Sense of Sensing Systems: Five Questions for Designers and Researchers. CHI' 02, ACM Press, Minneapolis, USA, p. 415 - 422.

BENFORD, S., SCHNADELBACH, H., KOLEVA, B., GAVER, B., SCHMIDT, A., BOUCHER, A., STEED, A., ANASTASI, R., GREENHALGH, C., RODDEN, T. & GELLERSEN, H. (2003), Sensible. Sensible and Desirable: A Framework for Designing Physical Interfaces, Available: http://machen.rnrl.nott.ac.uklPUblicationStore/2003-benford'Pdf. [Accessed: 9 December 2021].

BERRY, J.W. (1996) Temne and eskimo perceptual skills. International Journal of Psychology. 1(3). p. 207-229.

BHAGAT, KAUSHAL KUMAR, WEI-KAI LIOU, AND CHUN-YEN CHANG (2016) “A Cost-Effective Interactive 3D Virtual Reality System Applied to Military Live Firing Training.” *Virtual reality : the journal of the Virtual Reality Society* 20.2: 127–140. Web.

BOWER S.J. & HELLSTROM, S.O. (2000) Simple interfaces to complex sound in improvised music. CHI'00 extended abstracts on Human factors in computing systems, ACM Press, The Hague, The Netherlands, p. 125-126.

BOTANA, F. (2013) The Making of L’Abreujamen de las estorias (Egerton MS. 1500). Electronic British Library Journal (eBLJ), article 16.

BUCHROITHNER, M., 2012. True-3D in cartography: auto stereoscopic and solid visualization of geodata. Revised ed. Berlin: Springer Berlin Heidelberg. p. 281-296.

BUXTON, W. (1986) There's More to Interaction Than Meets the Eye: Some Issues in Manual Input', in D. A. Borman & S. W. Draper (eds), User Centered System Design: New Perspectives on Human Computer Interaction, Lawrence Erlbaum, Hillsdale, N.J., p. 319-337.

CALIXTE, X., LECLERCQ, P. (2017) The Interactive Projection Mapping as a Spatial Augmented Reality to Help Collaborative Design: Case Study in Architectural Design. In Lecture Notes in Computer Science; Springer International Publishing: Basel, Switzerland, pp. 143–152.

CABADA, ELISANDRO, ERIC KURT, AND DAVID WARD (2021) “Constructing a Campus-Wide Infrastructure for Virtual Reality.” *College & undergraduate libraries* 27.2-4: 281–304. Web.

CAMARATA, K., YI-LUEN DO, E., GROSS, M. D., & JOHNSON, B. R. (2002) Navigational Blocks: Tangible Navigation of Digital Information. CH1'02, ACM Press, Minneapolis, USA, p. 752-753.

CEREZO, F.T. (2012) Finger Tracking with Kinect SDK: Frantracerkinectft. http://www.java2s.com/Open-Source /CSharp_Free_Code/ Xbox/ Download_Finger_Tracking_with_Kinect_SDK_for_XBOX.htm

CHAPMAN, G. (2015) Microsoft HoloLens googles captivate with holograms. [online] January 2015. Available from http://phys.org/news/2015-01-microsoft-hololens-goggles-captivate-holograms.html. [Accessed: 9 December 2021].

CHATWIN, B. (1988) The Songlines. New York: Penguin Books.

CHUA, P. T., CRIVELLA, R., DALY, B., HU, N., SCHAAF, R., VENTURA, D., CAMILL, T., HODGINS, J. & PAUSCH, R. (2003) Training for Physical Tasks in Virtual Reality Environments: Tai Chi. VR '03, p. 87- 94.

CHUNG, ANDY, W. M TO, AND BRIGITTE SCHULTE-FORTKAMP (2017) "Soundscape Design of an Open-Air Concert Venue Using Virtual Reality Technologies." *The Journal of the Acoustical Society of America* 141.5: 3620–3620. Web.

COLLIER, P., FORREST D., PEARSON A (2003). The representation of topographic Information on maps the depiction of relief. The Cartographic Journal, 40(1), p. 17-26.

CORNELL, E.H., SORENSON, A. and MIO, T (2003). Human sense of direction and way finding. Annals of the Association of Americans Geographers. 93(2). p. 399-425.

DEAKY, B A, and A. L. PARV (2018) "Virtual Reality for Real Estate - a Case Study." *IOP conference series. Materials Science and Engineering* 399.1: 12013. Web.

DEMMING, G. (2004) Sony Eyetoy (TM): Developing Mental Models for 3-D Interaction in a Gaming Environment'. APCHI'04, vol. LNCS 3101, eds. M Masoodian, S. Jones & B. Rogers, Springer, Rotorua, New Zealand, p. 575-82.

DOWMAN, I., and ARORA, V. (2012) 3D data Exploring new horizon. Geospatial World. August 2012. p. 20-26.

ELLARD, C. (2010) You are here: why we can find our way to the moon but get lost in the mall. New York: Anchor Books.

ETHERINGTON, D. (2013) Leap Motion. https://techcrunch.com/2013/04/25/leap-motion-controller-ship-date-delayed-until-july-22-due-to-a-need-for-a-larger-longer-beta-test/

FALLS, C., and, BECKE, A.F. (1930) Detail of Ottoman counterattack on morning of 28 November 1917. Official History of Great War: Egypt and Palestine. Uckfield , United Kingdom: Naval and Military Press Ltd. (in https://en.wikipedia.org/wiki/Battle_of_Jerusalem [Accessed: 9 December 2021].

FISHER, R., HECKBERT, S., MARIA, J., & SUTTON, S. (2019). Augmenting physical 3D models with projected information to support environmental knowledge exchange. *Applied Geography*, *112*, 1-10. [102095]. https://doi.org/10.1016/j.apgeog.2019.102095

GAGNE, R. (1971) Spatial concept in eskimo language. In Eskimo of the Canadian Artic. Edited by V.F. Valentine and F.G. Valee. Toronto: McClelland and Steward

GADRINGER, M., et al. (2018) “Virtual Reality for Automotive Radars.” *Elektrotechnik und Informationstechnik* 135.4-5 (2018): 335–343. Web.

GALOTTI, K.M. (2007) Cognitive Psychology: in and out of the laboratory. 4th edition. California: Wadsworth Publising.

GAVISH, N. et al. (2015) "Evaluating Virtual Reality and Augmented Reality Training for Industrial Maintenance and Assembly Tasks." *Interactive learning environments* 23.6 (2015): 778–798. Web.

GLASS (2021) Discover Glass Enterprise Edition [Online] Available from: https://www.google.com/glass/start/. [Accessed: 9 December 2021].

GOLD, A.U., PENDERGAST, P.M., ORMAND, C.J., BUDD, D.A., STEMPIEN, J.A., MUELLER, K.J., AND KRAVITZ, K.A. (2018) Spatial skills in undergraduate students—Influence of gender, motivation, academic training, and childhood play. Geosphere 14 (2): 668-683.

GONZALEZ-JORGE H., RIVEIRO B., VAZQUEZ-FERNANDEZ E., MARTÍNEZ-SÁNCHEZ J., ARIAS P. (2013) Metrological evaluation of Microsoft Kinect and Asus Xtion sensors. Meas. J. Int. Meas. Confed. doi: 10.1016/j.measurement.2013.01.011.

GORADIA, I., DOSHI, J. and KURUP, L. (2014) A Review Paper on Oculus Rift and Project Morpheus. International Journal of Current Engineering and Technology. Vol. 4(5). p. 3196-3200.

HAHMANN, T., EISFELDER, C. and BUCHROITHNER, M. (2012) Cartographic representation of Dresden's historical development by projecting a movie onto a solid terrain model. In: M. Buchroithner, ed. True-3D in cartography: auto stereoscopic and solid visualization of geodata. Revised ed. Berlin: Springer Berlin Heidelberg. p. 281-296

HAMMER, M.C. (2006) The Conquest of the Swiss Alps The Survey and Engineering Work of Xaver Imfeld (1853 – 1909). XXIII FIG Congress. Munich, 8-13 October 2006. Copenhagen: International Federations of Surveyors.

HEGARTYA, M., RICHARDSON, A.E., MONTELLO, D.R., LOVELACE, K., SUBBIAH, I. (2002) Development of a self-report measure of environmental spatial ability. Intelligence 30 p. 425–447.

HERMAN, J.F. AND SIEGEL, A.W. (1975) The development of spatial representations of large-scale environments. In H. W. Reese (Ed.), Advances in child development and behavior, Vol. 10, p. 9-55. New York: Academic Press.

HOLOLENS (2021) Microsoft Hololens 2 [Online] Available from: https://www.microsoft.com/en-us/hololens. [Accessed: 9 December 2021].

HONGYUN, Z., et al. (2021) "A Methodology for Producing Realistic Hill-Shading Map Based on Shaded Relief Map, Digital Orthophotographic Map Fusion and IHS Transformation." *Annals of GIS* 27.4: 371–382. Web.

HOWARD, C.J. et.al. (2011) Visual search in the real world: evidence for the formation of distractor representations. Perception. [Online] Vol. 40. p. 1143-1153. Available from: http://www.perceptionweb.com/abstract.cgi?id=p7088. [Accessed: 9 December 2021].

HOWARD (2014) Architectural Models, Renderings, Terrain Models - Howard Models. [Online] Available from: http://www.howardmodels.com/index.html. [Accessed: 9 December 2021].

HÜLSMANN, F., et al. (2018) "Classification of Motor Errors to Provide Real-Time Feedback for Sports Coaching in Virtual Reality — A Case Study in Squats and Tai Chi Pushes." *Computers & graphics* 76: 47–59. Web.

HUND, A.M. and NAZARCZUK., S.N. (2009) The effect of sense of direction and training experience of way finding efficiency. Journal of Environmental Psychology. Vol. 29(1). p. 151-159.

HUNG, S. et al (2021) “A New Reality: Exploring Continuance Intention to Use Mobile Augmented Reality for Entertainment Purposes.” *Technology in society* 67: 101757. Web.

HURNI, L. (2008) Cartographic mountain relief presentation: 150 years of tradition and progress at ETH Zurich. Proceedings of the 6th ICA Mountain Cartography Workshop Mountain Mapping and Visualization. Lenk, Switzerland: 11-15 February 2008. Lenk: International Cartographic Association, p. 85-92.

HUTCHINS, E. L., HOLLAN, J.D. & NORMAN, D. (1986) Direct Manipulation Interfaces', in D. Norman & S. Draper (eds), User-Centred System Design, Lawrence Erlbaum Associates, Hillsdale, p. 87- 124.

ISHII, H and ULMER, B (1997) Tangible bits: towards seamless interfaces between people, bits and atoms. Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems. Atlanta: 22-27 March 1997. ACM SIGCHI. p. 234-241.

IMHOF, E. (1981) Sculptors of the Mountains: a report on Alpine Mountain models in Switzerland. Bern: SAC-Verl

JACOB, R. J. K., SIBERT, L. E., MCFARLANE, D. C. AND MULLEN. M. P. J. (1994) Integrality and Separability of Input Devices. ACM Transactions on Computer-Human Interaction, vol. I (1), p. 3-26.

JEAN, J. (2012) Kinect Hacks. O’Reilly Media Inc. JENG, W. (2012) Microsoft Kinect Sensor and Its Effect. IEEE Vol. 12.

JENG, W. (2012) Microsoft Kinect Sensor and Its Effect. IEEE Vol. 12.

JENSEN, BO SONDERGAARD et al. (2021) “Enhanced Mental Health with Virtual Reality Mental Hygiene by a Veteran Suffering from PTSD.” *Case reports in psychiatry* 2021: 1–5. Web.

KAPLAN-RAKOWSKI, REGINA, KAREN R JOHNSON, AND TOMASZ WOJDYNSKI (2021) “The Impact of Virtual Reality Meditation on College Students’ Exam Performance.” *Smart learning environments* 8.1: 1–15. Web.

KARAN, B. (2015) Calibration of Kinect-Type RGB-D Sensors for Robotic Applications. Faculty of Mechanical Engineering (FME) Journal Vol. 43(1).

KENNELY, P.J. (2008) Terrain maps displaying hill-shading with curvature. Elsevier: Geomorphology. Vol. 102. p. 567–577.

KLEINFELD, J. (1971) Visual memory in village eskimo and urban caucasian children. Artic Institute of America, 24(2), p. 132-138.

KOCH, W.G. (2013) J.G. Lehmann’s system of slope hachures – an investigation on the quality of relief representation at the beginning of the 19th century. Proceedings of 26th International Cartographic Conference (ICC2013). Dresden, 25-30 August 2013.

KOZLOWSKI, L.Y., and BRYANT, K.J. (1977) Sense of direction, spatial orientation, and cognitive maps. Journal of experimental Psychology: Human Perception and Performance. Vol. 3(4). p. 590-598.

KOHAVI, RON & TANG, DIANE & XU, YA. (2020). Trustworthy Online Controlled Experiments: A Practical Guide to A/B Testing. 10.1017/9781108653985.

KRASTEV, G. & ANDREEVA, M. (2015) A Software Tool for Experimental Study Leap Motion. International Journal of Computer Science & Information Technology (IJCSIT) Vol. 7(6).

KREYLOS, O. (2021) Augmented Reality Sandbox. [Online] California, USA: Institute Data Analysis and Visualization (IDAV) available: https://arsandbox.ucdavis.edu/. [Accessed: 9 December 2021].

KULSHRESHTH, A., ZORN, C., and LAVIOLA, J.J. (2013). Poster: Real-time Markerless Kinect based Finger Tracking and Hand Gesture Recognition for HCI. IEEE

Symposium on 3D User Interfaces 2013 (3DUI2013). Orlando, 16-17 March 2013.IEEE. p. 187-188.

LABAN, R. (1980) The Mastery of Movement, 3rd revised and enlarged by Lisa Ullmann edn, Plays, Inc., Boston.

LI, YI. (2012) Hand gesture recognition using Kinect. IEEE International Conference on Computer Science and Automation Engineering.

LIM, KENNETH Y. T, AND RYAN LIM (2020) "Semiotics, Memory and Augmented Reality: History Education with Learner-generated Augmentation." *British journal of educational technology* 51.3: 673–691. Web.

MALTA, A., MENDES, M., AND TORRES, F. (2021) "Augmented Reality Maintenance Assistant Using YOLOv5." *Applied sciences* 11.11 (2021): 4758. Web.

MCKENZIE, G., and KLIPPEL, A. (2014) The Interaction of Landmarks and Map Alignment in You-Are-Here Maps.The Cartographic Journal. London: Maney Press. p. 1-12.

MCVEIGH-SCHULTZ, JOSHUA, ANYA KOLESNICHENKO, AND KATHERINE ISBISTER (2019) "Shaping Pro-Social Interaction in VR." *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. ACM. 1–12. Web.

MENDES, M., ALMEIDA, J., MOHAMED, H., AND GIOT, R. (2019) Projected Augmented Reality Intelligent Model of a City Area with Path Optimization. Algorithms 12(7) 140; doi:10.3390/a12070140.

MERCHAN, M. J, P MERCHAN, and E PEREZ (2021) "Good Practices in the Use of Augmented Reality for the Dissemination of Architectural Heritage of Rural Areas." *Applied sciences* 11.5 (2021): 2055. Web.

MERLEAU-PONTY, M. (1962) Phenomenology of Perception. Trans. C. Smith, Routledge, London.

MENDEZ-LOPEZ, MAGDALENA et al. (2021) "Evaluation of an Augmented Reality Application for Learning Neuroanatomy in Psychology." *Anatomical sciences education*: n. pag. Web.

MILGRAM, P et al. (1994) Augmented Reality: A class of displays on the reality-virtuality continuum. SPIE: Telemanipulator and Telepresence Technologies. Society of Photo-Optical Instrumentation Engineers (SPIE). Vol. 2F351. p. 283.

MINE, M.R., BROOKS JR., F.P. & SEQUIN, C. (1997) Moving Objects in Space: Exploiting Proprioception in Virtual-Environment Interaction. SIGGRAPH'97, ACM Press/Addison-Wesley Publishing Co, p. 19-26.

MONTELLO, D.L. (1994) Recall memory for topographic maps and natural terrain: effects of experience and task performance. Cartographica. Vol. 31. p. 18-36.

MONTELLO, D.R., HEGARTY, M., and RICHARDSON A.E. (2004) Spatial Memory of Real Environments, Virtual Environments, and Maps. In: Allen, G.L (Ed.), Human spatial memory: Remembering where, p. 251-285. Mahwah, NJ: Lawrence Erlbaun Associates.

NIEDEROEST, J., 2002. Landscape as a historical object 3D reconstruction and evaluation of a relief model from the 18th century. The International Archives of the Photogrametry, Remote Sensing and Spatial Information Science (ISPRS). Vol. XXXIV (5/W3). Kunming, 26-28 February 2002.

NORMAN, D. A. (1988), The Design of Everyday Things, Basic Books, New York.

PANTERA, L., HUDIN, C., and PANEELS, S. (2020) Two -point Haptic Pattern Recognition with the Inverse Filter Method. EuroHaptics 2020, LNCS 12272, pp. 545-553

PEARSON, A., SCHAEFER, and M., JENNY, B. (2008) The terrain models of Joachim Eugen Muller (1752-1833) and the production of the "Atlas suisse par meyer et swiss". Proceedings of the 6th ICA Mountain Cartography Workshop Mountain Mapping and Visualization. Lenk, Switzerland: 11-15 February 2008. Lenk: International Cartographic Assosiation. p 185-193.

PIDWIRNY, M. (2006) "Introduction to the Oceans". Fundamentals of Physical Geography, 2nd Edition.

PIEKARSKI, W., and THOMAS, B.H. (2002) The Tinmith System - Demonstrating New Techniques for mobile augmeted modelling. Third Australasian User Interfaces Confrence (AUIC2002), Vol. 7.

PIPER, B., RATTI, C., and ISHII, H. (2002a) Illuminating clay: A 3-D tangible interface for landscape analysis. Proceedings of CHI 2002, Minnesota: HCI2002.

PIPER, B., RATTI, C., and ISHII, H. (2002b) Illuminating clay: A tangible interface with potential GRASS application. Proceedings of the open source GIS - GRASS Users Conference 2002.

PREECE, J., ROGERS, Y. & SHARP, H. (2002) Interaction Design: Beyond Human-Computer Interaction, John Wiley & Sons, New York.

PRIESTNALL, G. (2009) Geospatial Widgets: Using visual technology to describe multiple dimensions in the School of Geography. Visual Learning Lab: VLL ACTUAL Landscape. Vol. 30. p. 48.

PRIESTNALL, G. (2012) Spots of Time. [online]. Nottingham: University of Nottingham. Available from: http://www.nottingham.ac.uk/~lgzwww/contacts/staffPages/gary/research/spots.html. [Accessed: 9 December 2021].

PRIESTNALL, G., et al. (2012) Projection Augmented Relief Models (PARM): Tangible Displays for Geographic Information. Electronic Visualisation and the Arts (EVA 2012).

PRIESTNALL, G., Goulding. J, Smith, A. & Arss, N. (2017) Exploring the Capabilities of Projection Augmented Relief Models (PARM) Proceedings of the Geographical Information Science Research UK (GISRUK) Conference, Manchester, April 2017

PRIESTNALL, G. AND CHEVERST, K. (2019) Understanding visitor interaction with a projection augmented relief model display: insights from an in-the-wild study in the English Lake District. S.I.: Pervasive Displays, Personal and Ubiquitous Computing, Springer.

PYBUS, C. (2019) "New Tools For Cultural Heritage Tourism: Accessible Virtual Reality For Milan's Basilica Sant'ambrogio." *International archives of the photogrammetry, remote sensing and spatial information sciences.* XLII-2-W11 (2019): 1003–1010. Web.

RABER, S. (2005) Handmade Relief Models. International Cartographic Association (ICA) 2005 Mountain Cartography Workshop.

RABER S., and HURNI L. (2008) An ambitious relief model project a combination of a handmade, a computer generated and a profiled relief model. Proceedings of the 6th ICA Mountain Cartography Workshop Mountain Mapping and Visualization, p. 185-193.

RADU, IULIAN (2014) "Augmented Reality in Education: a Meta-Review and Cross-Media Analysis." *Personal and ubiquitous computing* 18.6: 1533–1543. Web.

RAHEJA, J.L., CHAUDHARY, A., and SINGAL, K. (2011) Tracking of Fingertips and Centre of Palm using Kinect. Proceedings of the 3rd IEEE International Conference on Computational Intelligence, Modelling and Simulation, p. 248-252.

RANN, K. (2022) Merwede River of Nicolaus Cruquius's 1730. Available from https://thegreatlinesproject.wordpress.com/2016/03/29/floods/. [Accessed: 20 January 2022].

RAPP, D.N., CULPEPPER, S.A., KIRKBY, K., AND MORIN, P. (2007) Fostering Students' Comprehension of Topographic Maps. Journal of Geoscience Education, 55:1, P. 5-16, DOI: 10.5408/1089-9995-55.1.5.

RASKAR, R., WELCH, G., CHEN, W.C. (1999) Table-top spatially-augmented realty: Bringing physical models to life with projected imagery. In Proceedings of the 2nd IEEE and ACM International Workshop on Augmented, San Francisco, CA, USA, p. 64–71.

REN, Z., et al. (2011) Robust Hand Gesture Recognition with Kinect Sensor. ACM Multimedia 2011.

RIPER, J.E.V. (1971) Man's Physical World. New York: McGraw-Hill Book Company.

ROBERTSON, T. (2000) Building bridges: negotiating the gap between work practice and technology design. International Journal of Human-Computer Interaction, vol. 53, p. 121-146.

RYOKAI K., MARTI, S., and ISHII H. (2004) I/O Brush: Drawing with Everyday Objects as Ink. CHI 2004. Video available from http://tangible.media.mit.edu/project/io-brush/. [Accessed: 9 December 2021].

SALANGER, M., LEWIS, D., VALLIER, T., MCDERMOTT, T., & DERGAN, A. (2020). Applying virtual reality to audiovisual speech perception tasks in children. *American Journal of Audiology, 29*(2), 244-258. doi:http://dx.doi.org/10.1044/2020_AJA-19-00004

SÁNCHEZ LAWS, ANA LUISA (2020) "Can Immersive Journalism Enhance Empathy?" *Digital journalism* 8.2: 213–228.

SCHNADELBACH, H., KOLEVA, B., FLINTHAM, M., FRASER, M., IZADI, S., CHANDLER, P., FOSTER. M., BENFORD, S., GREENHALGH, C. & RODDEN. T. (2002) The

Augerscope: A Mixed Reality Interface for Outdoors. CHI'02, ACM Press, Minneapolis, USA, p. 9-16.

SHNEIDERMAN, B. (1998) Designing the User Interface: Strategies for Effective Human-Computer Interaction. 3rd edn. Addison-Wesley Longman, Inc., Reading, Massachusetts.

SHOLL, M.J. (1988) The relation between sense and of direction and mental geographic updating. Elsevier: Intelligence. Vol. 12(3). p. 299-314.

SKAGERLUND, K., KIRSH, D. and DAHLBACK, N. (2012) Maps in the head and maps in the hand. Proceedings of the 34th Annual Science Society, Lawrence Elbraum.

SMITH, A. D., MCKEITH, L. and HOWARD, C. J. (2013) The development of path integration: Combining estimations of distance and heading. Springer: Experimental Brain Research. Vol. 231(4), 445-455

SOLID TERRAIN MODELING (2013) Solid Terrain Models. [Online]. SOLID TERRAIN MODELING, INC. Available from: http://www.solidterrainmodeling.com. [Accessed: 9 December 2021].

SUN, L., FUKUDAN, T., TOKUHARA, T., YABUKI, N. (2014) Differences in spatial understanding between physical and virtual models. Frontiers of Architectural Research Vol. 3 (1), p. 28-35.

SVANRES, D. (2001) Context-Aware Technology: A Phenomenological Perspective. HCI Journal, special issue on context-aware computing, p. 379-400.

TATEOSIAN et al. (2010) TanGeoMS: Tangible Geospatial Modeling System. IEEE Transactions on Visualization & Computer Graphics. Vol. 16(6). p. 1605-1612.

THEODOSSIOU, N., KARAKATSANIS, D., AND FOTOPOULOU, E. (2018) The Augmented Reality Sandbox as A Tool for The Education of Hydrology to Civil Engineering Students. IV International Conference on Civil Engineering Education, EUCEET.

THOWER, N. J.W. (1972) Maps & Civilization. Engelwood Cliffs, New Jersey: Prentice-Hall, Inc

TOOLEY, R.V. (1978) Maps and Map-Makers. 6th Ed. London: B.T. Batsford LTD.

TURNBULL, DAVID. (2016). Maps and Mapmaking of the Australian Aboriginal People. In book: Encyclopedia of the History of Science, Technology and Medicine in Non-Western Cultures (pp. 2685-2688), DOI: 10.1007/978-94-007-7747-7_8728.

TVERSKY, B. et al. (1999) Three spaces of spatial cognition. Association of American Geographers: Professional Geographers. Vol. 51(4), p. 516-527.

ULLMER, B., & ISHII, H. (2000) Emerging frameworks for tangible user interfaces. IBM Systems Journal, 39(3-4), pp. 915-931

XIAOHAN, Z. (2015). “A Helmet for Virtual Reality Recreation.” , European Pantent Office Espacenet patent search CN204864894(U).

WASENMÜLLER O. AND STRICKER D. (2017) Comparison of kinect v1 and v2 depth images in terms of accuracy and precision. Lecture Notes in Computer Science. Springer; Cham, Switzerland.

WOOD, C.S. (2005) “Maximilian I as Archeologist.” *Renaissance quarterly* 58.4: 1128–1174.

YANG, L., ZHANG, L., DONG, H., ALELAIWI, A., SADDIK, A. (2015) Evaluating and improving the depth accuracy of Kinect for Windows v2. IEEE Sens. J. doi: 10.1109/JSEN.2015.2416651.

ZENG, W. (2013) A new Writing Experience: Finger Writing in the Air Using a Kinect Sensor. IEEE Computer Society.

School of Geography
Research ethics checklist for staff and research students
(updated September 2014)

[strongly informed by ESRC (2010) *Framework for Research Ethics*]

This form must be completed for **all** research projects, research assignments or dissertations which are conducted within the School. You must not begin data collection or approach potential research participants until you have completed this form, received ethical clearance, and submitted this form for retention with the appropriate administrative staff.

Completing the form includes providing brief details about yourself and the research in Sections 1 and 2 and ticking some boxes in Sections 2 and/or 3, 4, 5, 6. Ticking a shaded box in Sections 2, 3, 4, 5 or 6 requires further action by the researcher. Two things need to be stressed:

- Ticking one or more shaded boxes does **not** mean that you cannot conduct your research as currently anticipated; however, it does mean that further questions will need to be asked and addressed, further discussions will need to take place, and alternatives may need to be considered or additional actions undertaken.
- Avoiding the shaded boxes does **not** mean that ethical considerations can subsequently be 'forgotten'; on the contrary, research ethics - for everyone and in every project – should involve an ongoing process of reflection and debate.

The following checklist is a starting point for an ongoing process of reflection about the ethical issues concerning your study.

SECTION 1: THE RESEARCHER(S)

1.1: Name of principal researcher (in CAPITALS): Nachnoer Arss

1.2: Status: ☐ Staff

✓ Postgraduate research student

1.3: Email address: lgxnna@nottingham.ac.uk

1.4: Names of other project members (if applicable):

1.5: Name of supervisors (if applicable): Dr. Gary Priestnall

	Yes	No
1.9: I have read the University of Nottingham's *Code of Research Conduct and Research Ethics* (2010) and agree to abide by it: http://www.nottingham.ac.uk/fabs/rgs/documents/code-of-research-conduct-and-research-ethics-approved-january-2010.pdf [also available on Moodle Dissertation Preparation module pages]	✓	

SECTION 2: THE RESEARCH

2.1: Title of project: Interaction of Projected Augmented Relief Model (PARM)

Please provide brief details (50-150 words) about your proposed research, as indicated in each section

2.2: Research question(s) or aim(s) and methodology

Please target this to the non-specialist to expedite review

Aim: To explore PARM's capabilities in interaction with people

Experiment 1: The students will be required to do the test in a controlled experimental room. The test will be involved PARM and 2-dimensional terrain map. The question will come on the models and participant will be allowed to view in particular distance. Questionnaire and video recorder will be use to record the test.

Experiment 2: Test the method of finger-point gesture on PARM in order to measure the accuracy of Finger detection. Participant would be require to point out by their finger to any spot on PARM and the result is to know the finger-point's accuracy measurement. Questionnaire and video recorder will be use to record the test.

Experiment 3: Study case simulation of interaction of PARM. The purpose of the test is to identify capability of PARM to present a study case to the audience. Participants need to interact with PARM to find out PARM functionality by using finger-point detection. This experiment explores the participants judgement and expectation on interaction of PARM. Questionnaire and video recorder will be use to record the test.

The function of video recorder is to record the time capture of participant's activity dealing with PARM's experimentation. The participants will be presented with a consent form before the session begins outlining the intentions of the research and how the data will be used and stored.

2.4: Proposed site(s) of data collection

The University Park campus

2.5: How will access to participants and/or sites be gained?

Recruitment of student volunteers through the University. Sights will all be public access.

	Yes	No
2.6: Will your research take place outside the UK? **(If Yes, please supply further details in Section 7)**		✓

SECTION 3: RESEARCH INVOLVING USE OF SECONDARY DATASETS OR ARCHIVES RELATING TO PEOPLE

If your research involves use of secondary datasets or archives relating to people all questions in Section 3 **must** be answered. If it does not, please tick the 'not relevant' box and go to Section 4.

NOT RELEVANT	✓

Please answer each question by ticking the appropriate box.

	Yes	No
3.1: Is the risk of disclosure of the identity of individuals low or non-existent in the use of this secondary dataset or archive?		
3.2: Have you complied with the data access requirements (where relevant) of the supplier, including any provisions relating to presumed consent and potential risk of disclosure of sensitive information?		

SECTION 4: RESEARCH INVOLVING ACCESS TO FIELD SITES AND ANIMALS

If your research involves access to field sites and/or animals all questions in Section 4 **must** be answered. If it does not, please tick the 'not relevant' box and go to Section 5.

NOT RELEVANT	

Please answer each question by ticking the appropriate box.

	Yes	No
4.1: Has access been granted to the site?	✓	
4.2: Does the site have an official protective designation of any kind?		✓
If yes, have the user guidelines of the body managing the site a) been accessed?		
b) been integrated into the research methodology?		
4.3: Will this research place the site and/or its associated wildlife at any greater physical risks than are experienced during normal site usage?		✓
4.4: Will this research involve the collection of any materials from the field site?		✓
4.5: Will this research expose the researcher and other people using the site to any significant risk of physical or emotional harm? If yes, please address this issue on the School of Geography Risk Assessment Form (RA409).		✓
4.6: Will the research involve vertebrate animals (fish, birds, reptiles, amphibians, mammals) or the common octopus (*Octopus vulgaris*) in any capacity?		✓
If yes, will the research with vertebrates or the common octopus involve handling or interfering with the animal in any way or involve any activity that may cause pain, suffering, distress or lasting harm to the animal?		

SECTION 5: RESEARCH WITHIN OR INVOLVING THE NHS OR SOCIAL CARE

If you are undertaking research within or involving the NHS or social care all questions in Section 5 **must** be answered. If not, please tick the 'not relevant' box and go to Section 6.

Further guidance on research and ethics related to the NHS can be found at

http://www.hra-decisiontools.org.uk/research/ and http://www.hra-decisiontools.org.uk/Ethics/

Please follow these decision trees and decide on how to proceed.

NOT RELEVANT	✓

Please answer each question by ticking the appropriate box.

	Yes	No
5.1: Does this research involve the recruitment of patients, or the use of their records through the NHS, or involve NHS sites or other property?		
5.2: Does this research involve participants aged 16 or over who are unable to give informed consent? (e.g. people with learning disabilities: see Mental Capacity Act 2005)?		
If you have answered **Yes** to either of the above questions (5.1 or 5.2), ethical approval **must** be sought from the relevant NHS research ethics committee (see National Research Ethics Service (NRES) http://www.nres.npsa.nhs.uk). Evidence of approval from such a committee **must** be lodged with the School Office prior to the commencement of data collection. Please indicate that you agree to this.		
5.3: Does this research involve the recruitment of users or staff, or the use of their records or other data through social service authorities (children and adult services), or involve social service sites or other property?		
If you have answered **Yes** to the above question (5.3), then you must check whether or not the relevant social service authority has its own ethical scrutiny procedures. If appropriate, evidence of approval from such an authority **must** be lodged with the School Office prior to the commencement of data collection. Please indicate that you agree to this.		

Where external ethical approval has been obtained from a NHS committee or social service authority completion of the remainder of this form is optional.

SECTION 6: RESEARCH INVOLVING THE PARTICIPATION OF PEOPLE

If your research involves the participation of people all questions in Section 6 **must** be answered (unless you have already obtained external ethical approval from a NHS committee or social service authority). If it does not, please tick the 'not relevant' box and go to Section 7.

NOT RELEVANT	

Please answer each question by ticking the appropriate box.

A. General issues

	Yes	No
6.1: Does the research involve other vulnerable groups: children, those with cognitive impairment, or those in unequal relationships e.g. your own students?		✓
6.2: Will this research require the cooperation of a gatekeeper for initial access to the groups or individuals to be recruited?		✓
6.3: Will this research involve discussion of sensitive topics (e.g. sexual activity, drug use, physical or mental health)?		✓
6.4: Will this research place participants at any greater physical or emotional risk than they experience during their normal lifestyles?		✓
6.5: Will this research involve the administering of any drugs, placebos or other substances (e.g. food substances, vitamins)?		✓
6.6: Will this research involve any physically invasive, intrusive or potentially harmful procedures of any kind or the collection of bodily samples?		✓
6.7: Will this research expose the researcher to any significant risk of physical or emotional harm?		✓
6.8: Will this research involve people taking part in the study without their knowledge and consent at the time?		✓
6.9: Will this research involve respondents to the internet or other visual/vocal methods where people may be identified?		✓
6.10: Will this research involve access to personal information about identifiable individuals without their knowledge or consent?		✓
6.11: Does the research involve recruiting members of the public as researchers (participant research)?		✓
6.11: Will tissue samples (including blood) be obtained from participants?		✓
6.12: Will the study involve prolonged or repetitive testing?		✓

	Yes	No
6.13: For those intending to work with children and/or vulnerable adults a) I have read the University's *Guidance on arrangements for Protection of Children and Vulnerable Adults* (2009) http://www.nottingham.ac.uk/wideningparticipation/downloads/Child%20&%20Vulnerable%20Adult%20Protection%20Policy%20Jan%202006.pdf		
b) I am prepared to allow a Disclosure and Baring Service (DBS) check to be made on me by organizations facilitating my research.		
6.14: My full identity will be revealed to all research participants.	✓	
6.15: All participants will be given accurate information about the nature of the research and the purposes to which the data will be put.	✓	
6.16: All participants will freely consent to take part, and, where appropriate, this will be confirmed by use of a consent form.	✓	
6.17: All participants will freely consent to take part, but due to the qualitative nature of the research a formal consent form is either not feasible or undesirable and alternative means of recording consent are proposed.		✓
6.18: A signed copy of the consent form or (where appropriate) an alternative record of evidence of consent will be held by the researcher.	✓	
6.19: It will be made clear that declining to participate will have no negative consequences for the individual.	✓	
6.20: It will be made clear that participation is unlikely to be of direct personal benefit to the individual.	✓	
6.21: Participants will be asked for permission for quotations (from data) to be used in research outputs where this is intended.	✓	
6.22: Will the data collected be retained securely for at least seven years from the date of any publication based upon them?	✓	
6.23: Incentives (other than basic expenses) will be offered to potential participants as an inducement to participate in the research. (Here any incentives include cash payments and non-cash items such as vouchers and book tokens.)	✓	
6.24: Will the research involve administrative or secure data that requires permission from the appropriate authorities before use?		✓

	Yes	No
I have read the *Data Protection Policy and Guidelines* of the University of Nottingham and agree to abide by them: Policy - http://www.nottingham.ac.uk/%7Ebrzdpa/local/dp-policy.doc Guidelines - http://www.nottingham.ac.uk/~brzdpa/local/dp-guidance.doc	✓	

SECTION 7: ETHICAL APPROVAL

If you ticked any of the shaded boxes in sections 2, 3, 4 or 6 of this form, then you must complete SECTION 7 (below).

FURTHER INFORMATION & JUSTIFICATION OF METHODOLOGY

One box should be completed for **each** shaded box ticked in sections 2, 3, 4 or 6 of this form.

Ethical issue: Providing vouchers as an incentive for participation

Rationale for chosen methodology and/or how ethical issue is to be addressed:

In order to guarantee enough volunteers for the study it is proposed to offer a small incentive such as a £5 shopping voucher as a thank you for giving their time.

Ethical issue:

Rationale for chosen methodology and/or how ethical issue is to be addressed:

Ethical issue:

Rationale for chosen methodology and/or how ethical issue is to be addressed:

Please continue on a separate sheet if necessary.

Declaration of ethical research

Please sign and date below.

If you ticked any of the shaded boxes in Sections 2, 3, 4 and 6 of this form, you should have completed Section 7.

Please submit this checklist to the School's Research Ethics Officer (matthew.jones@nottingham.ac.uk).

By signing this form you are agreeing to work within the protocol which you have outlined and to abide by the University of Nottingham's Code of Research Conduct and Research Ethics. If you make changes to your research protocol (such as changes to methods of data collection, the proposed sites of data collection, the means by which participants are accessed) which in turn would change your answers to any of the above questions then you **must** complete a new form and submit a copy to your supervisor (if relevant).

Once approved this checklist will be archived with the School Office.

Signed .... Date 14 July 2015

For postgraduate research student this form must be additionally signed by your supervisor before review by the research ethcis committee:

Supervisor's name: Dr. Gary Priestnall

Signed .... Date 14 JULY 2015

The Research Ethics Panel

☐ agrees that the research can go ahead as planned

☐ requests further information and/or amendments to the research protocol (see details below)

School REO.. Date 16/7/2015

Appendix 2. Consent Form

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Explore the Capabilities of Projected Augmented Relief Models (PARM)

Researcher(s): Nachnoer Arss (lgxnna@nottingham.ac.uk)
Supervisor(s): Gary Priestnall (Gary.Priestnall@nottingham.ac.uk)
Alastair Smith (Alastair.Smith@nottingham.ac.uk)

The participant should answer these questions independently:

- Have you read and understood the Information Sheet? YES/NO
- Have you had the opportunity to ask questions about the study? YES/NO
- Have all your questions been answered satisfactorily? YES/NO
- Do you understand that you are free to withdraw from the study? YES/NO (at any time and without giving a reason)
- I give permission for my data from this study to be shared with other researchers provided that my anonymity is completely protected. YES/NO
- Do you agree to take part in the study? YES/NO

[*For online studies:*
By clicking the button above I indicate that the study has been explained to me to my satisfaction, and I agree to take part. I understand that I am free to withdraw at any time.]

"This study has been explained to me to my satisfaction, and I agree to take part. I understand that I am free to withdraw at any time."

Signature of the Participant: Date:

Name (in block capitals)

I have explained the study to the above participant and he/she has agreed to take part.

Signature of researcher: Date:

Appendix 3. Information Sheet

Explore the Capabilities of Projected Augmented Relief Models (PARM)

Researchers: Nachnoer Arss

Supervisors: Gary Priestnall and Alastair Smith

Contact Details: lgxnna@nottingham.ac.uk

This is an invitation to take part in a research study on environment understanding. Before you decide if you wish to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

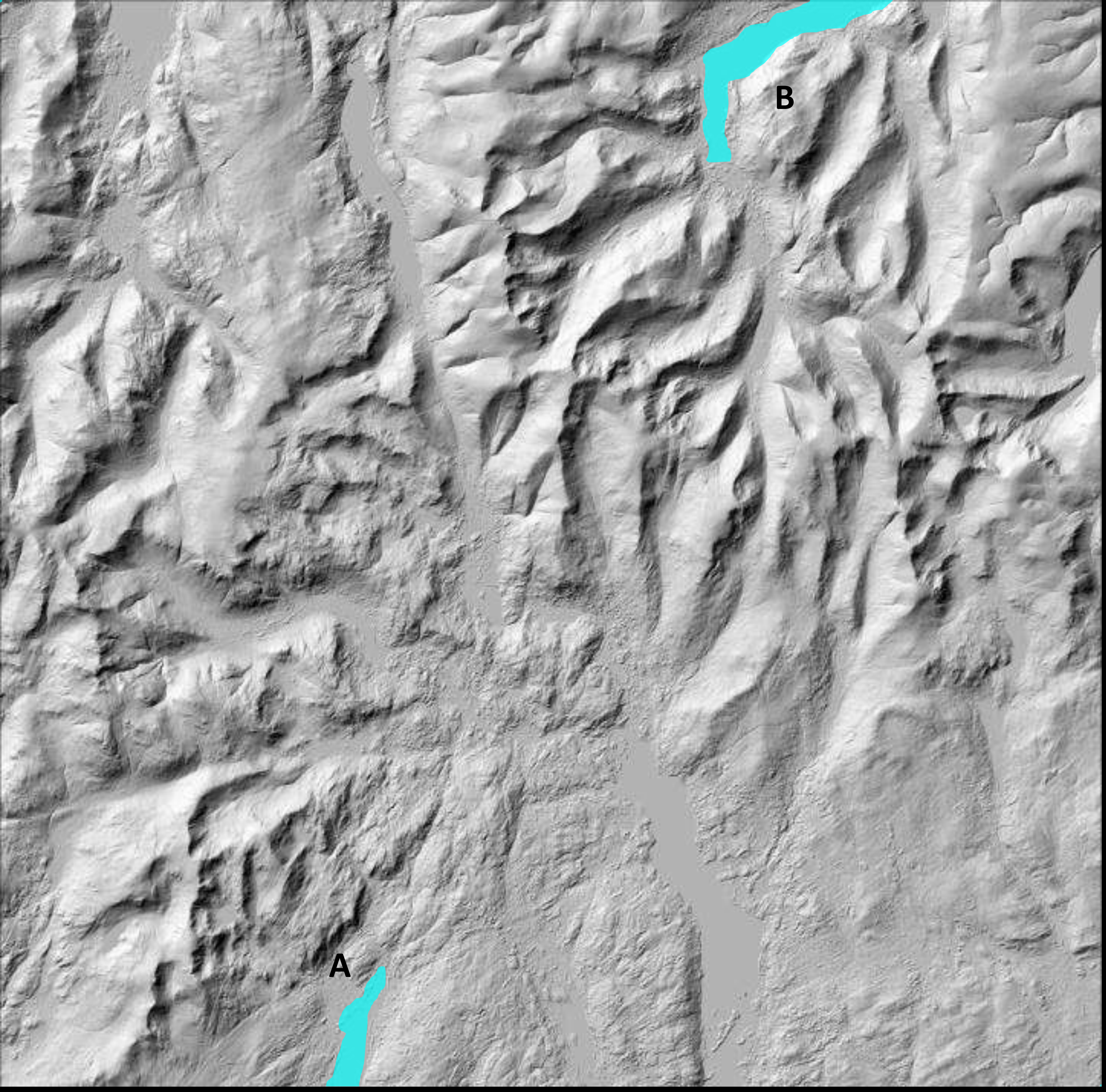
This study addresses how the type of information presented in maps can affects people's understanding of the environment depicted. We will project different forms of digital data onto a model and participants are asked to make a number of simple judgements about the environment. Sessions will take place in the Sir Clive Granger building – participants will be met at the entrance by the researcher.

The whole procedure will last 1 hour

Participation in this study is totally voluntary and you are under no obligation to take part. You are free to withdraw at any point before or during the study. All data collected will be kept confidential and used for research purposes only. It will be stored in compliance with the Data Protection Act.

If you have any questions or concerns please don't hesitate to ask now. We can also be contacted after your participation at the above address.

If you have any complaints about the study, please contact:
Stephen Jackson (Chair of Ethics Committee)
stephen.jackson@nottingham.ac.uk

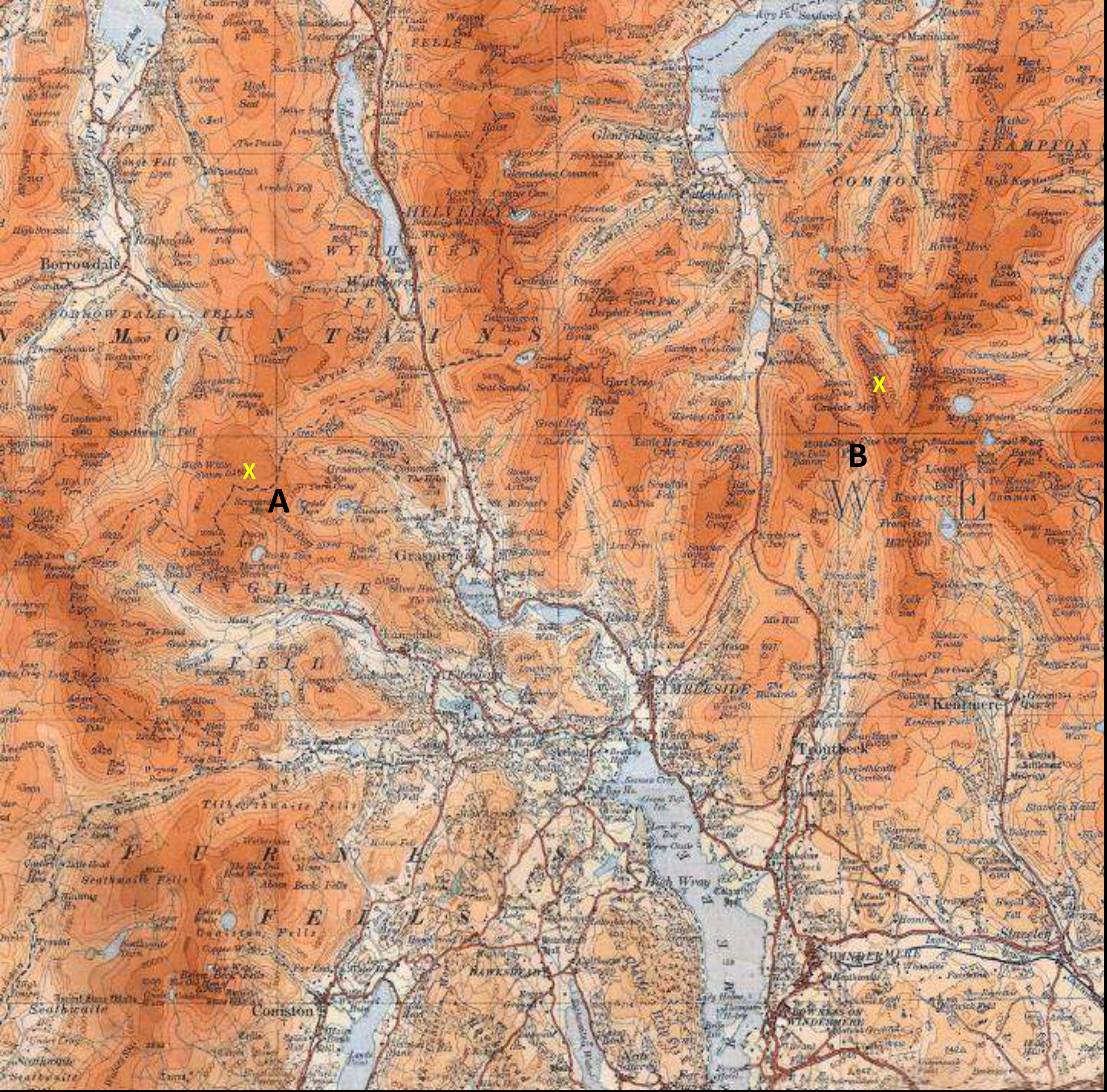


Notice both lakes (blue area).

Which is the highest lake?

A or B

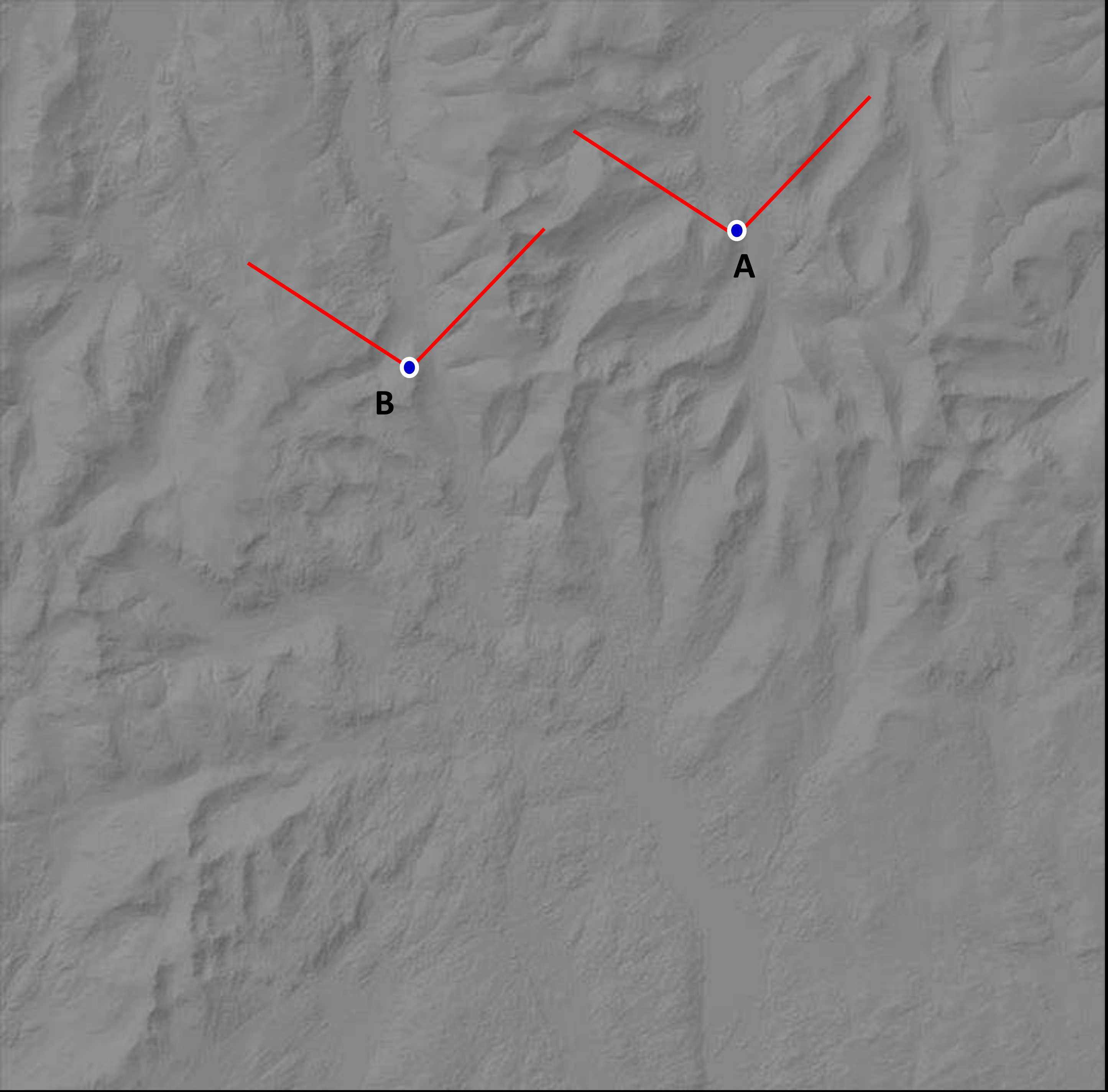
101



Notice both peaks (X sign). Which is the highest peak?

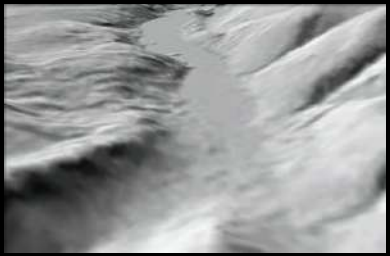
A or B

204

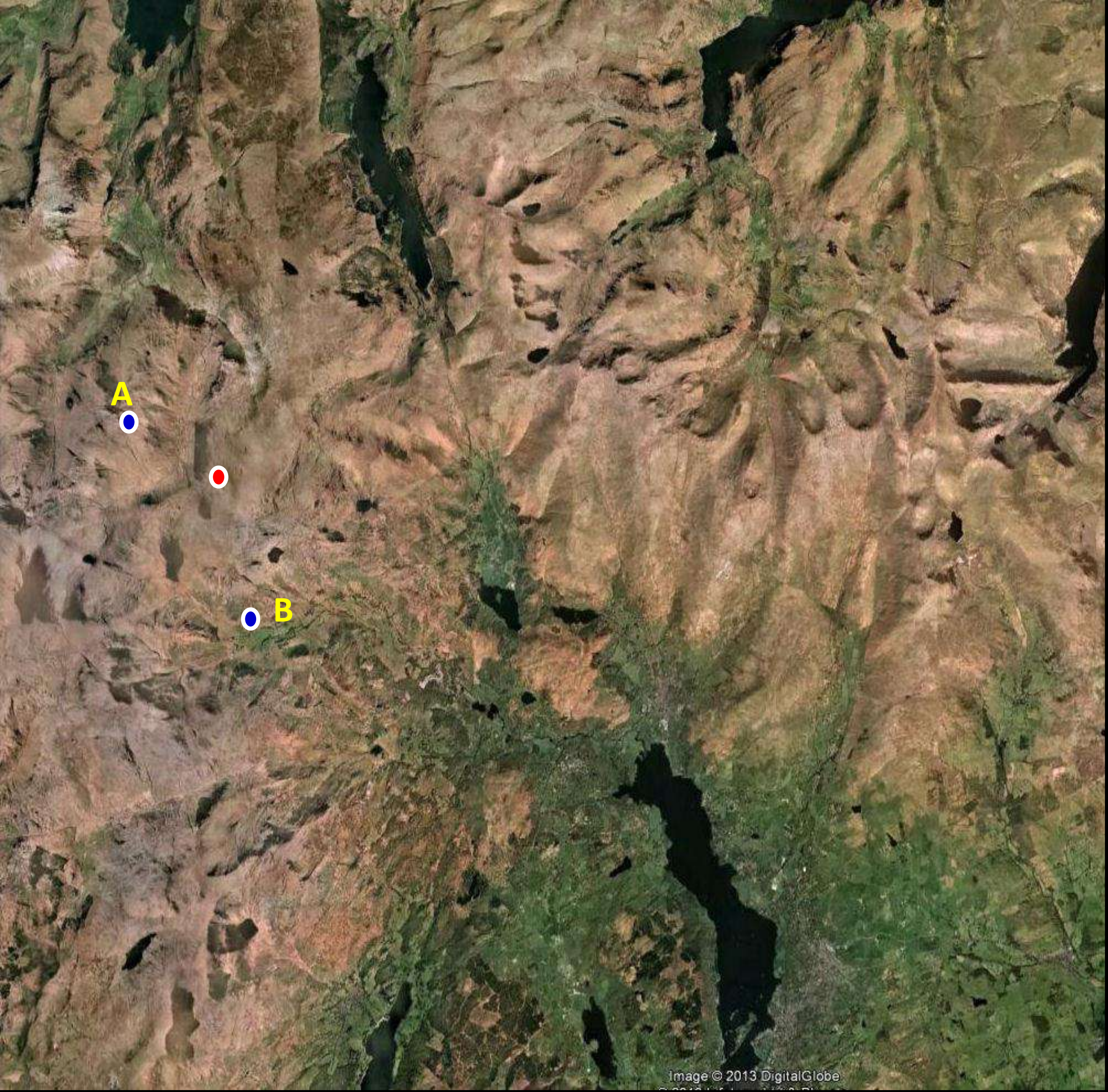


Which viewpoint matches the picture below?

A or B



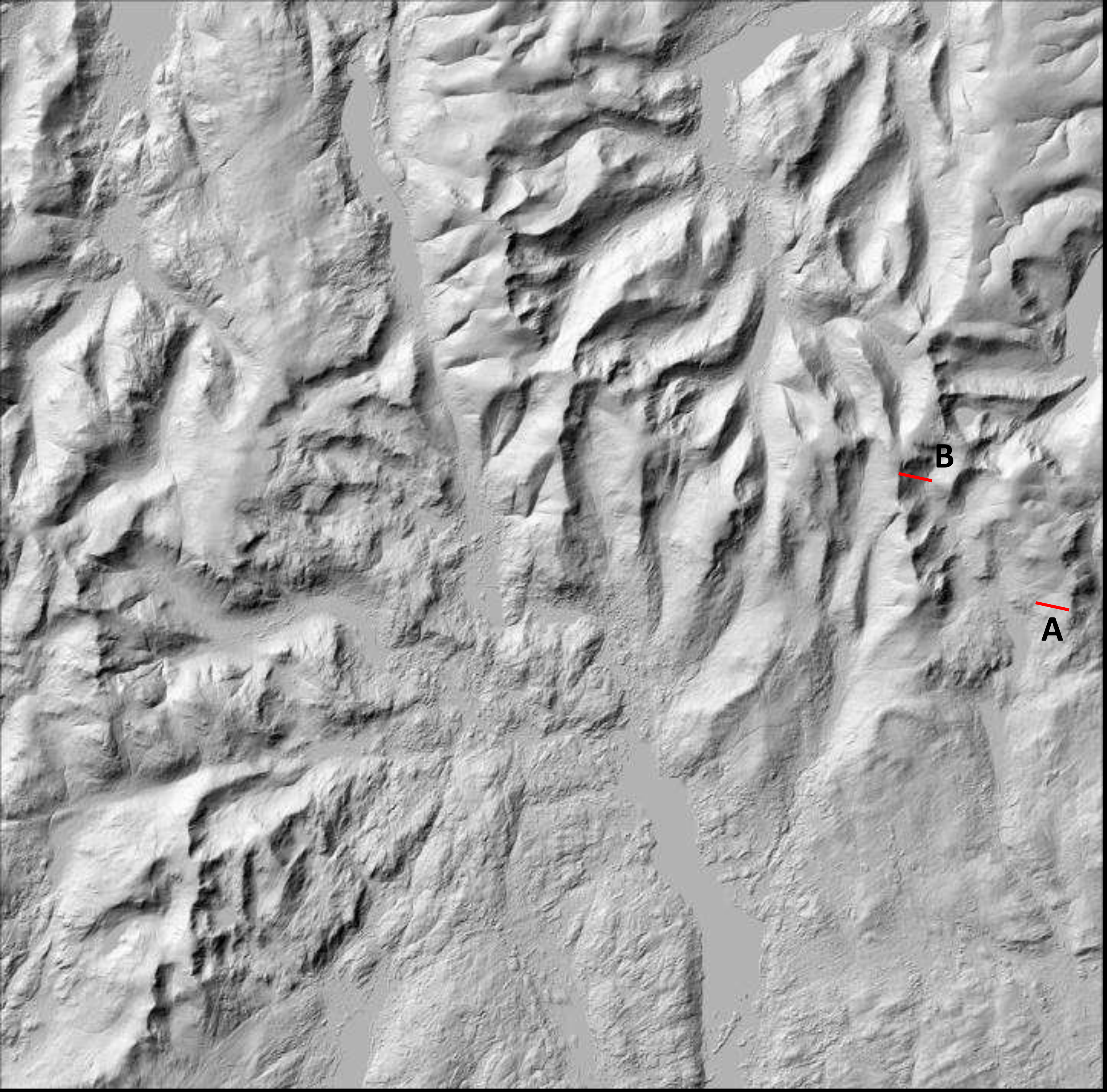
307



From which point is the red location visible?

A or B

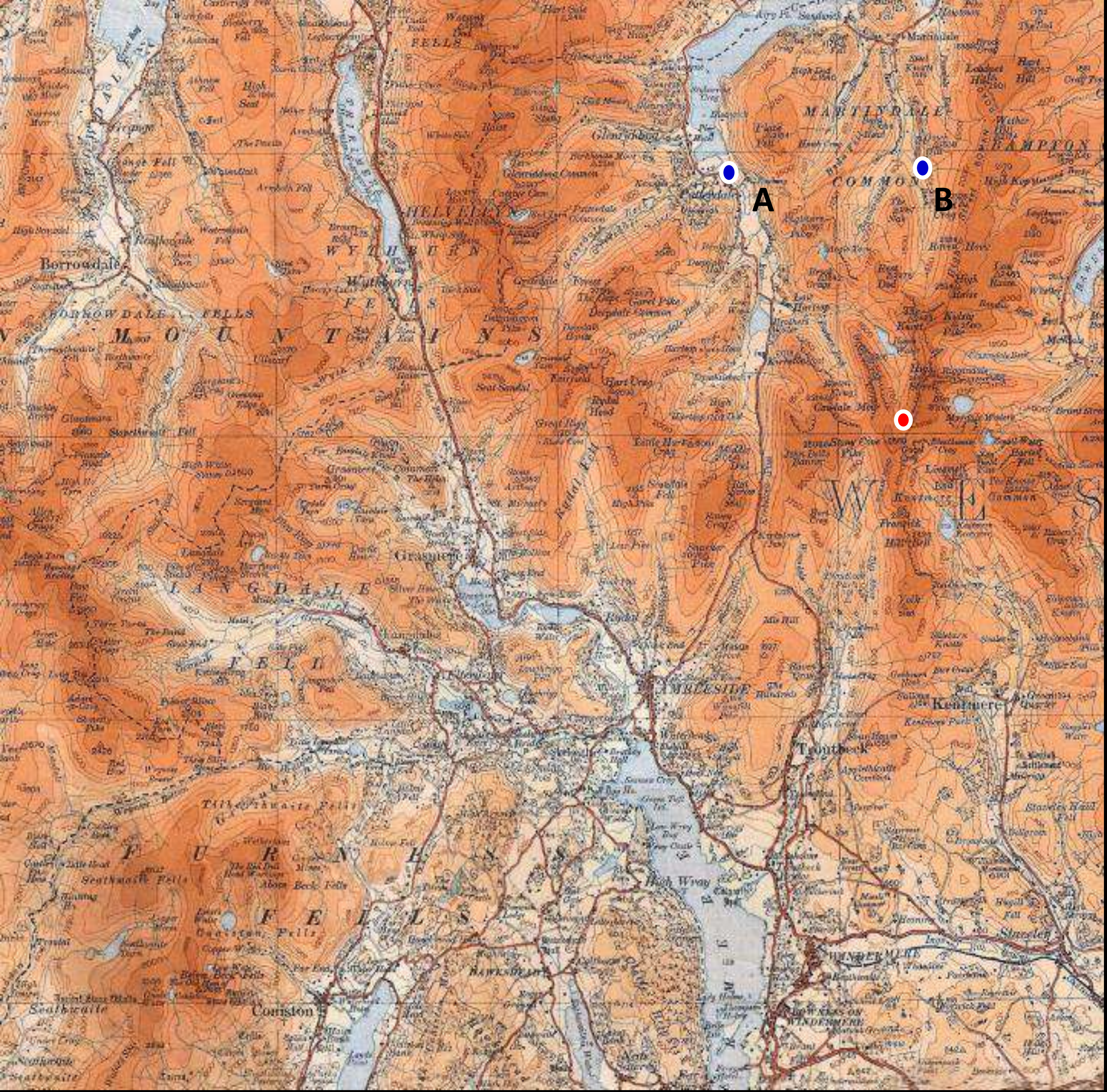
410



Which line follows the steepest path?

A or B

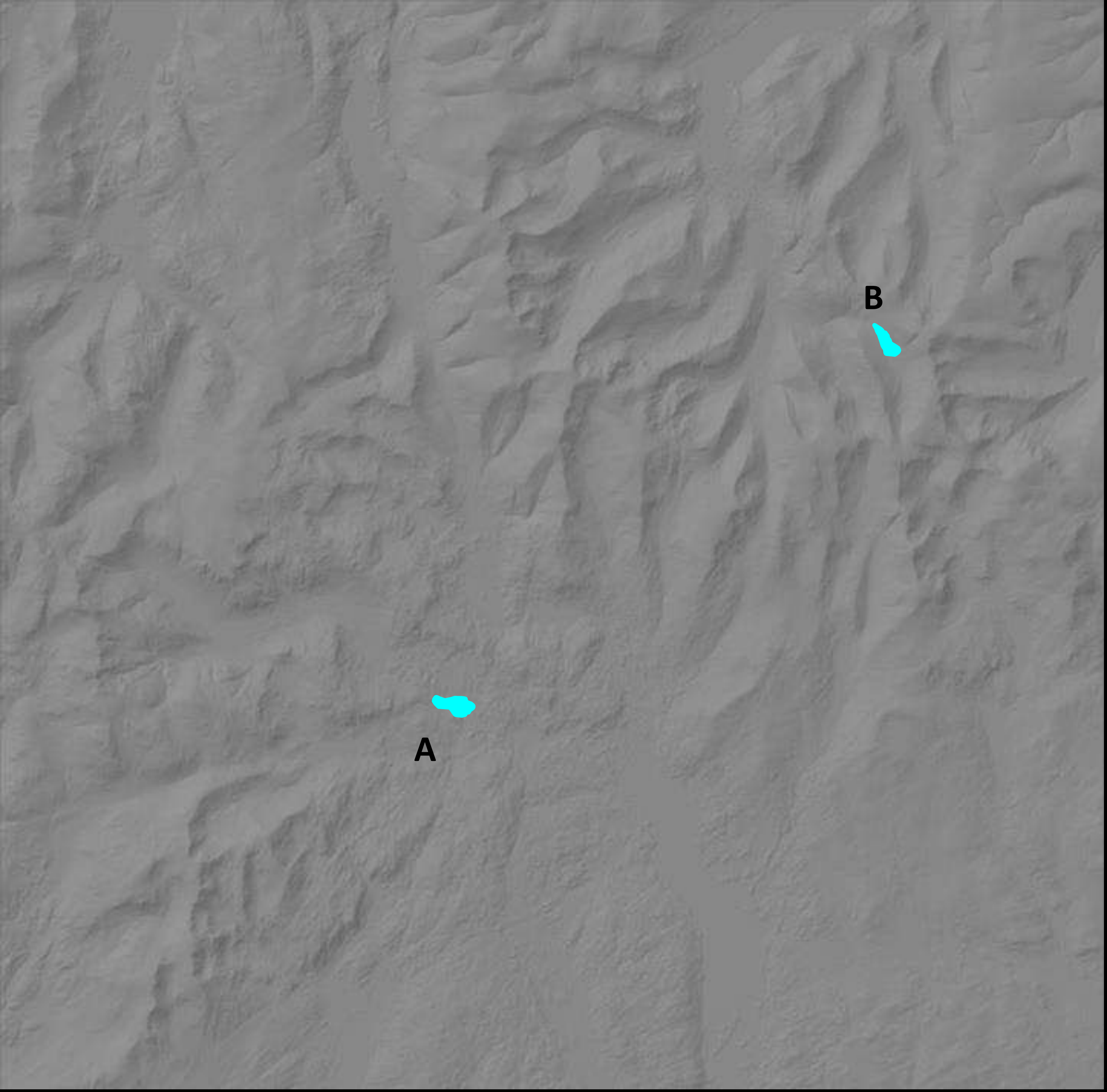
503



To which point would water flow from the red location?

A or B

605



Notice both lakes (blue area).

Which is the highest lake?

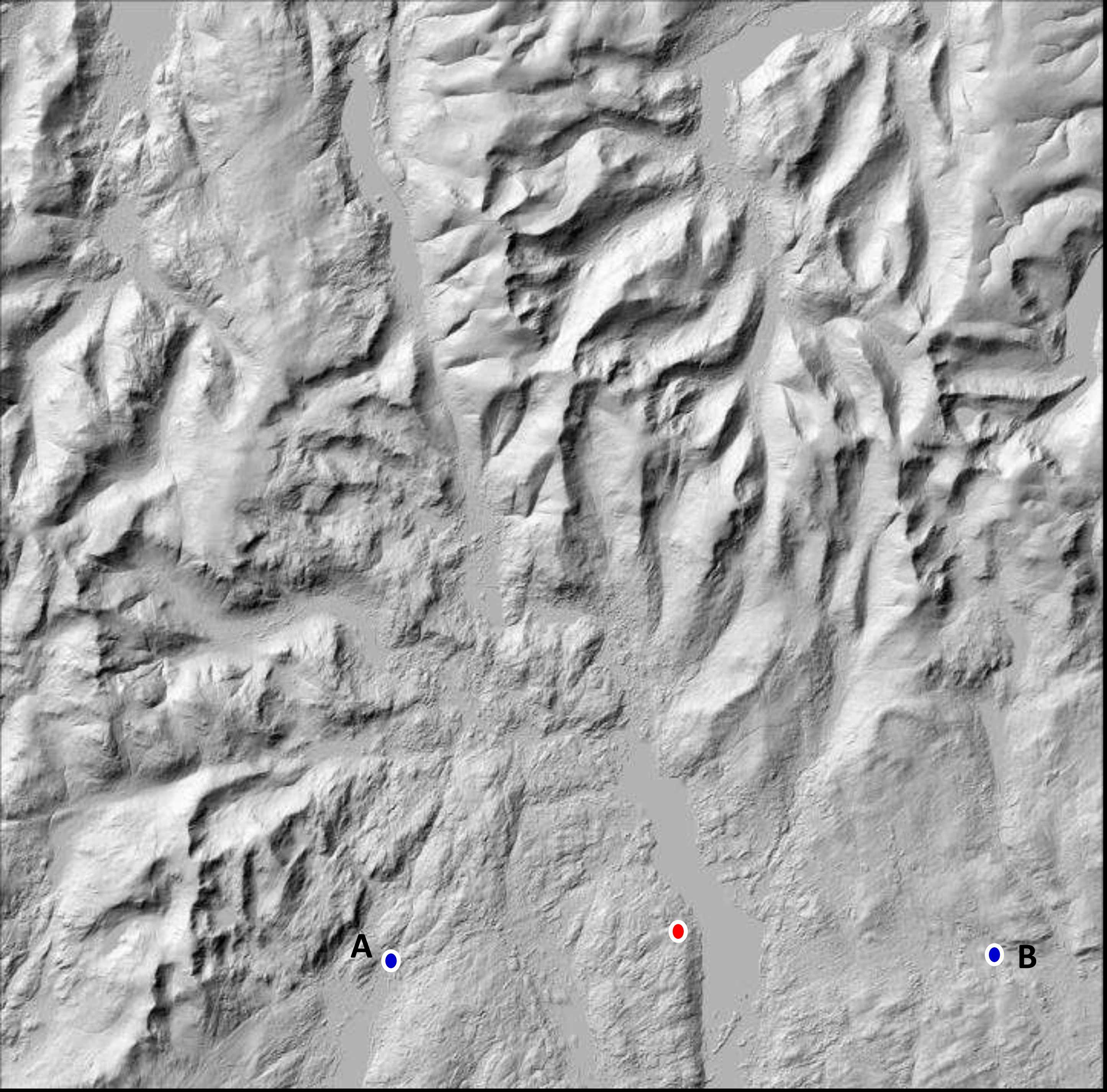
A or B

115

Notice both peaks (X sign). Which is the highest peak?

A or B

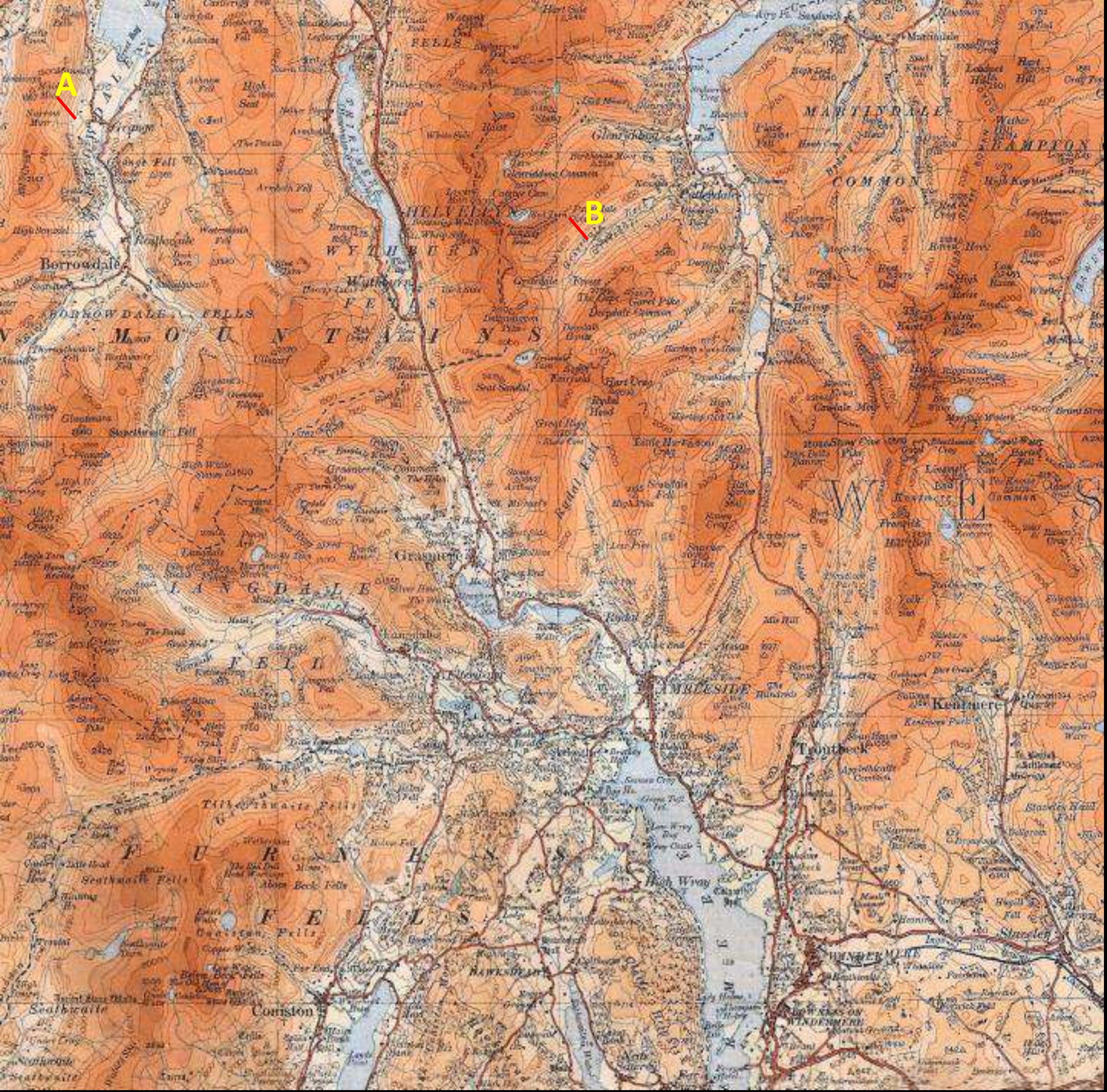
212



From which point is the red location visible?

A or B

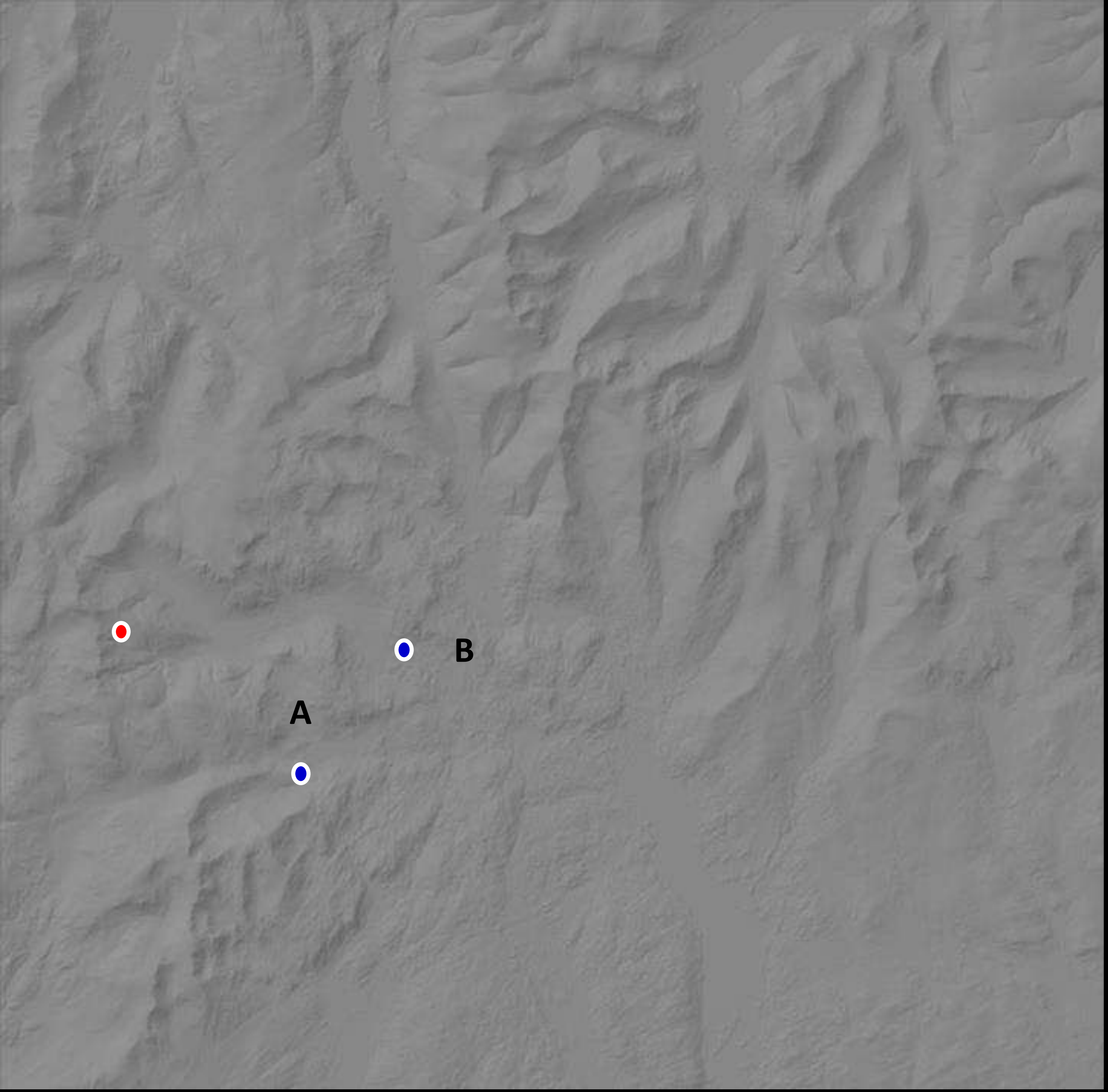
413



Which line follows the steepest path?

A or B

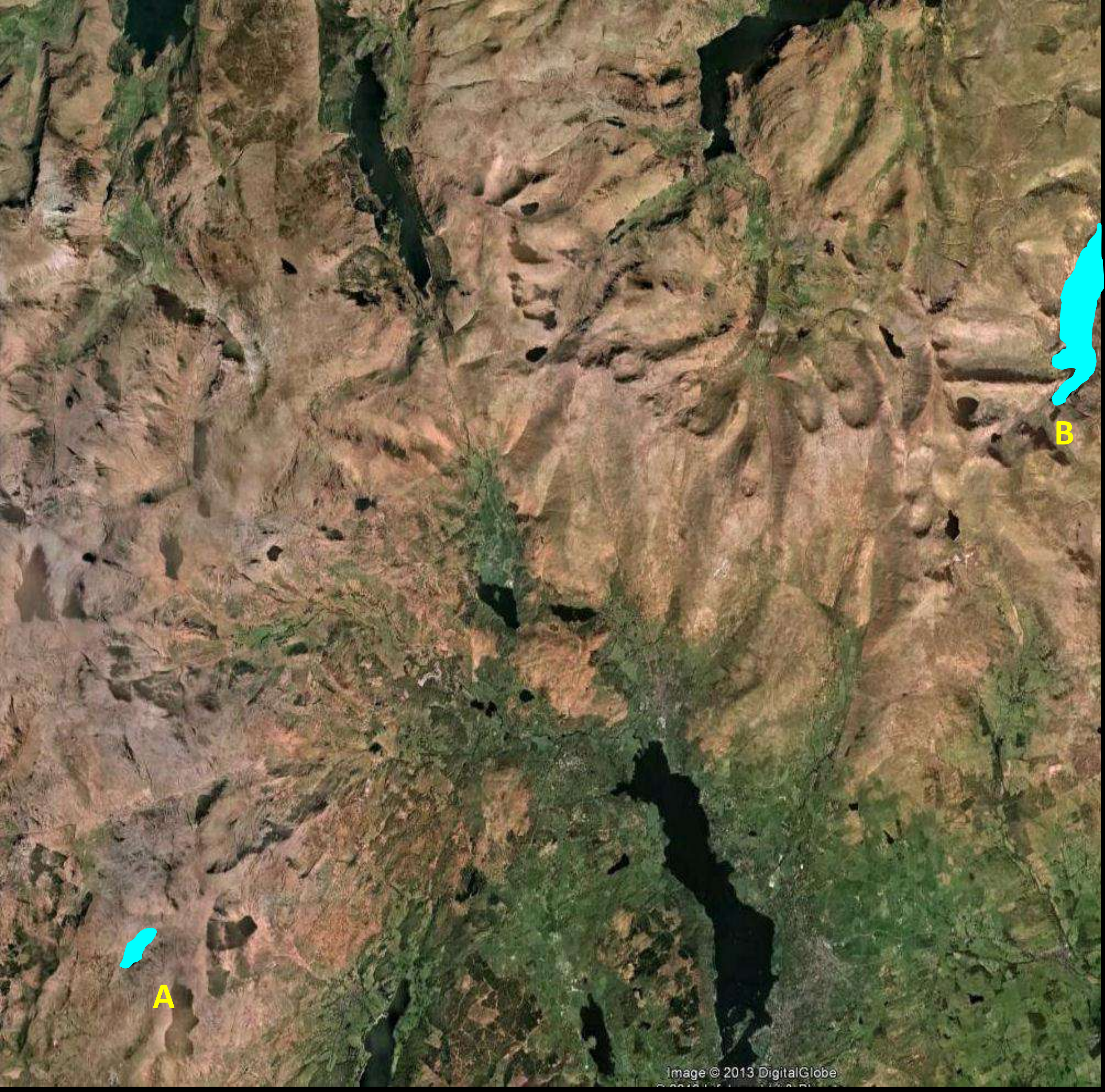
505



To which point would water flow from the red location?

A or B

615

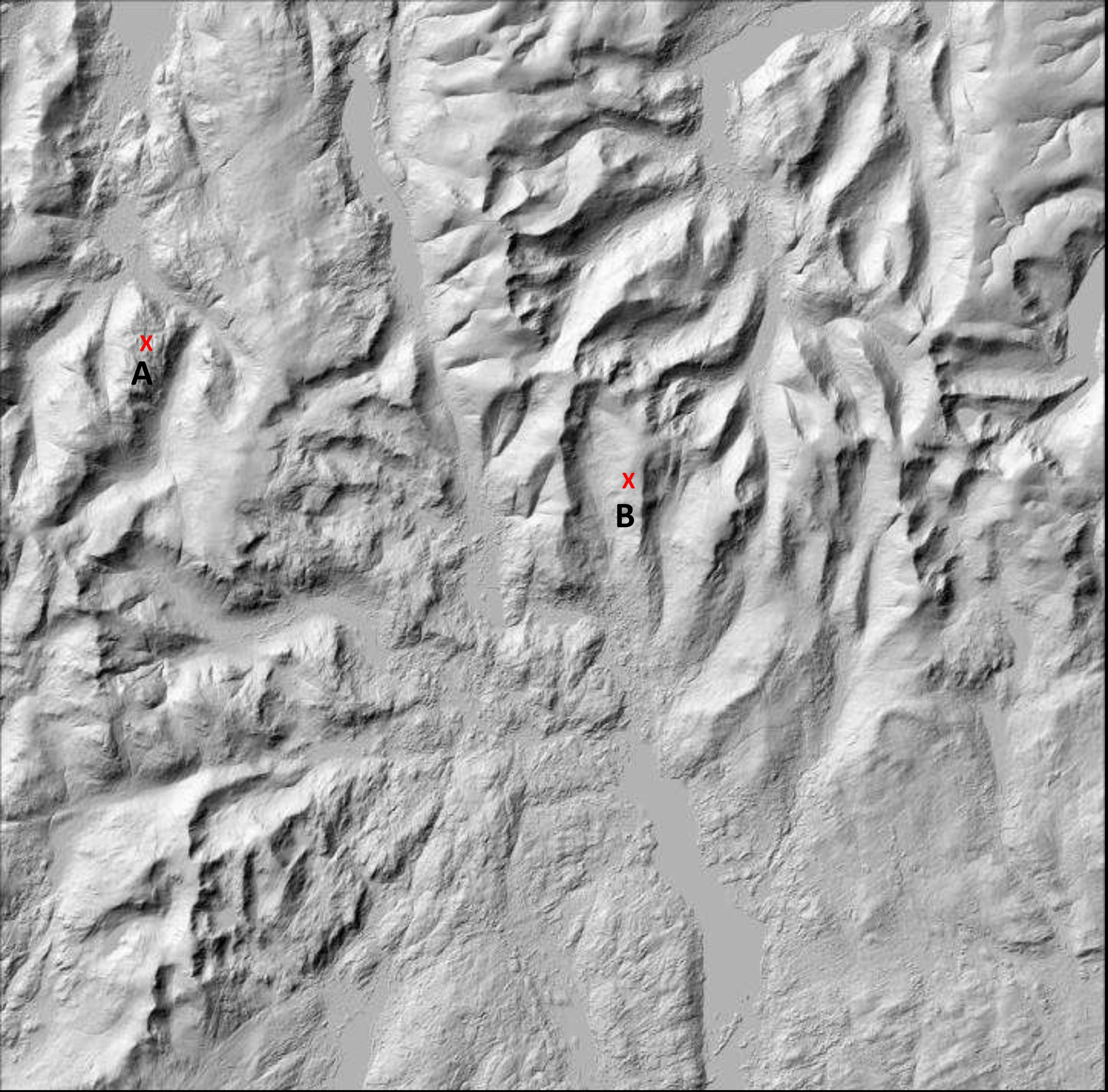


Notice both lakes (blue area).

Which is the highest lake?

A or B

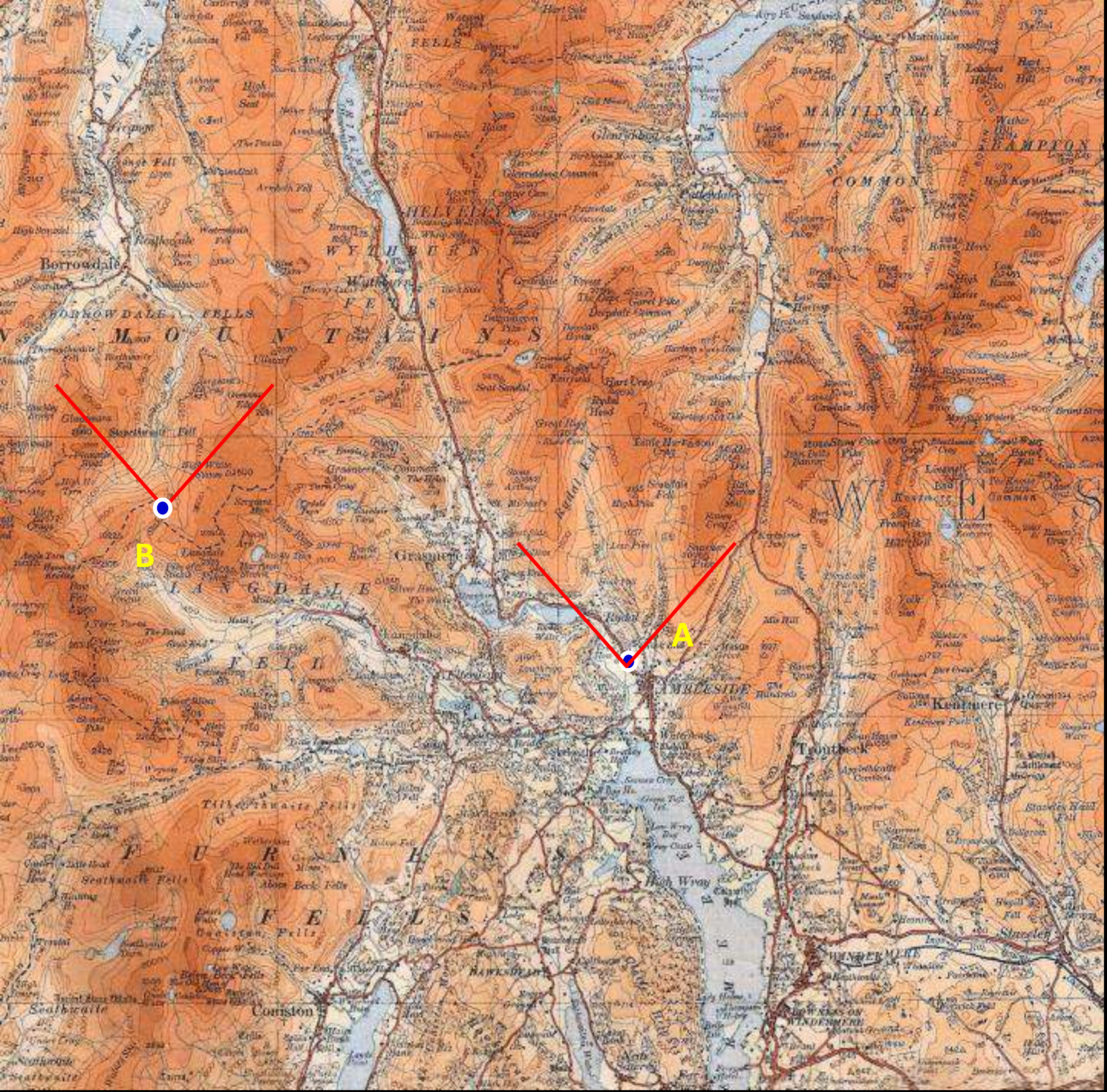
110



Notice both peaks (X sign). Which is the highest peak?

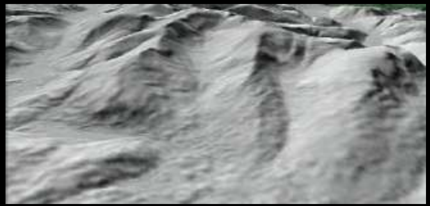
A or B

213

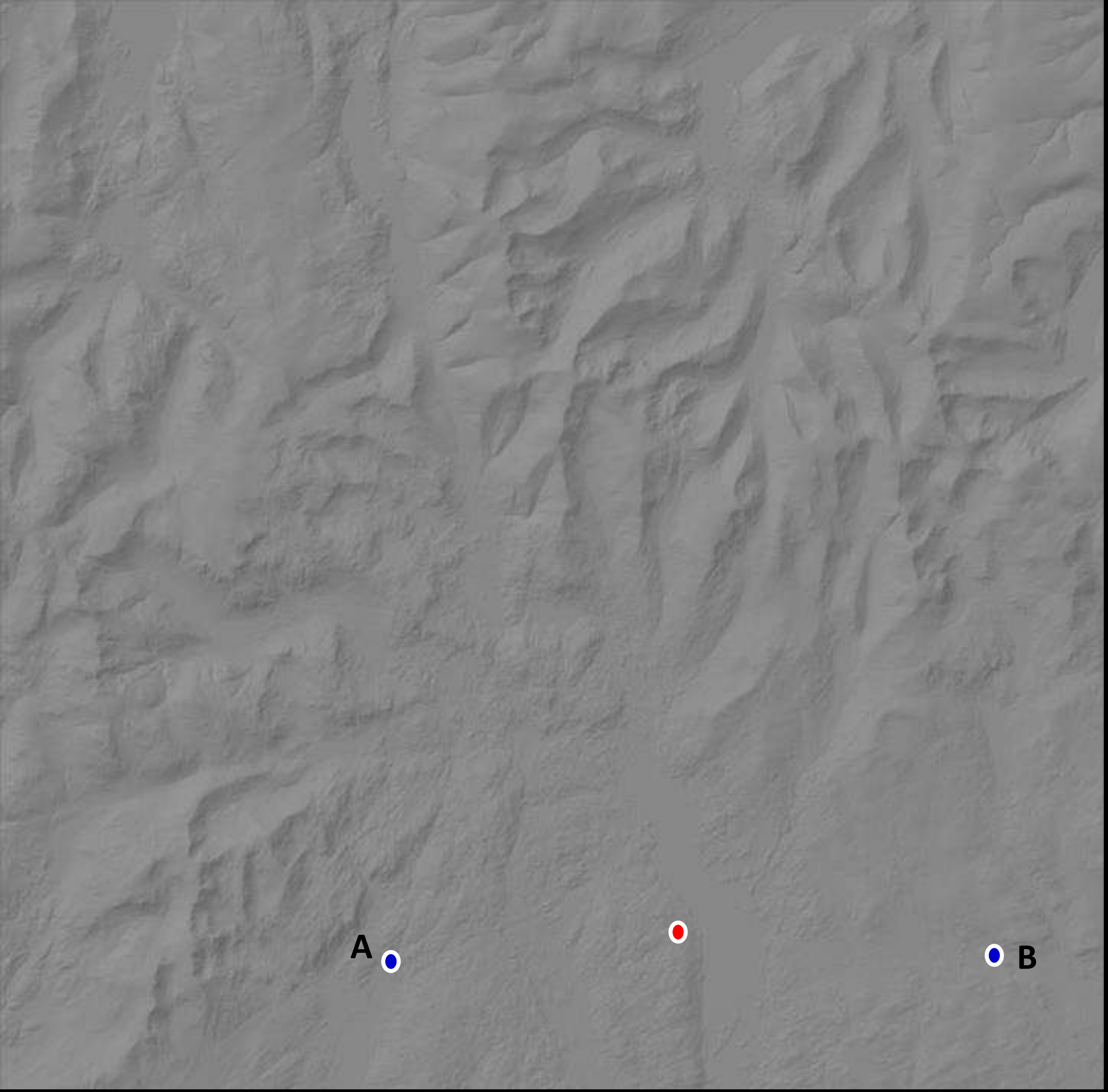


Which viewpoint matches the picture below?

A or B



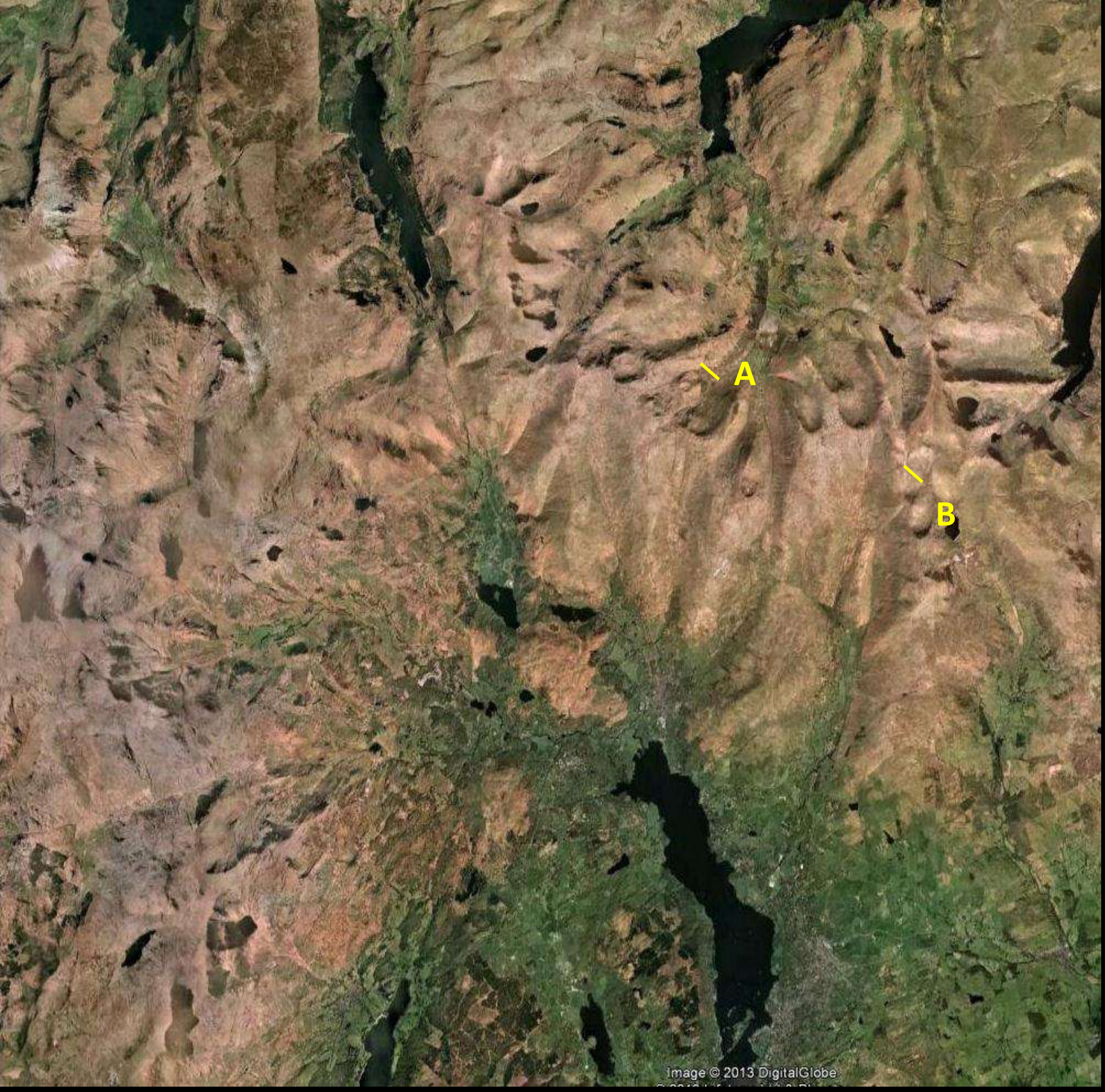
304



From which point is the red location visible?

A or B

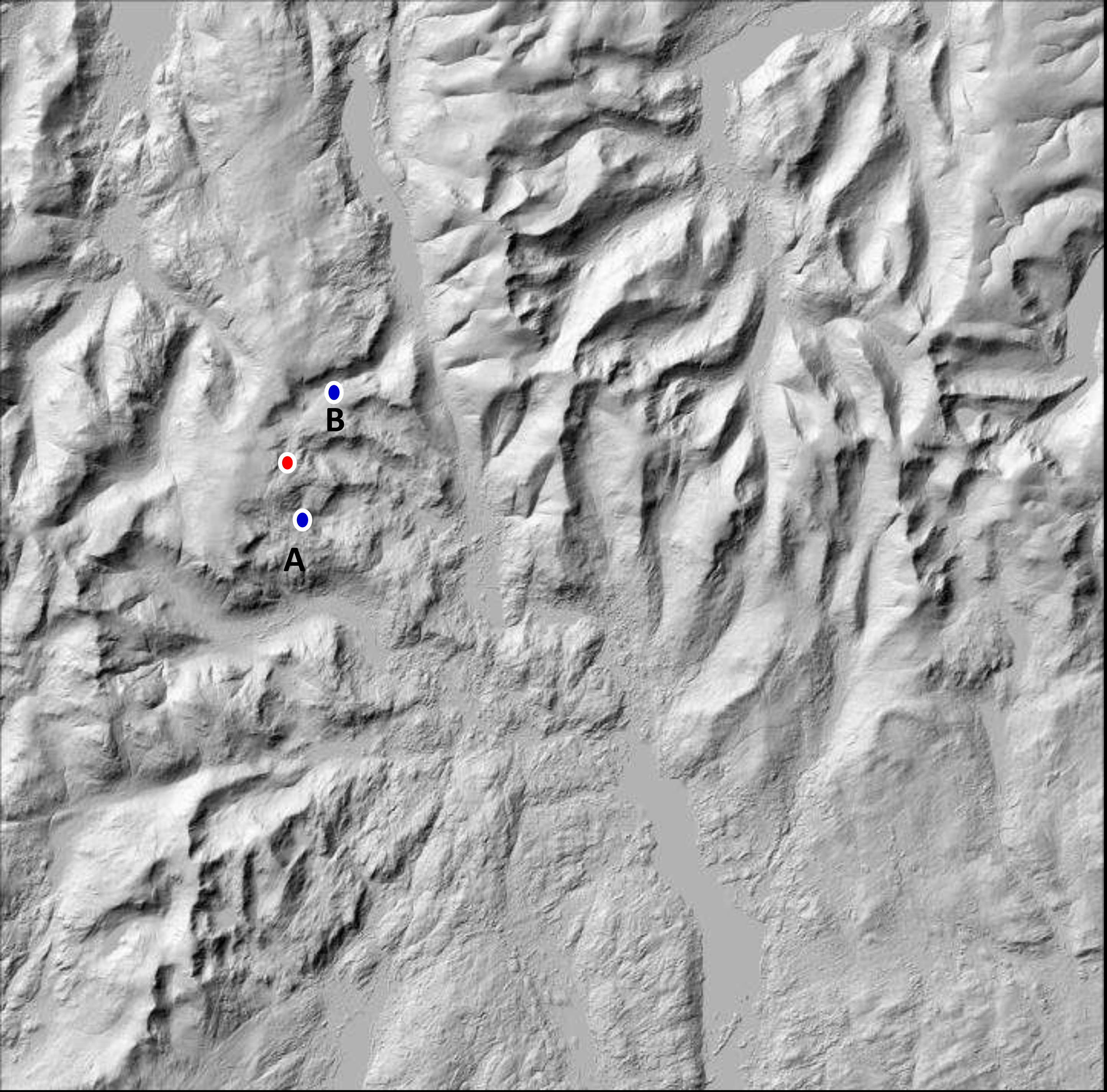
415



Which line follows the steepest path?

A or B

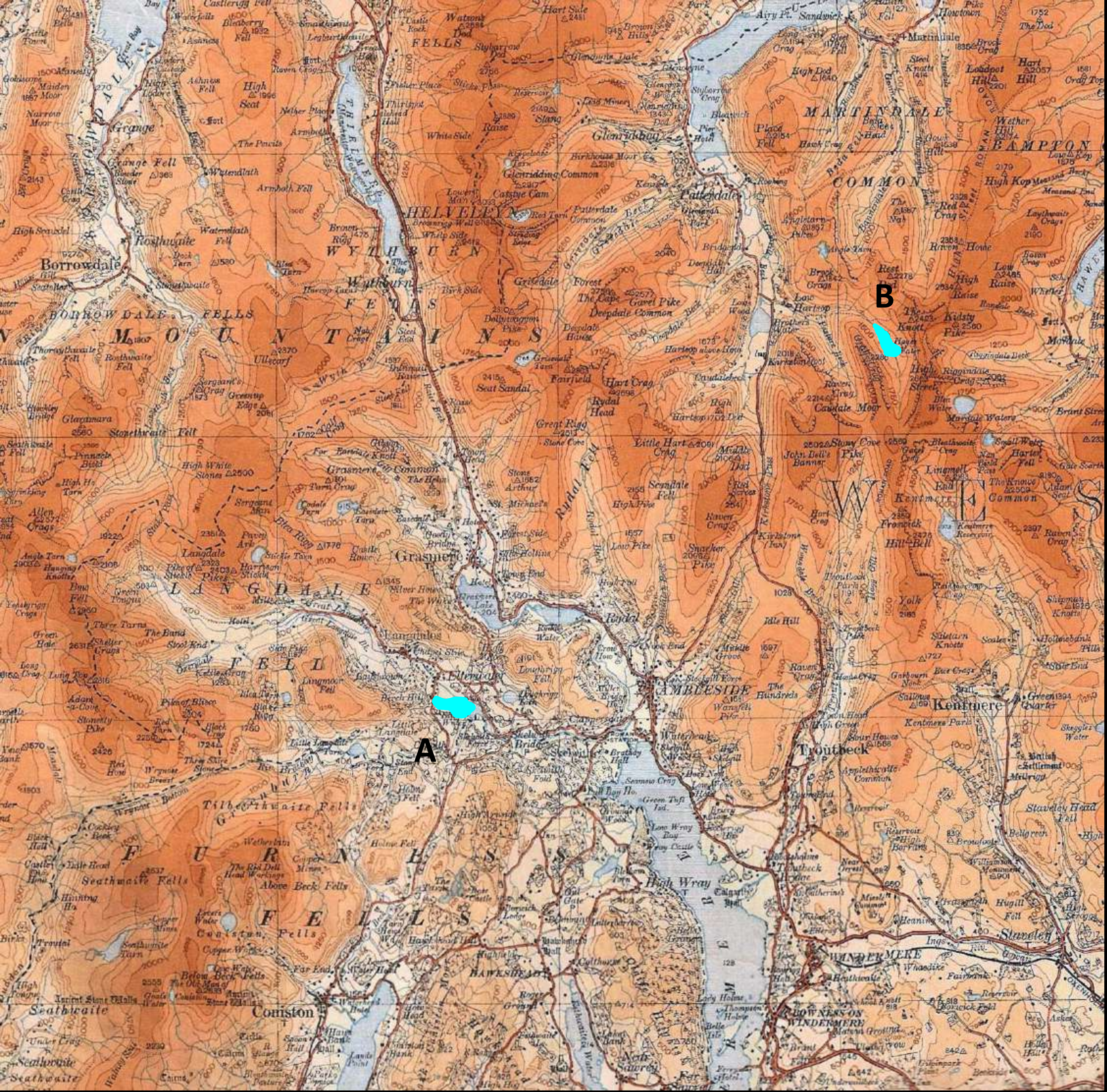
510c



To which point would water flow from the red location?

A or B

601

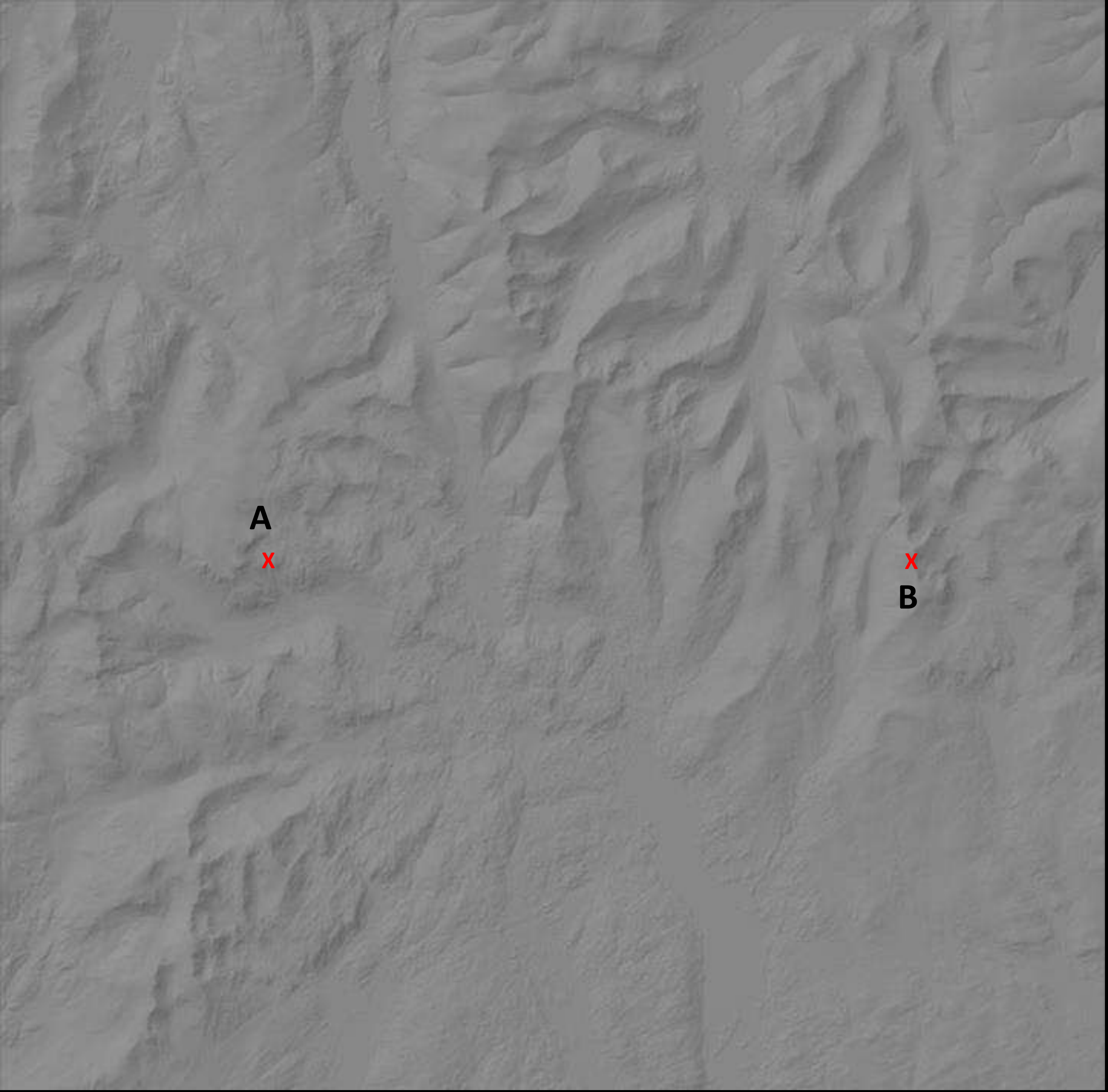


Notice both lakes (blue area).

Which is the highest lake?

A or B

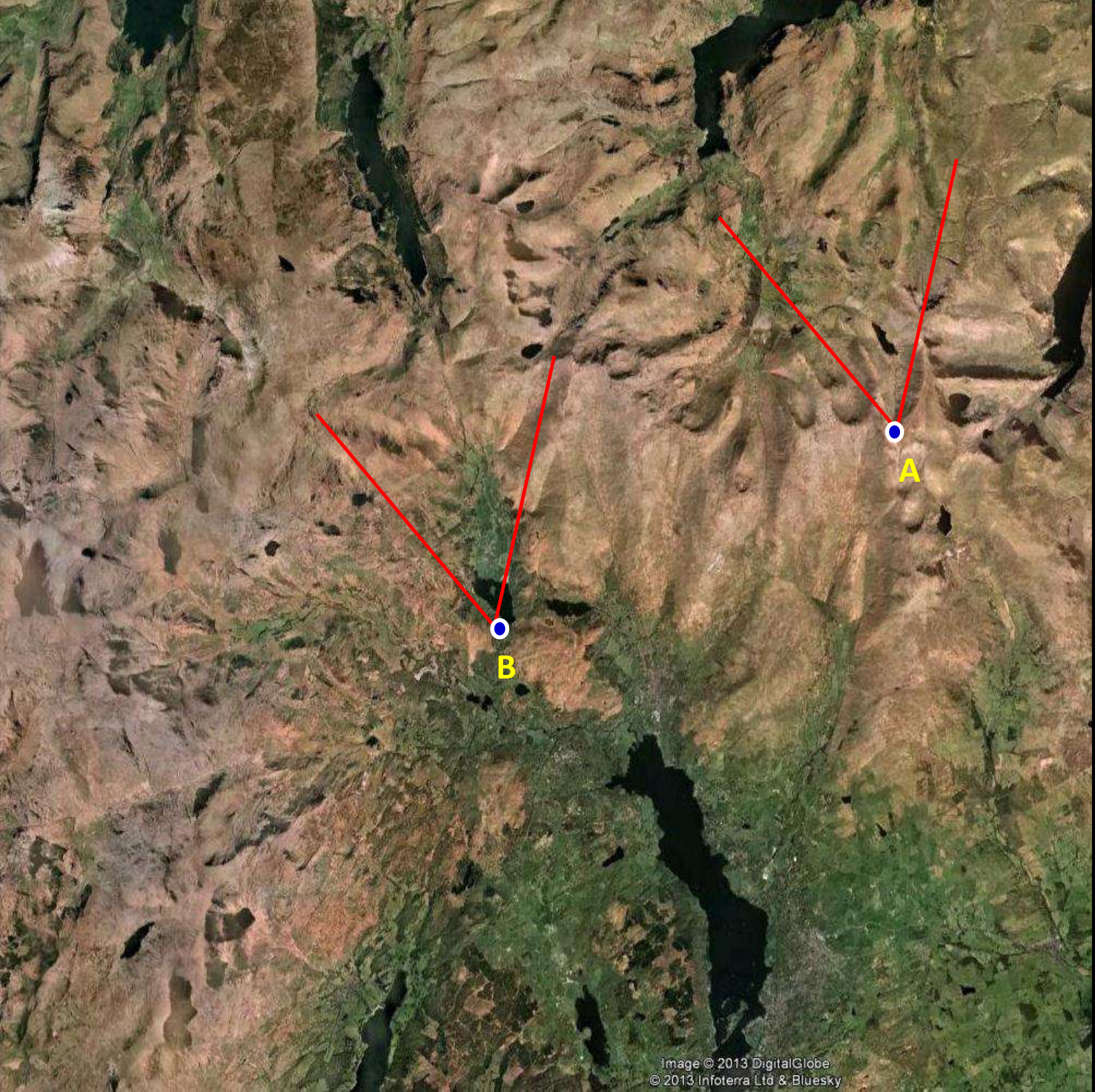
114



Notice both peaks (X sign). Which is the highest peak?

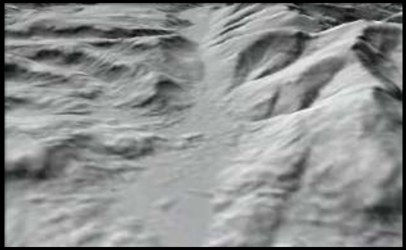
A or B

208

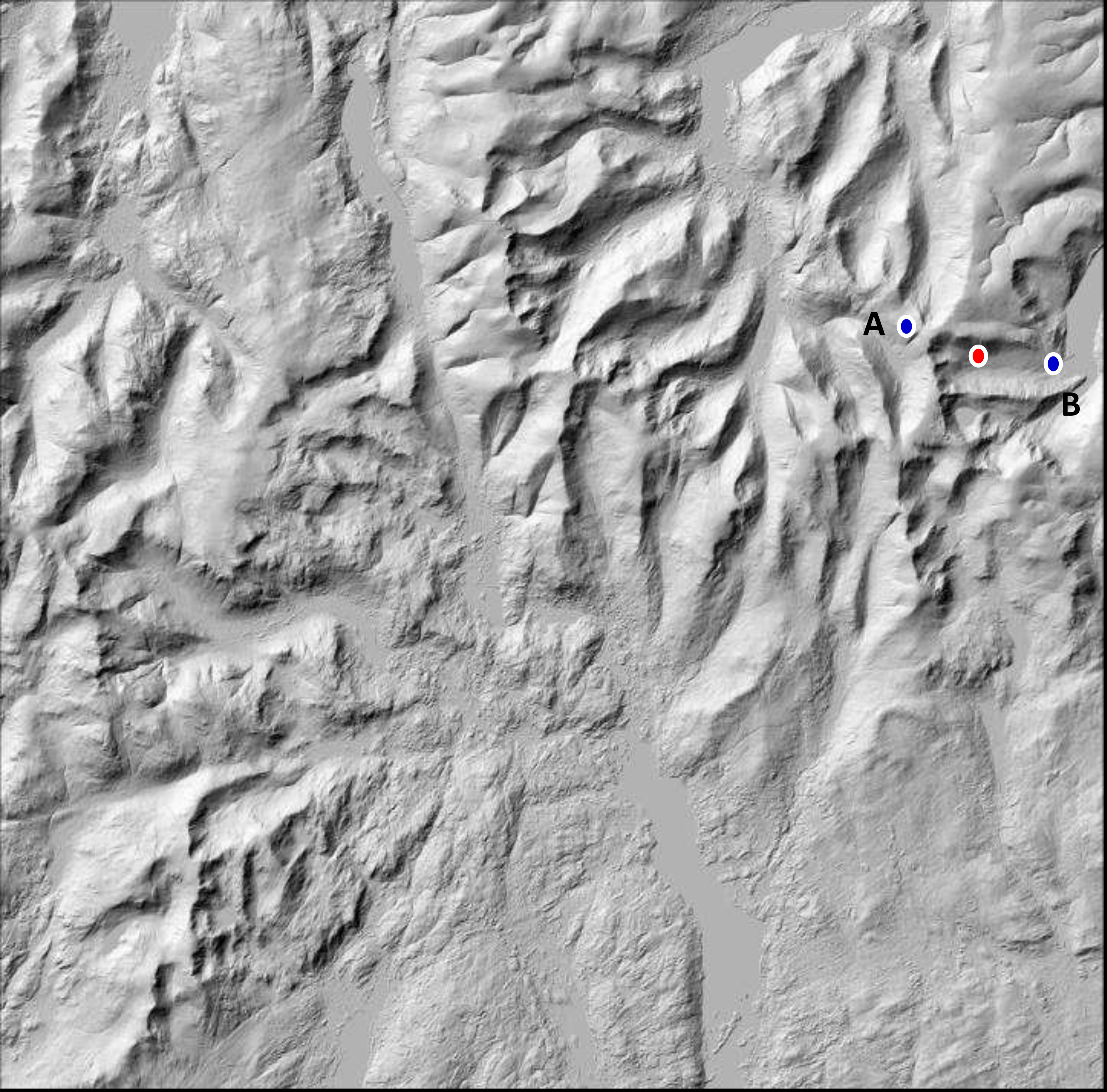


Which viewpoint matches the picture below?

A or B

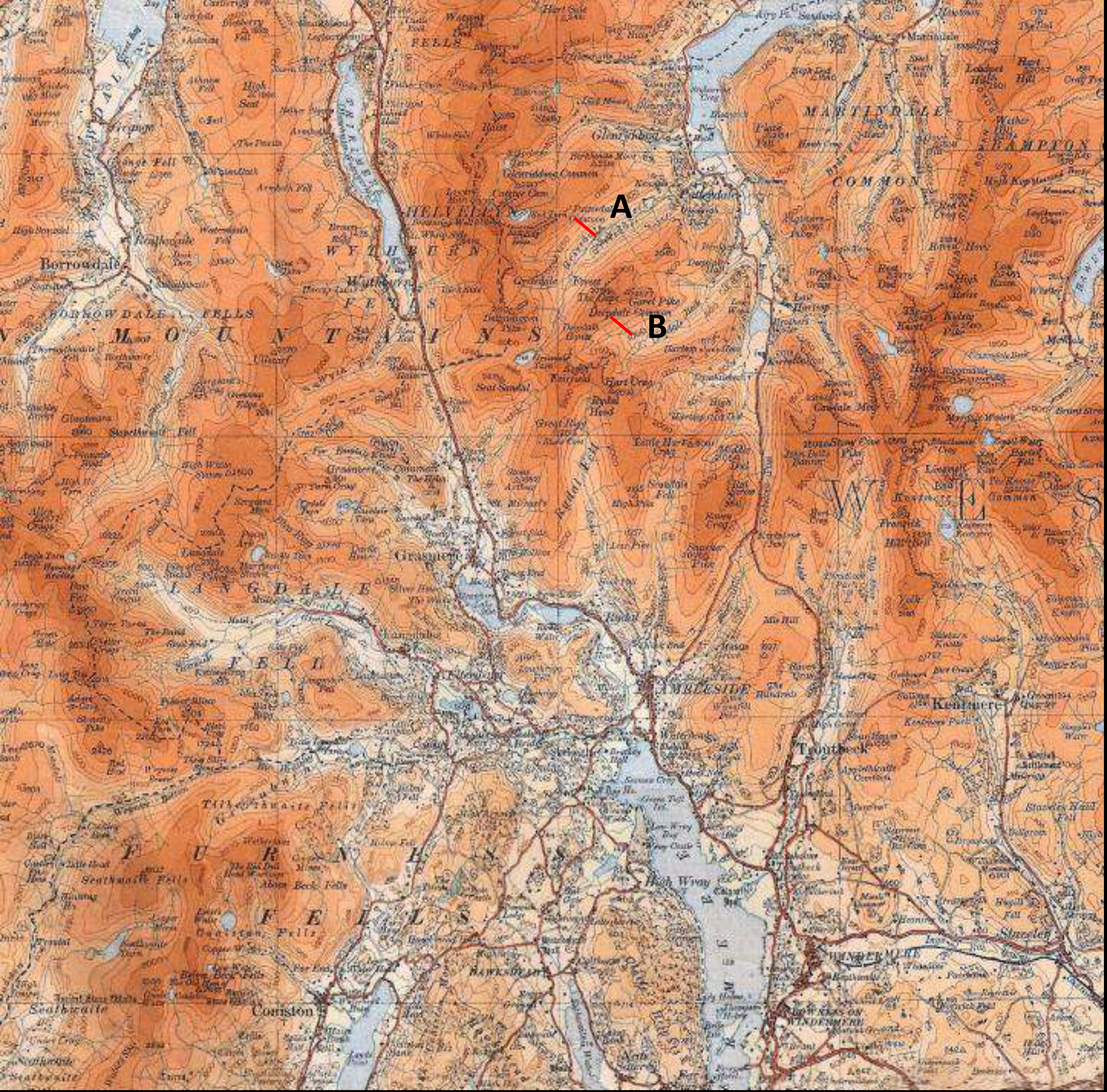


316



From which point is the red location visible?
A or B

401



Which line follows the steepest path?

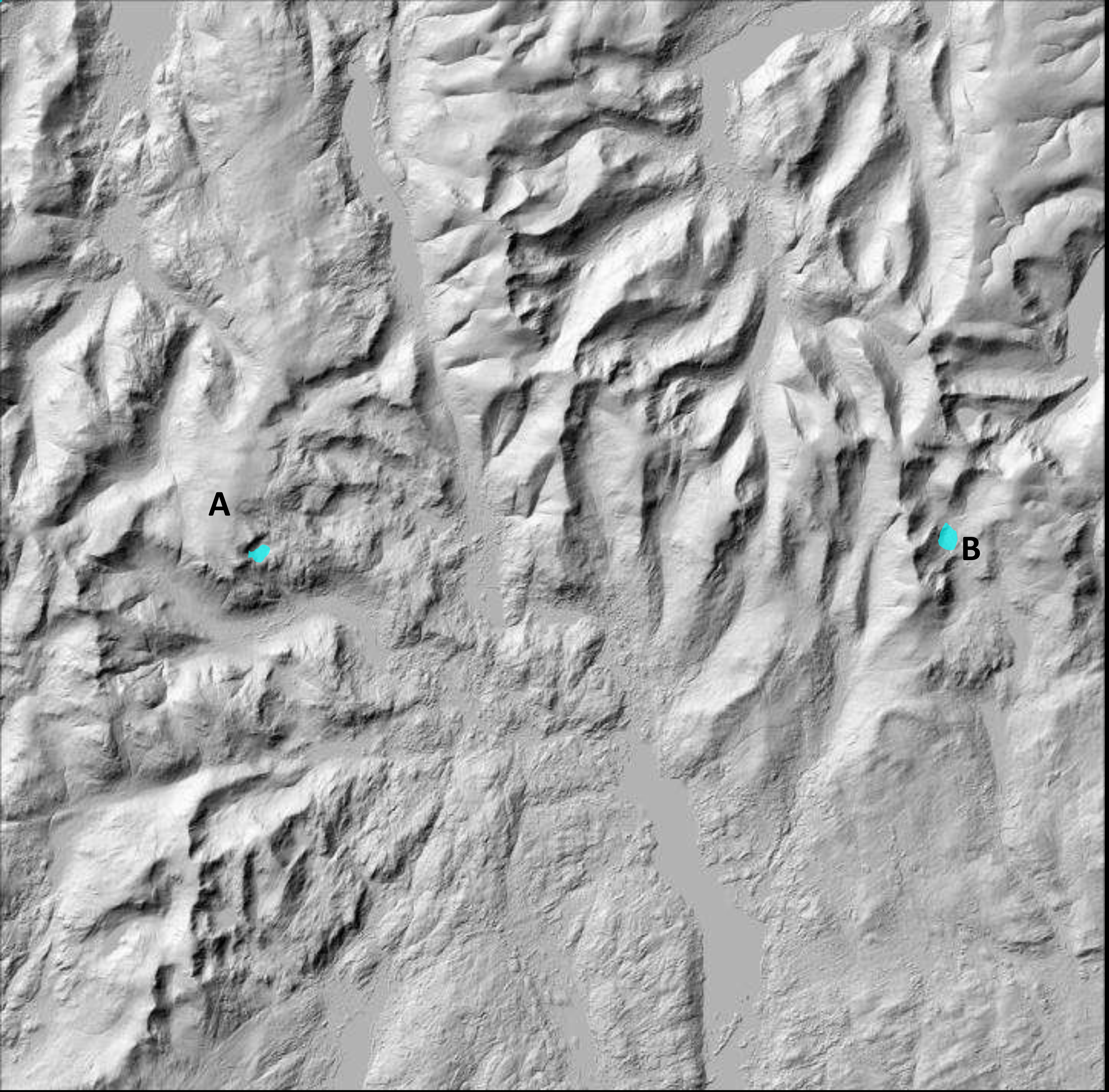
A or B

514

To which point would water flow from the red location?

A or B

610

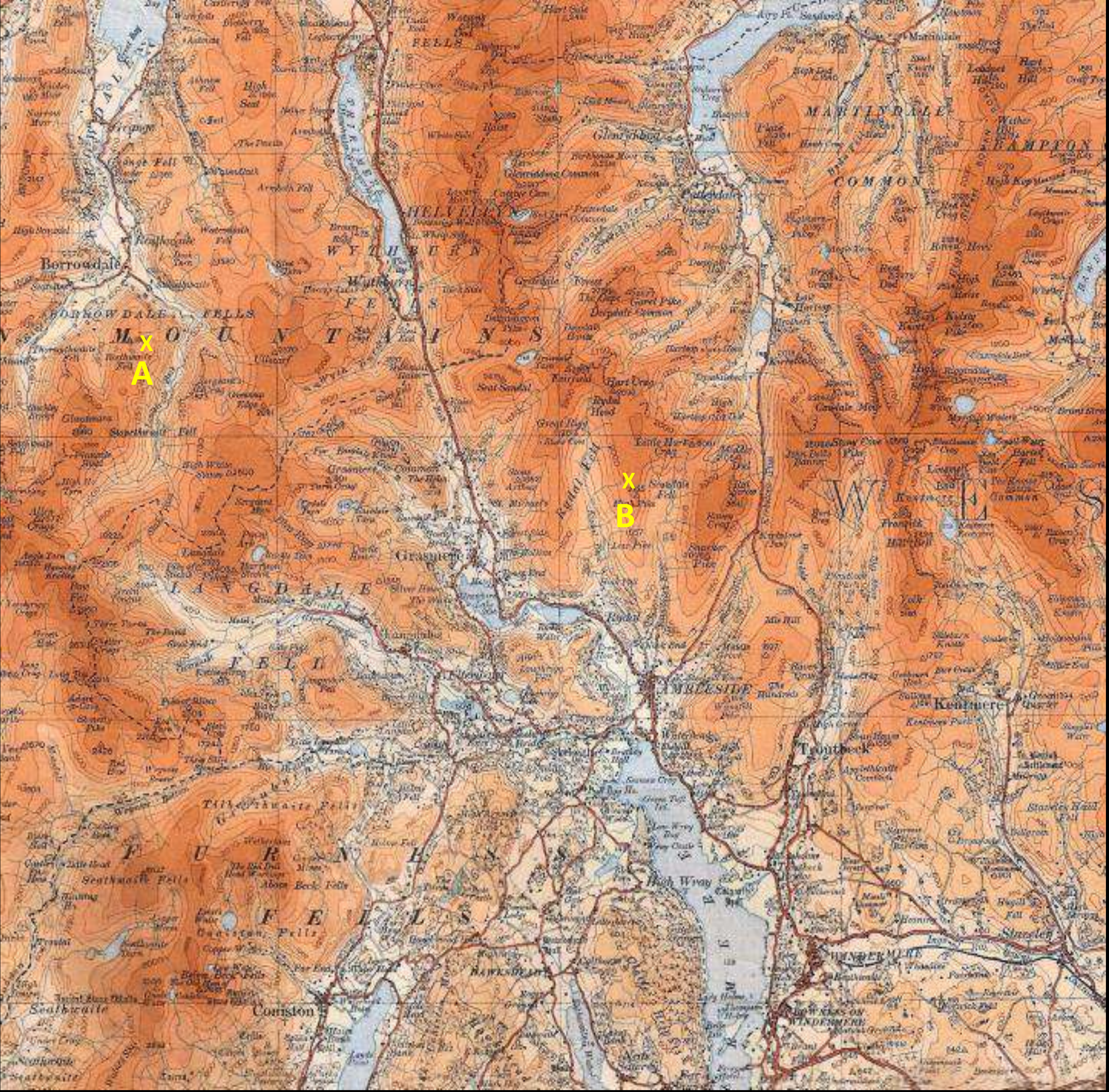


Notice both lakes (blue area).

Which is the highest lake?

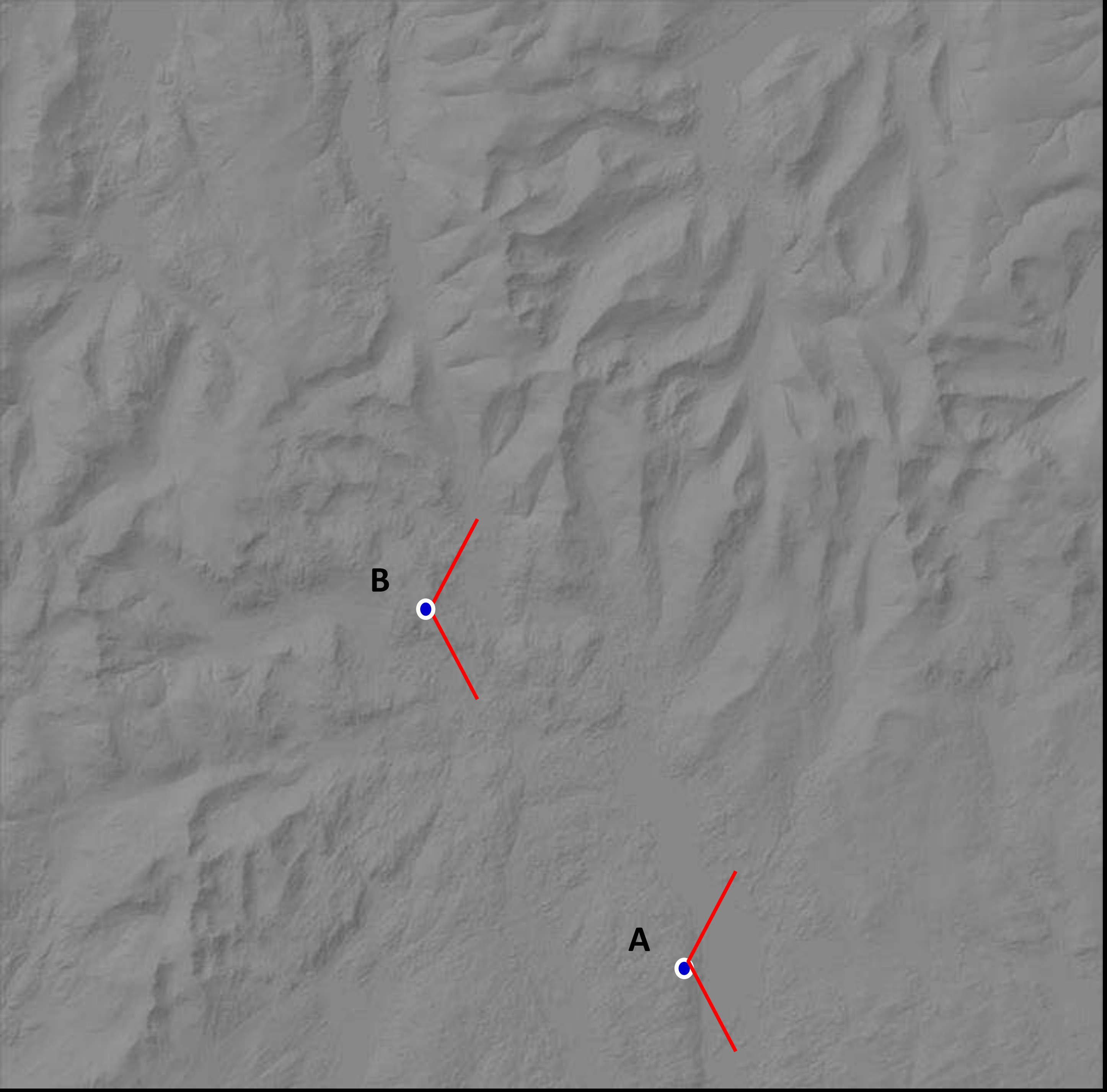
A or B

102



Notice both peaks (X sign). Which is the highest peak?

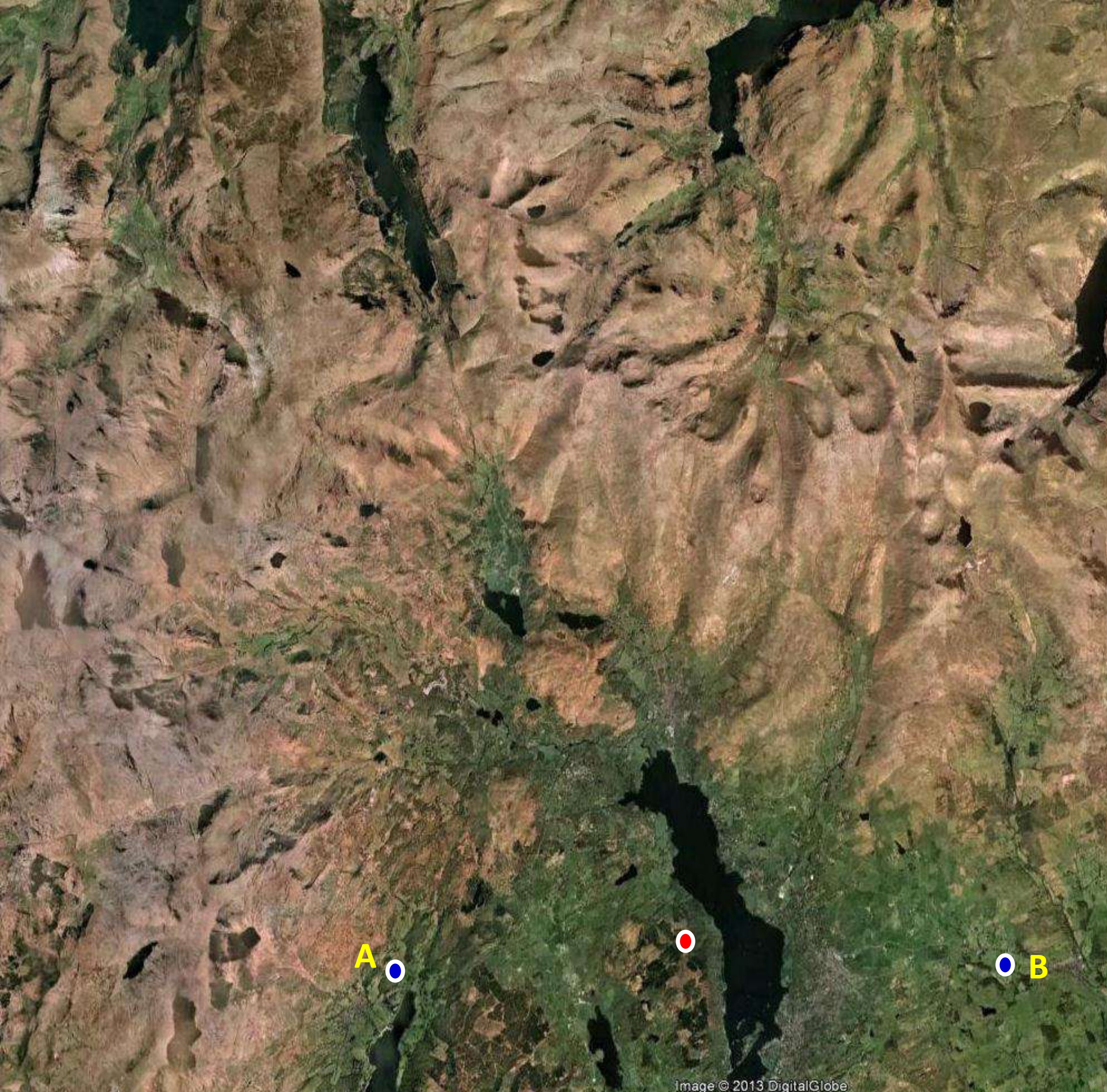
A or B



Which viewpoint matches the picture below?

A or B

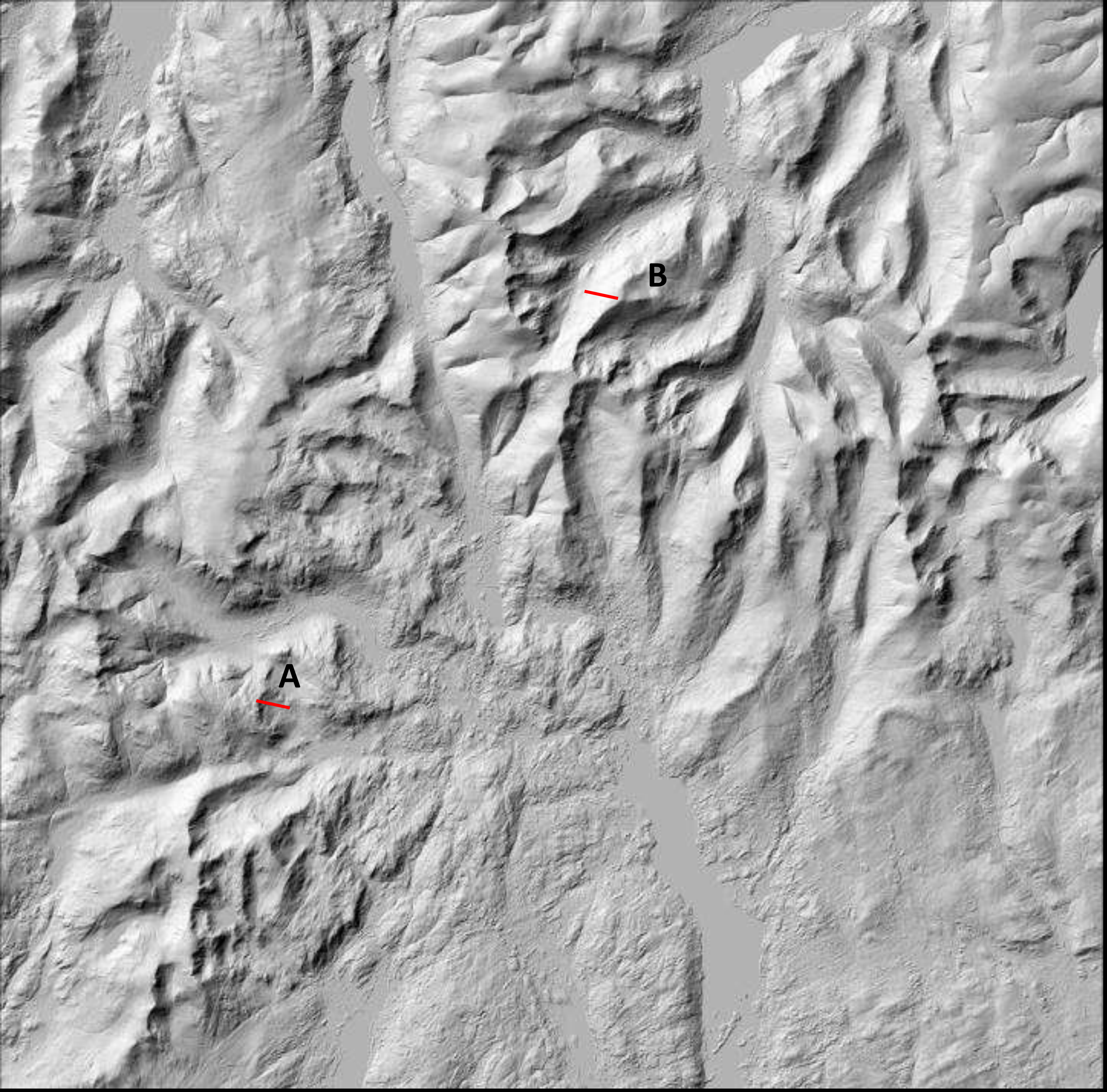
309



From which point is the red location visible?

A or B

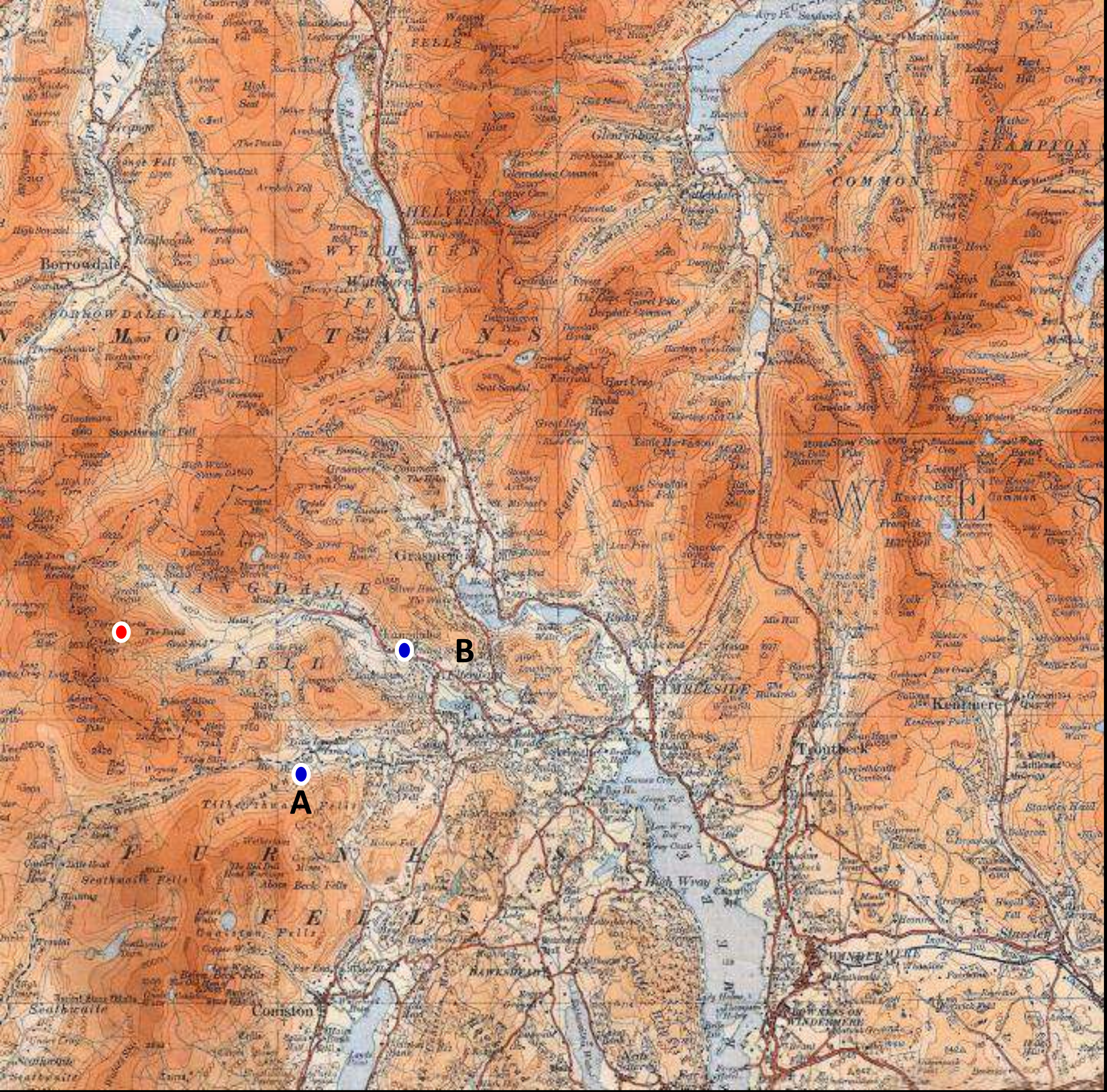
416



Which line follows the steepest path?

A or B

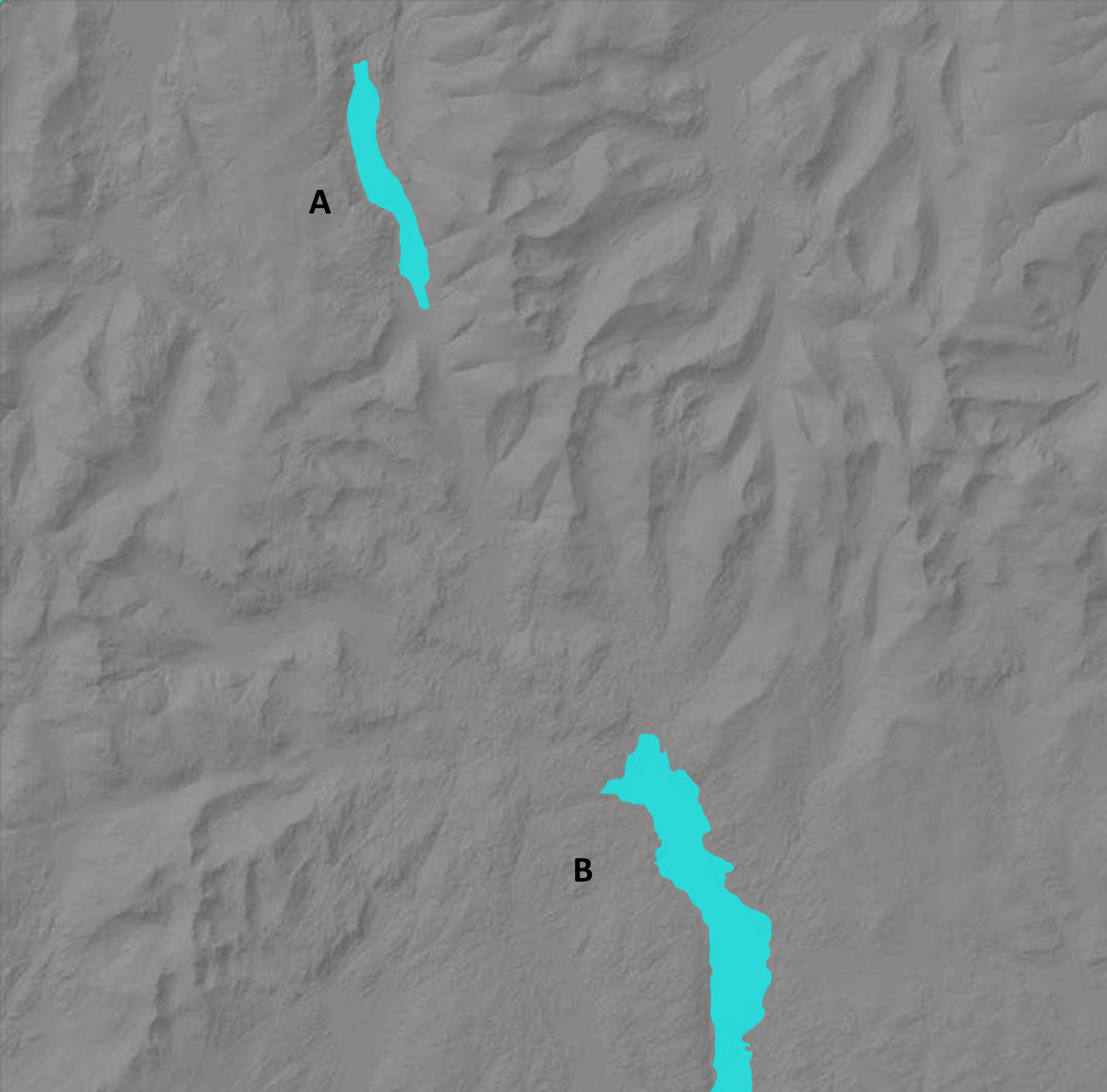
501



To which point would water flow from the red location?

A or B

614



Notice both lakes (blue area).

Which is the highest lake?

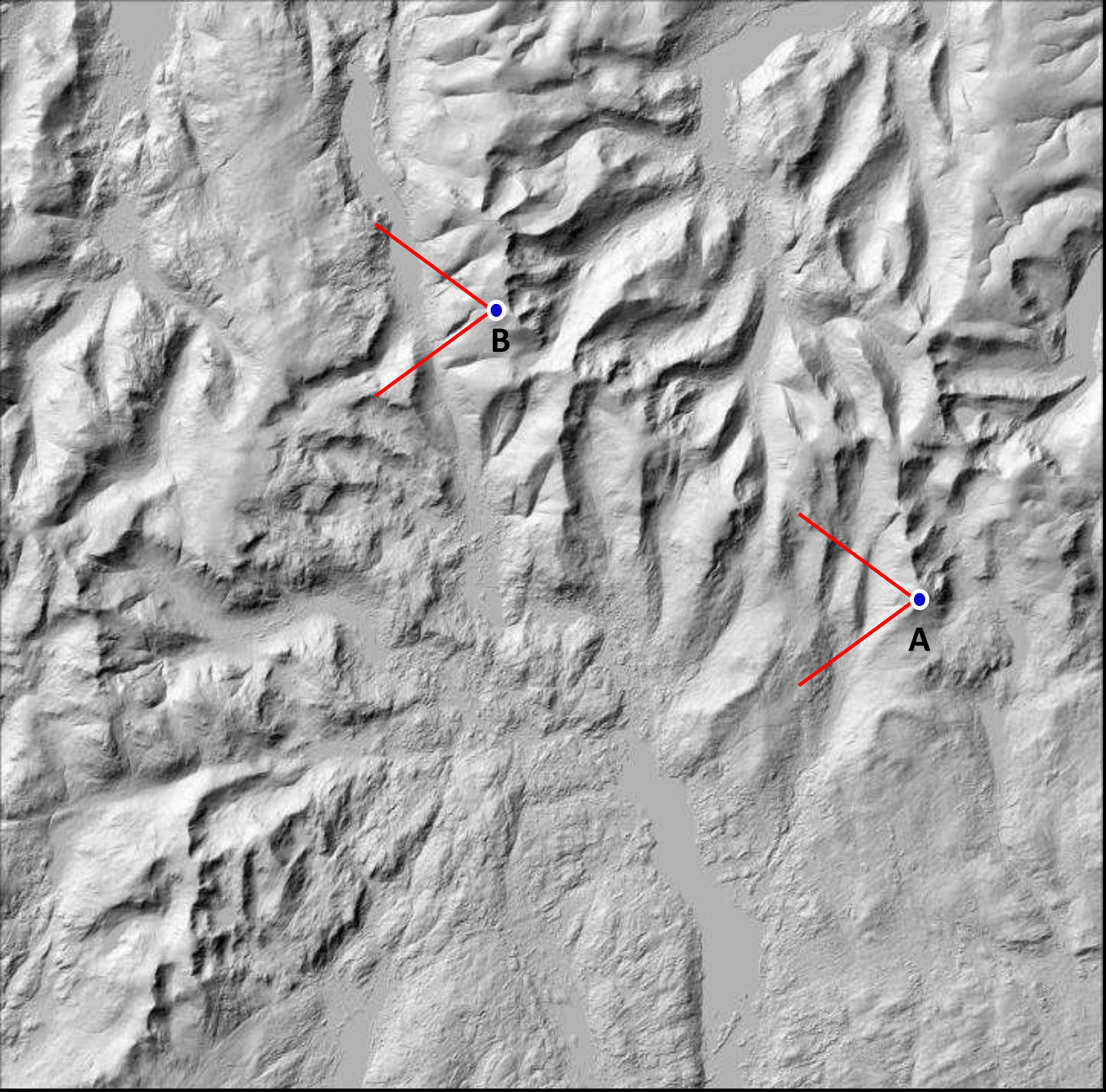
A or B

107

Notice both peaks (X sign). Which is the highest peak?

A or B

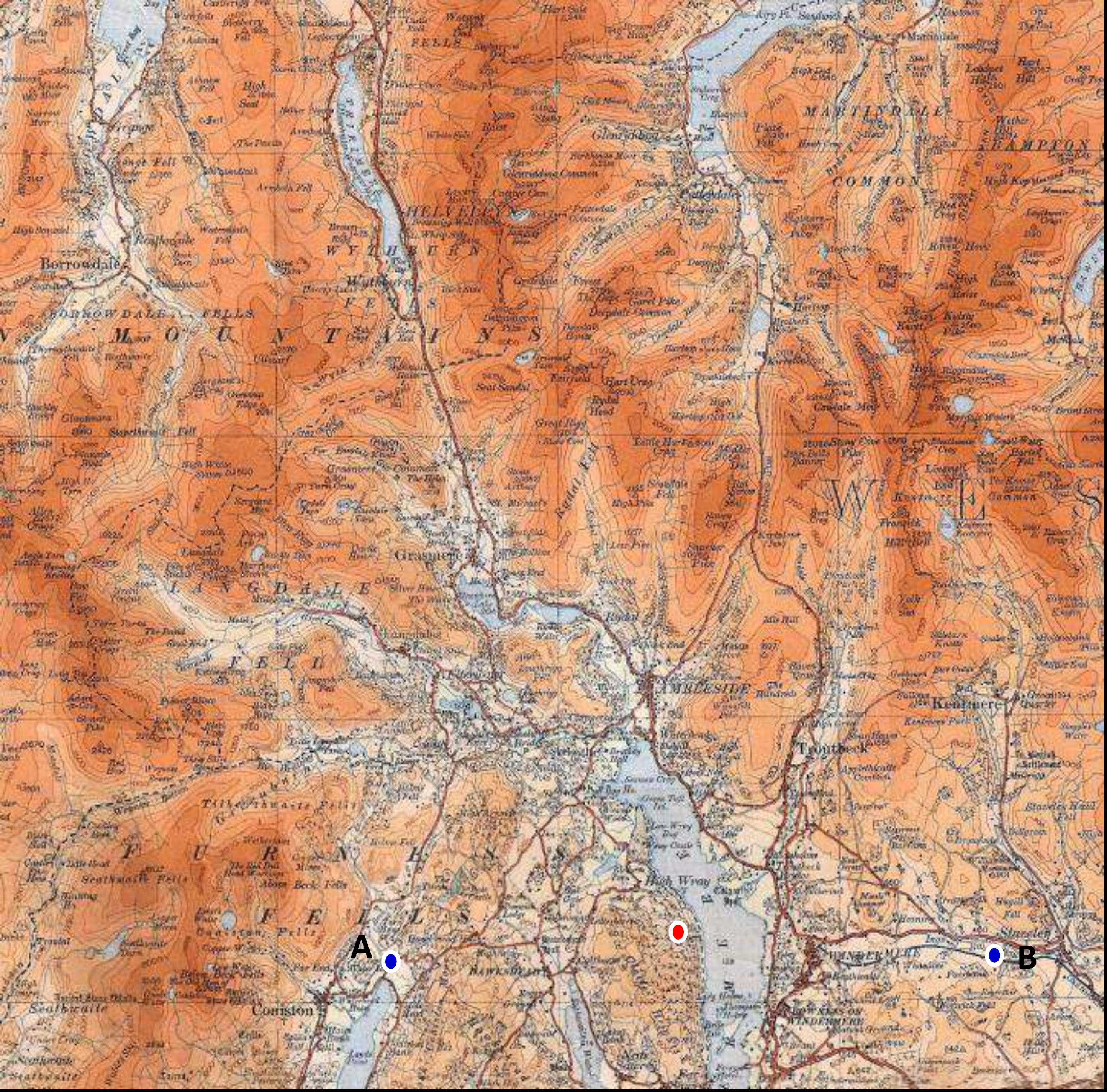
216



Which viewpoint matches the picture below?

A or B

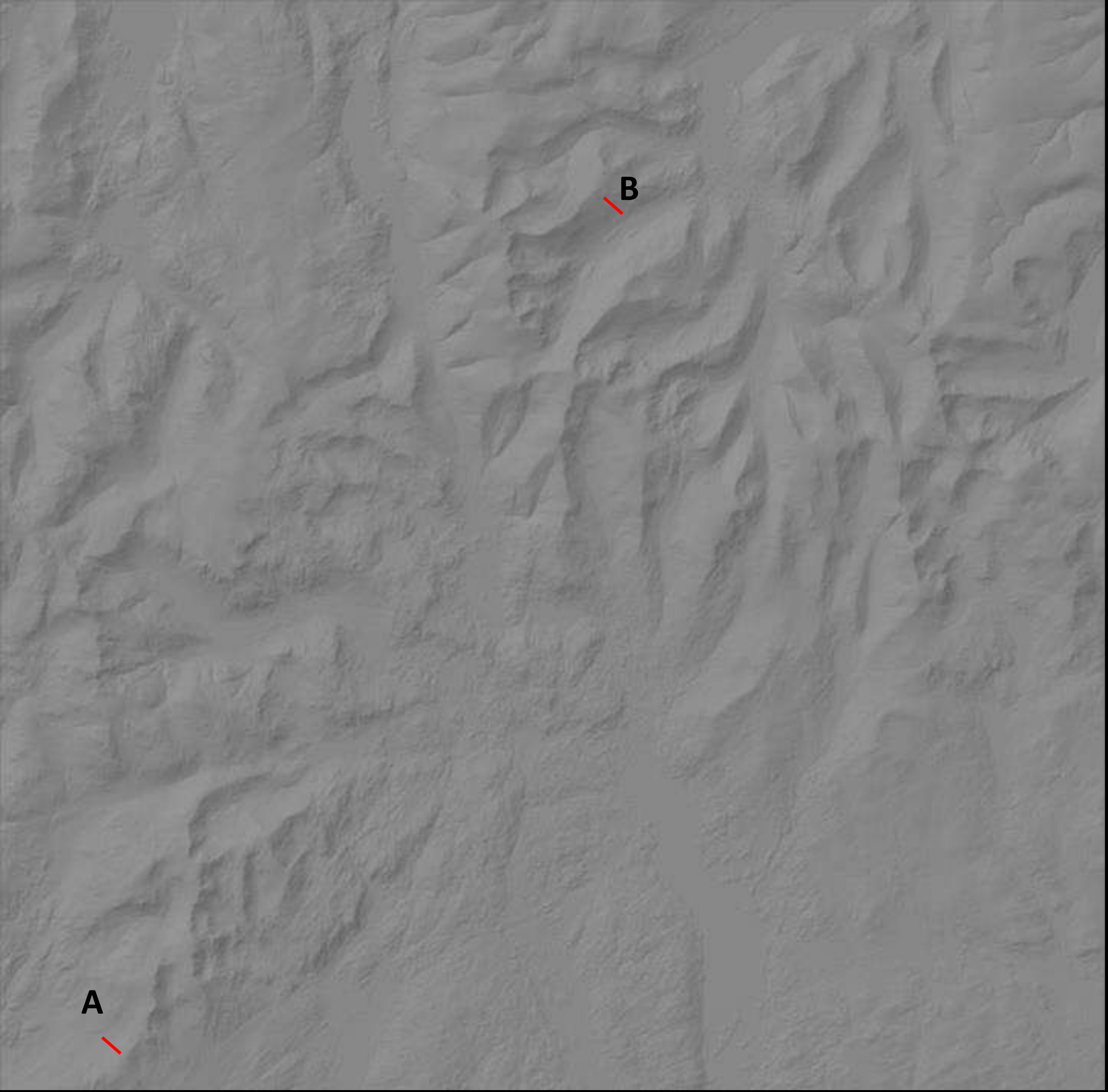
301a



From which point is the red location visible?

A or B

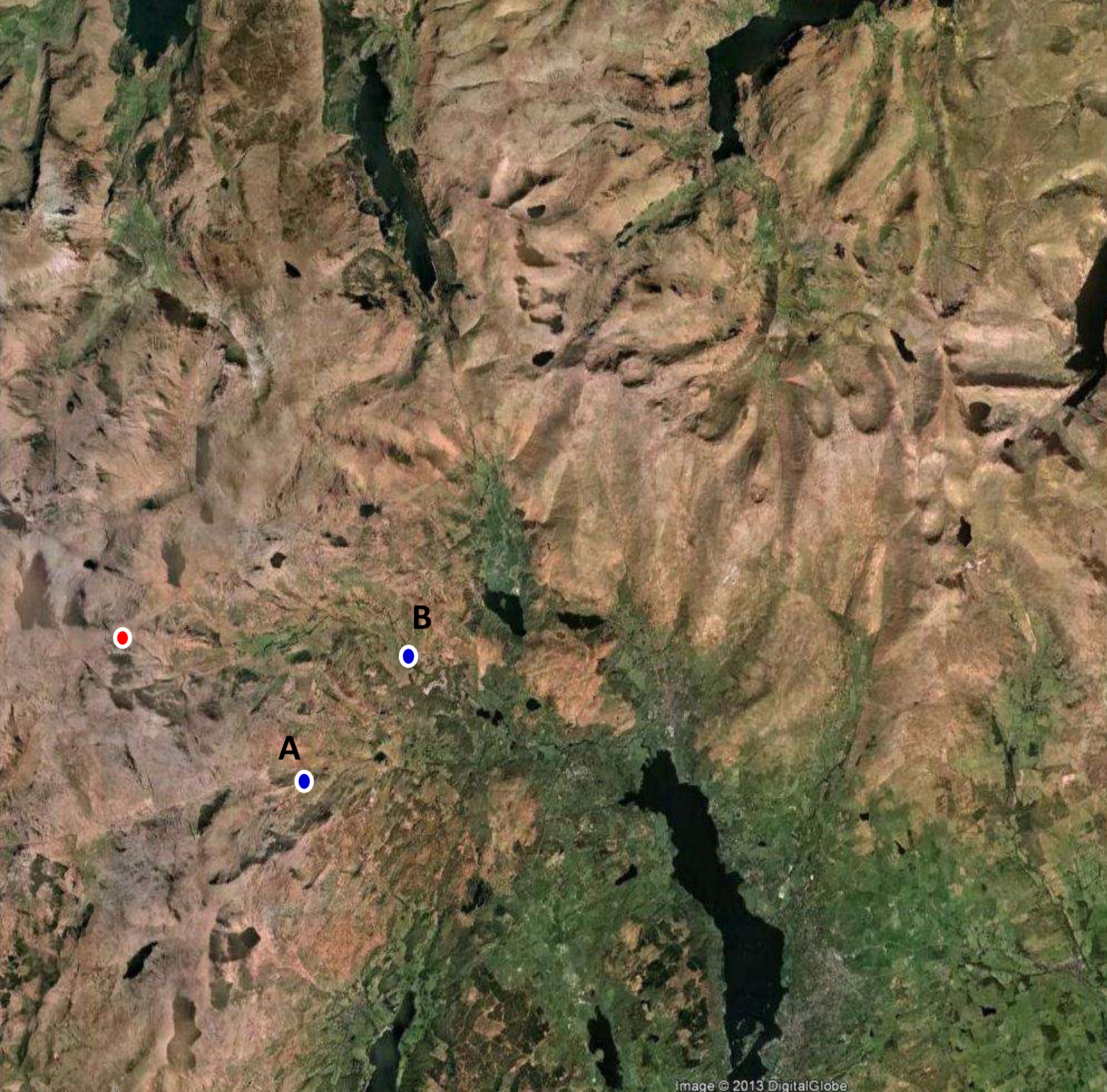
414



Which line follows the steepest path?

A or B

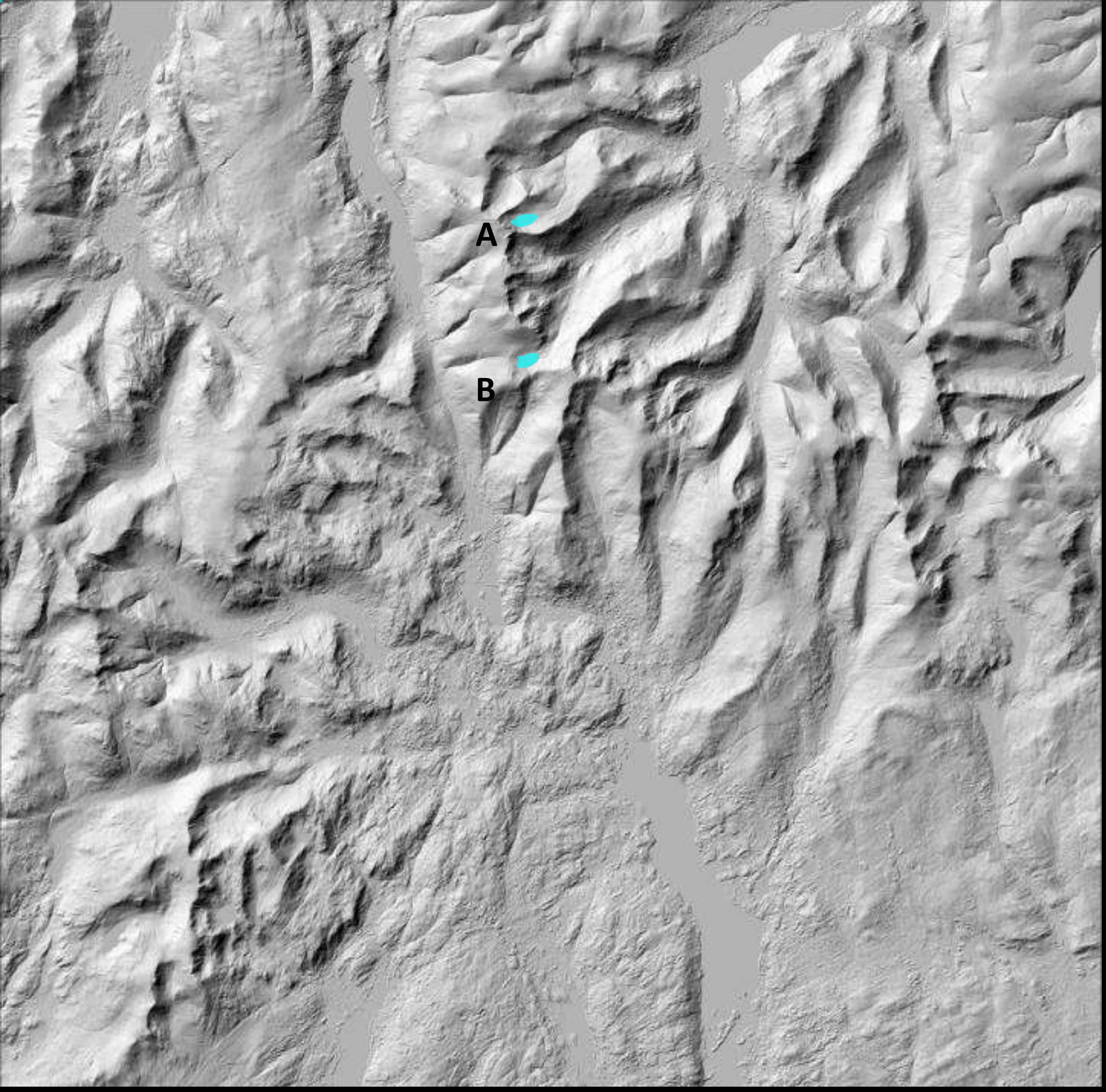
509c



To which point would water flow from the red location?

A or B

616

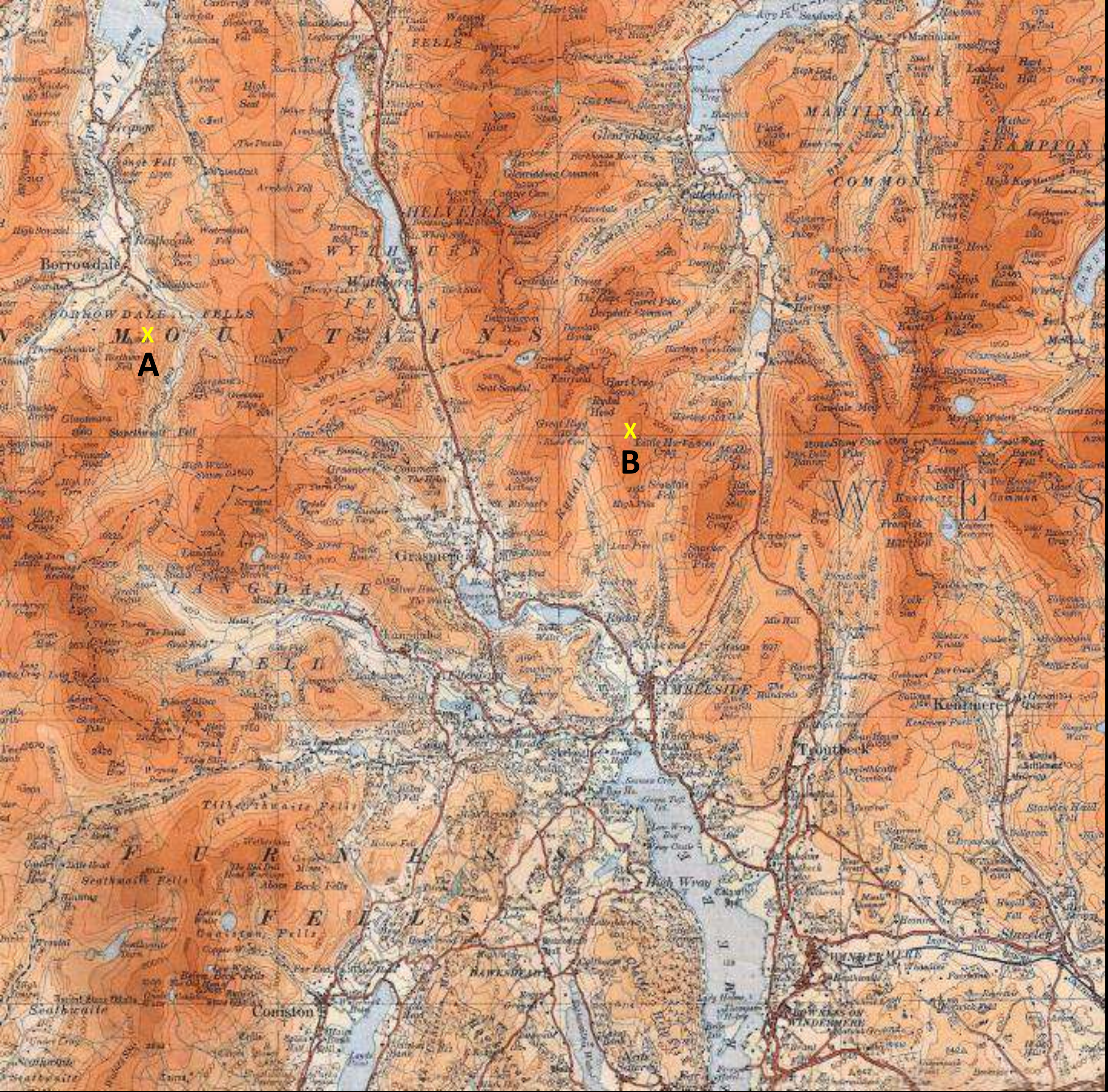


Notice both lakes (blue area).

Which is the highest lake?

A or B

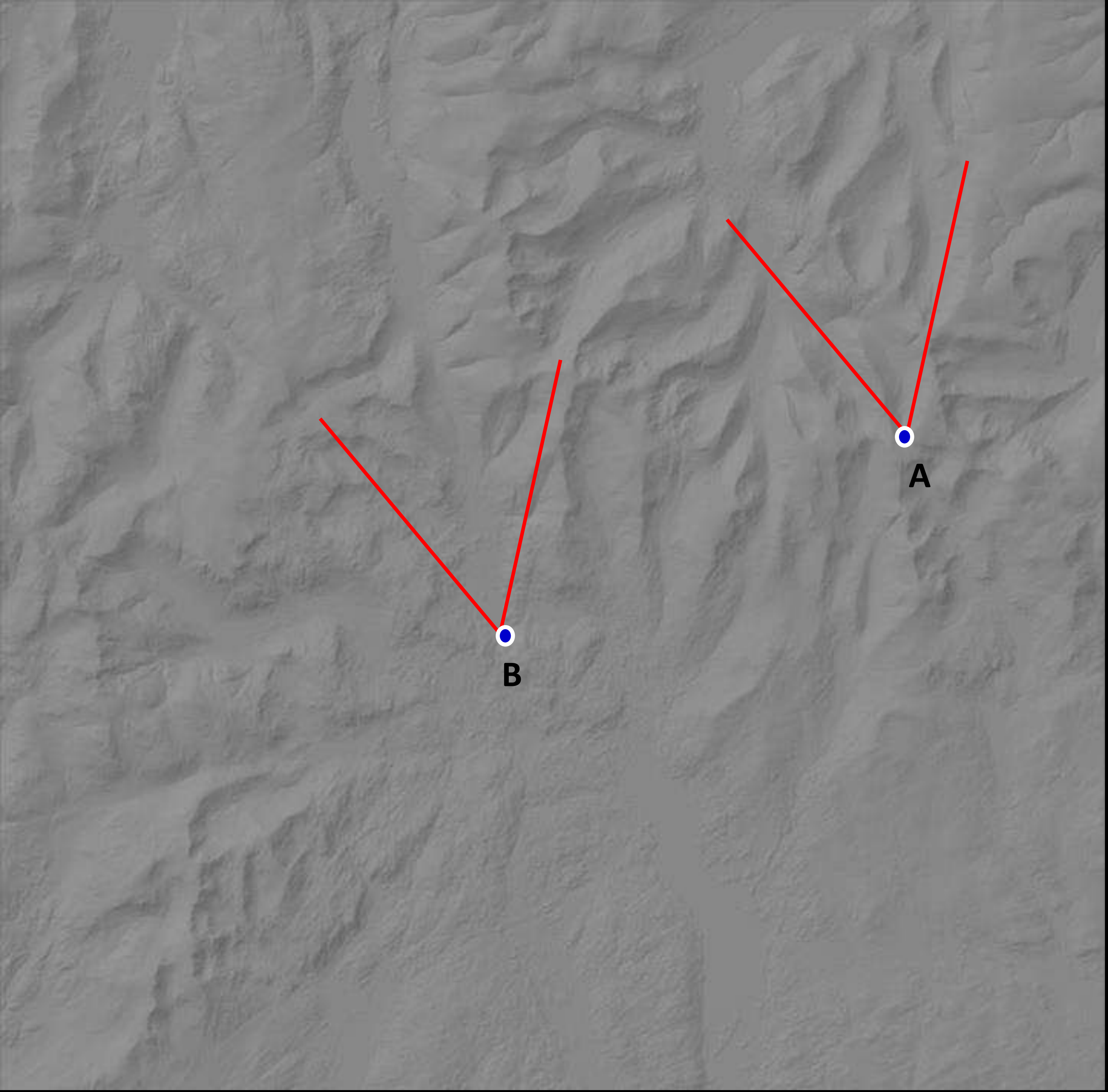
103



Notice both peaks (X sign). Which is the highest peak?

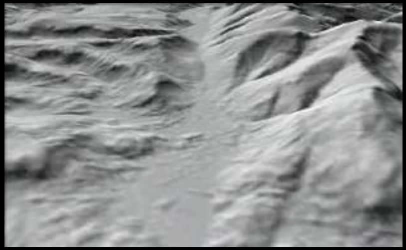
A or B

205

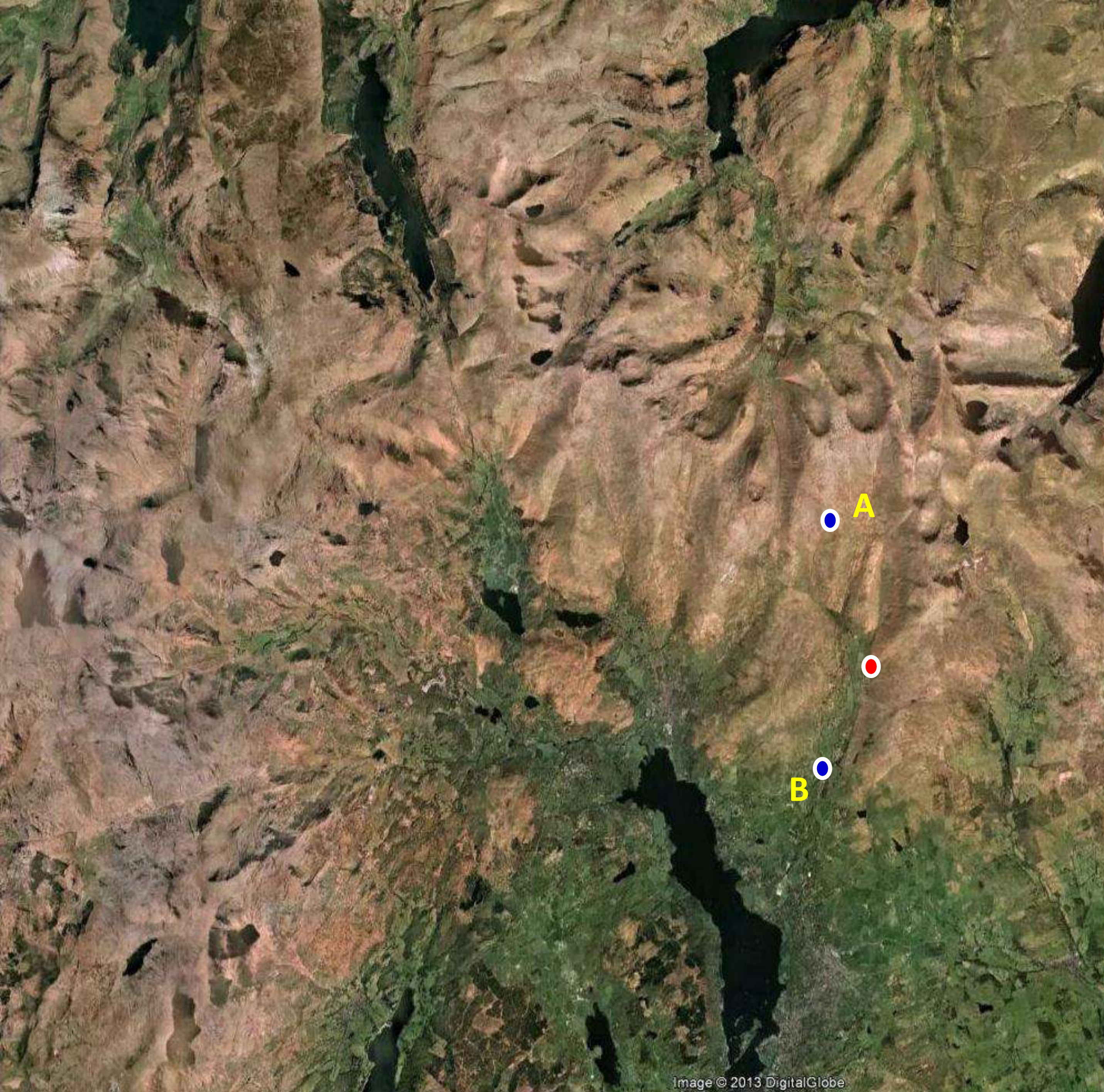


Which viewpoint matches the picture below?

A or B



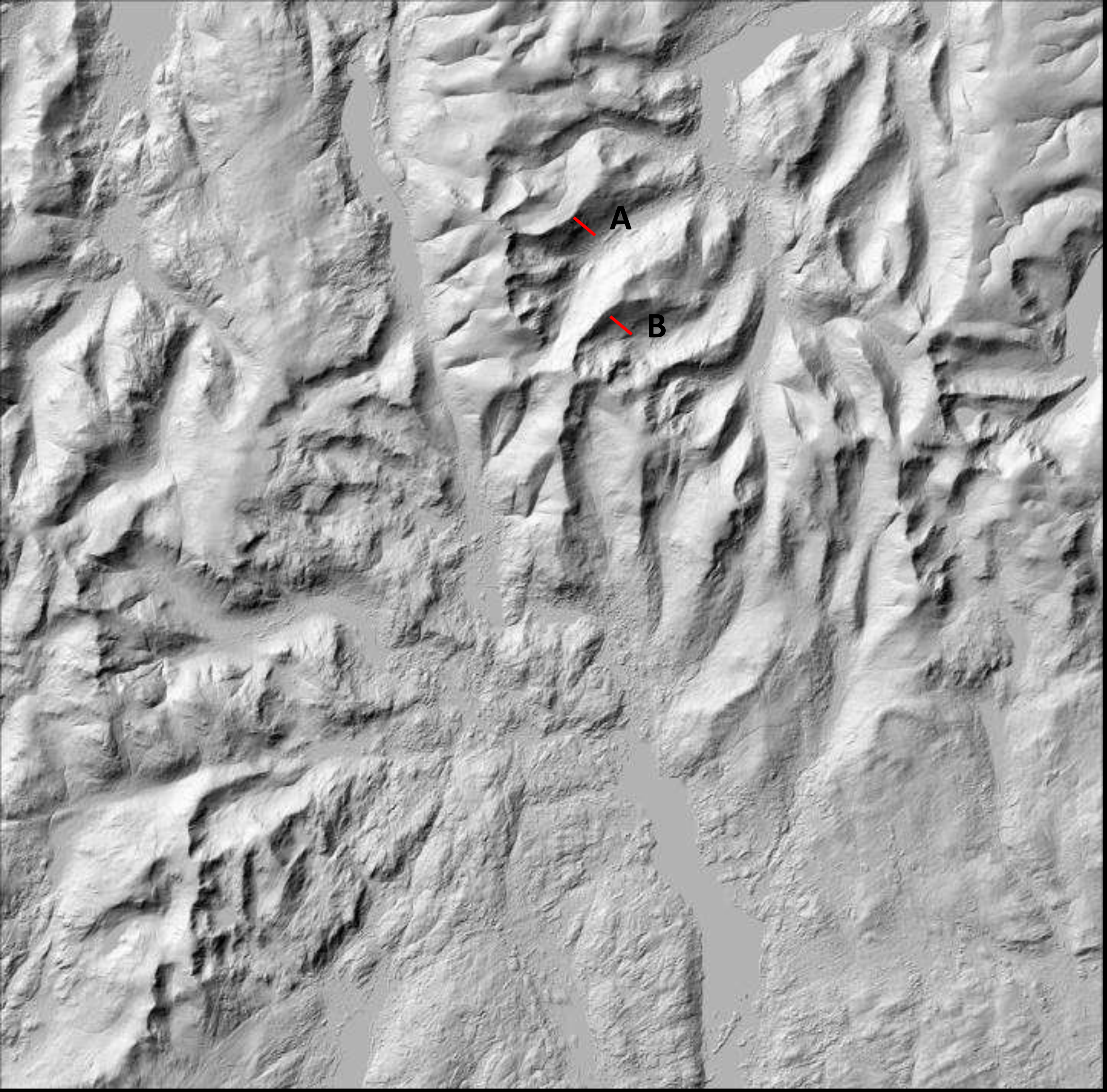
315



From which point is the red location visible?

A or B

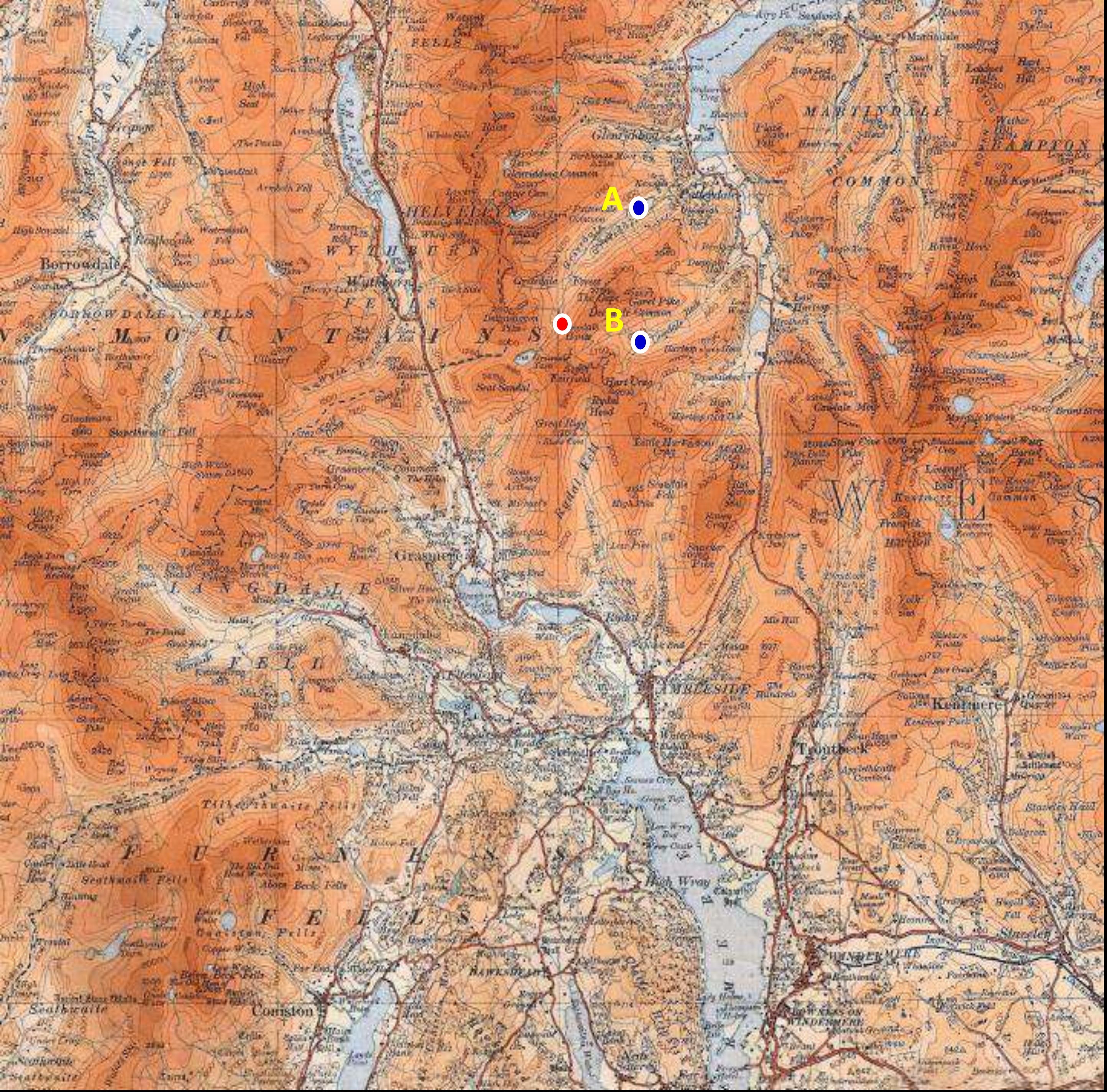
412



Which line follows the steepest path?

A or B

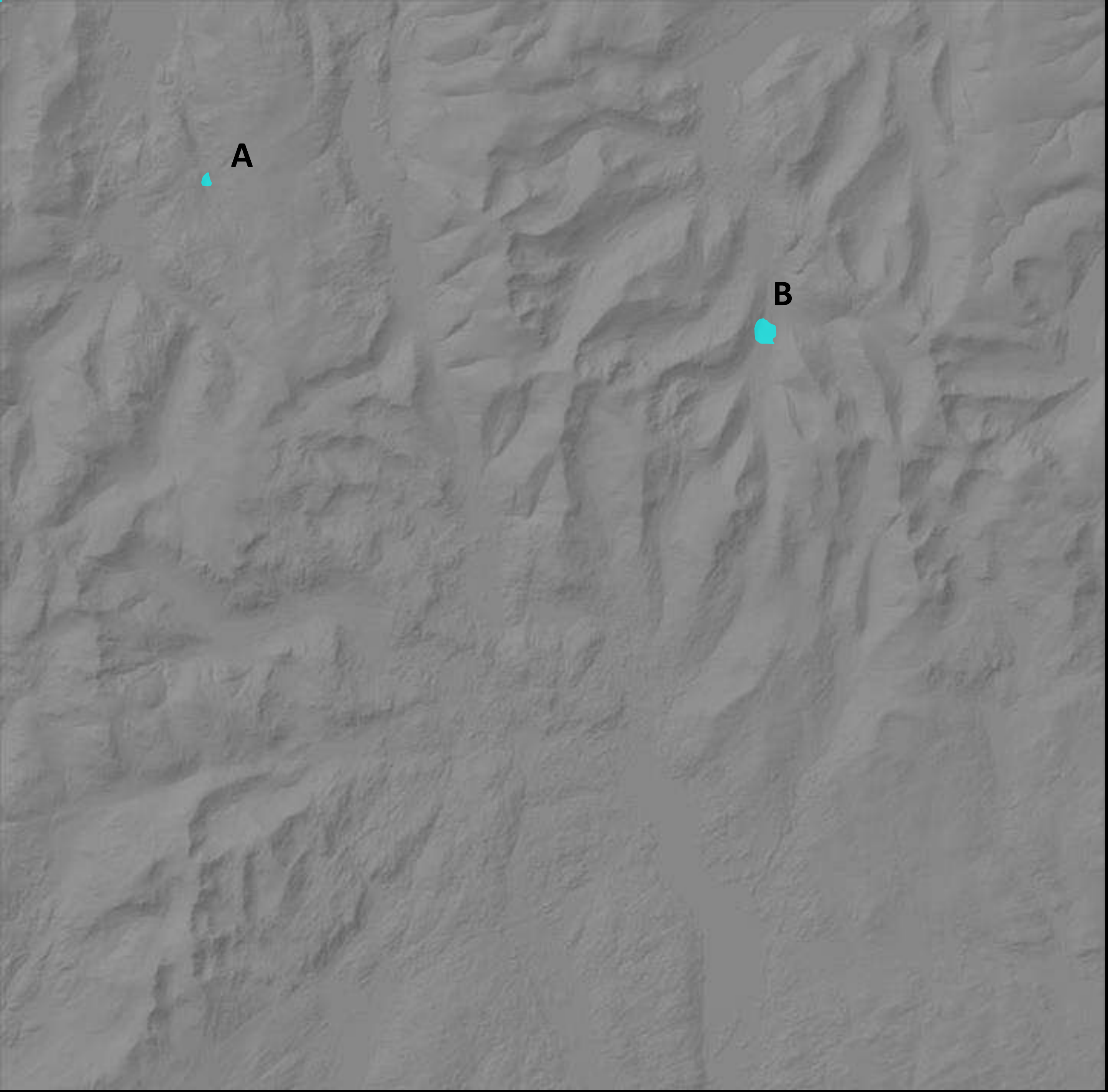
513



To which point would water flow from the red location?

A or B

604

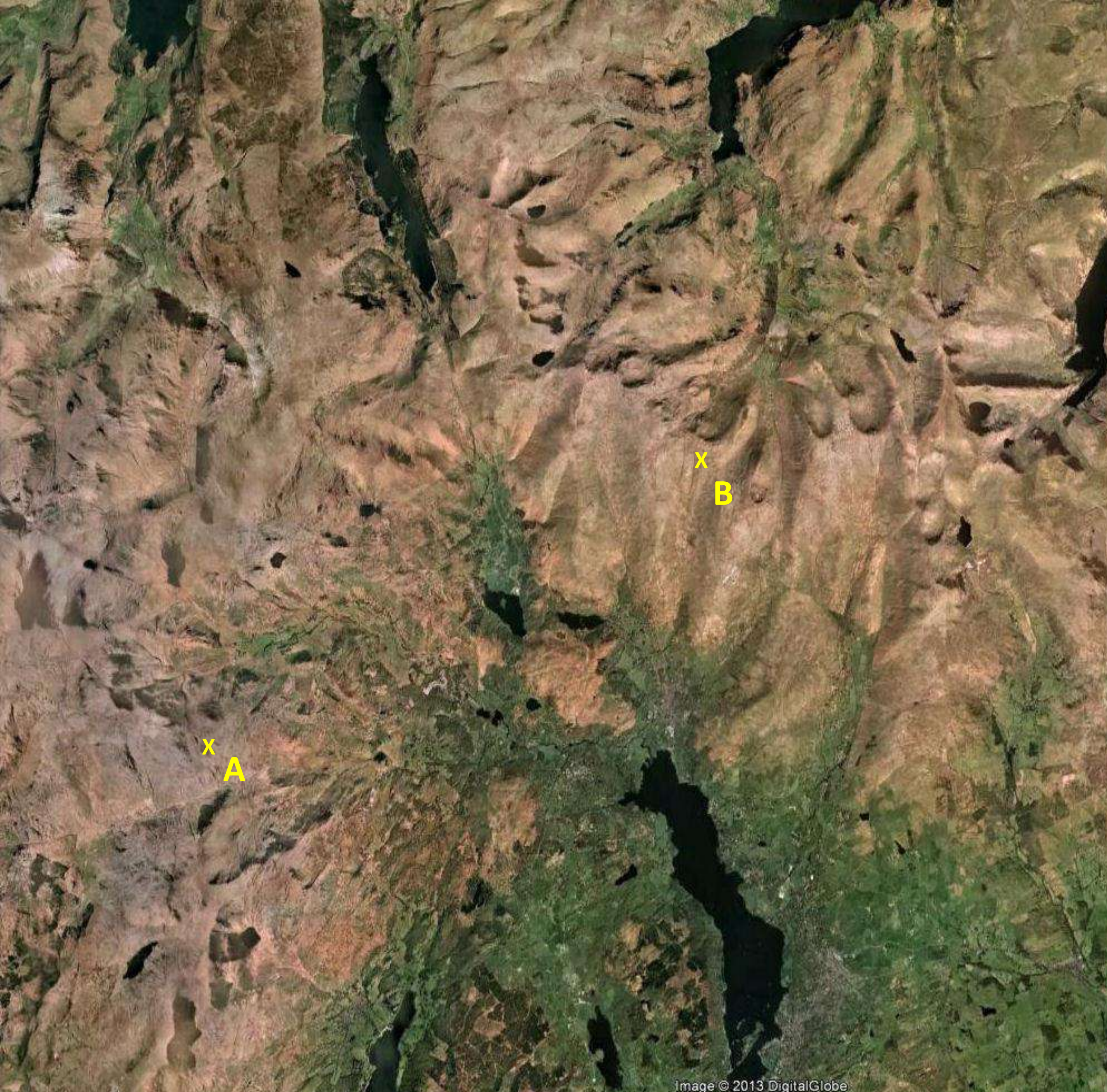


Notice both lakes (blue area).

Which is the highest lake?

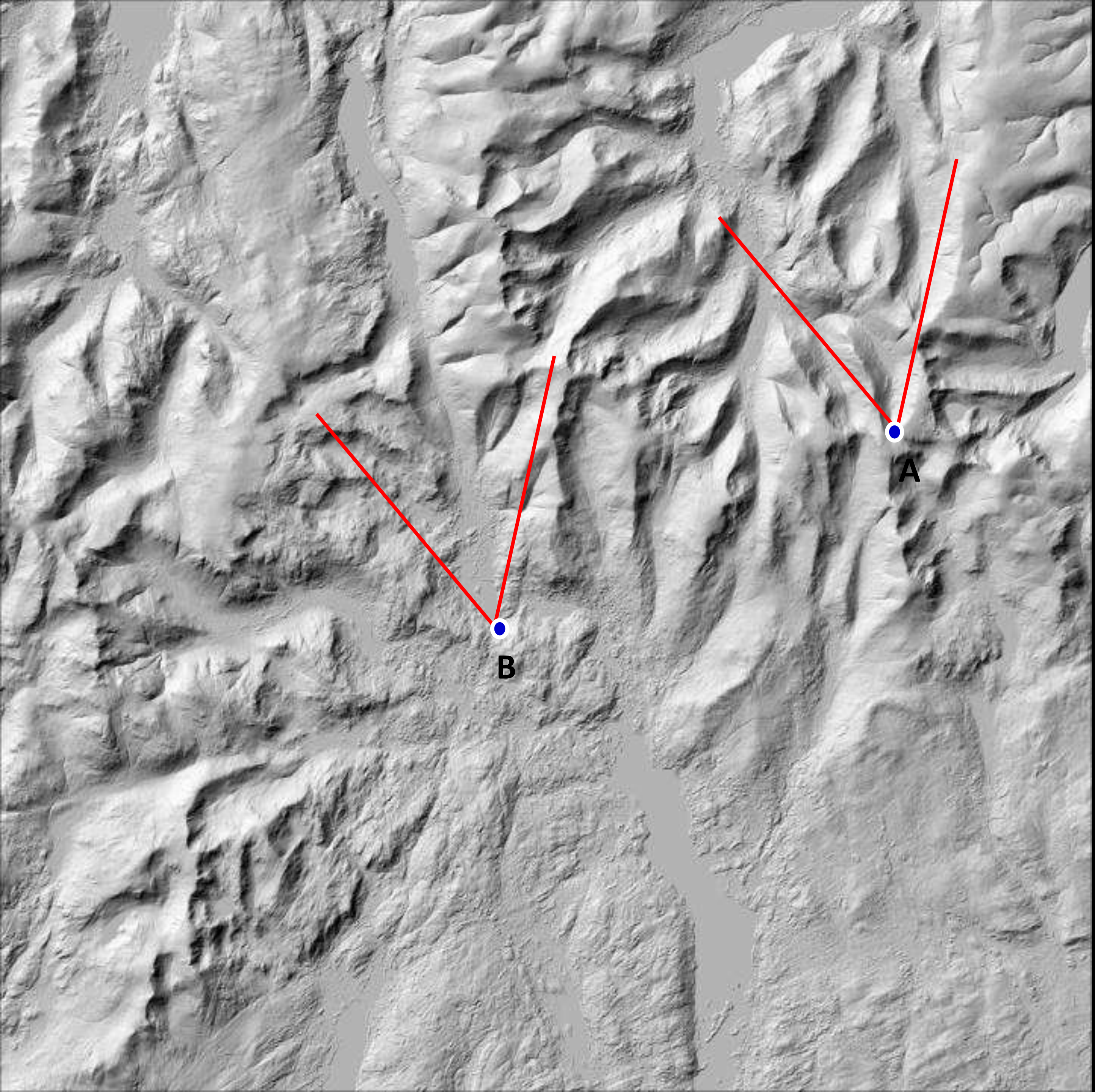
A or B

108



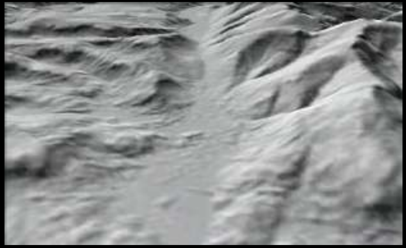
Notice both peaks (X sign). Which is the highest peak?

A or B

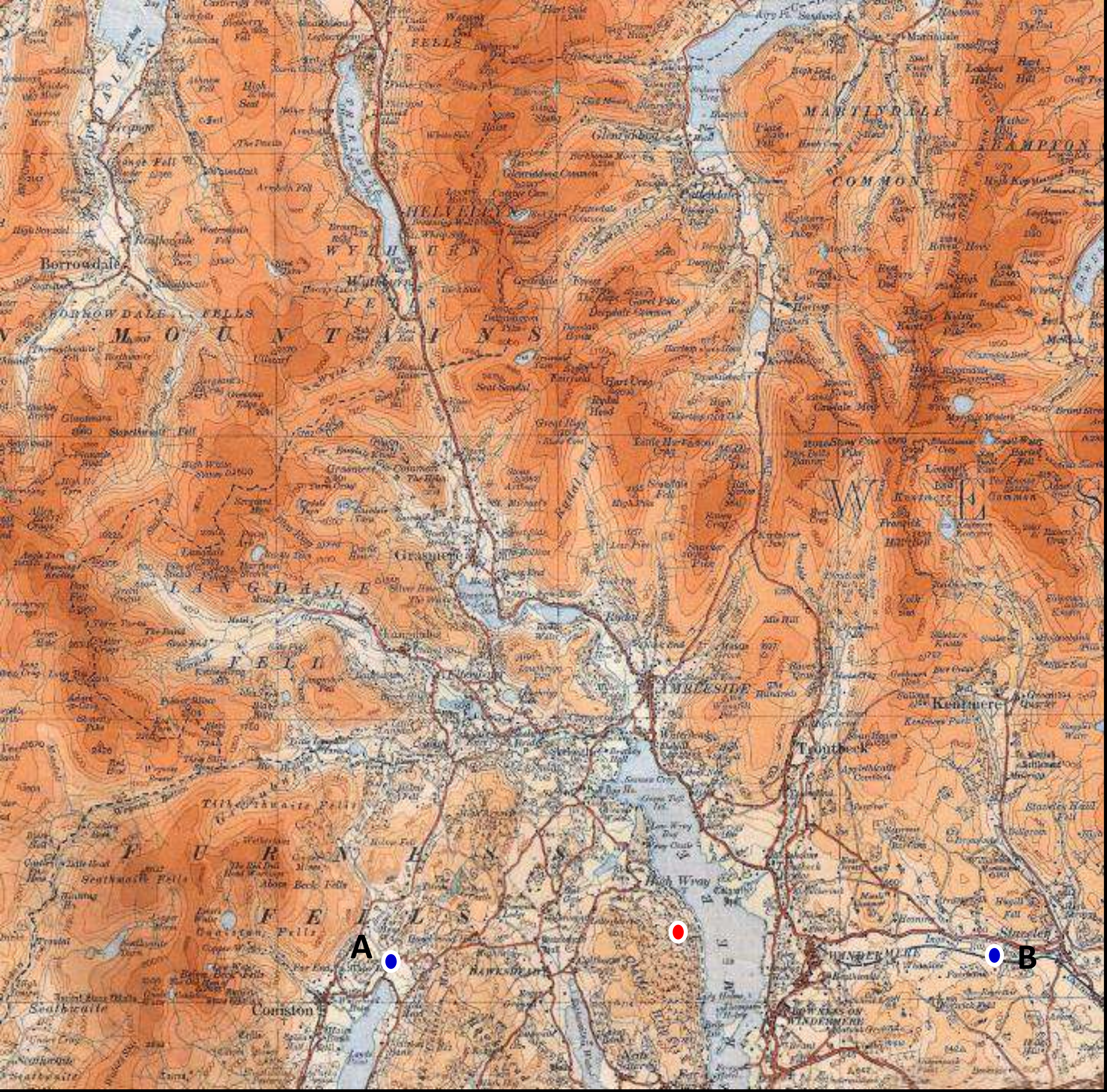


Which viewpoint matches the picture below?

A or B



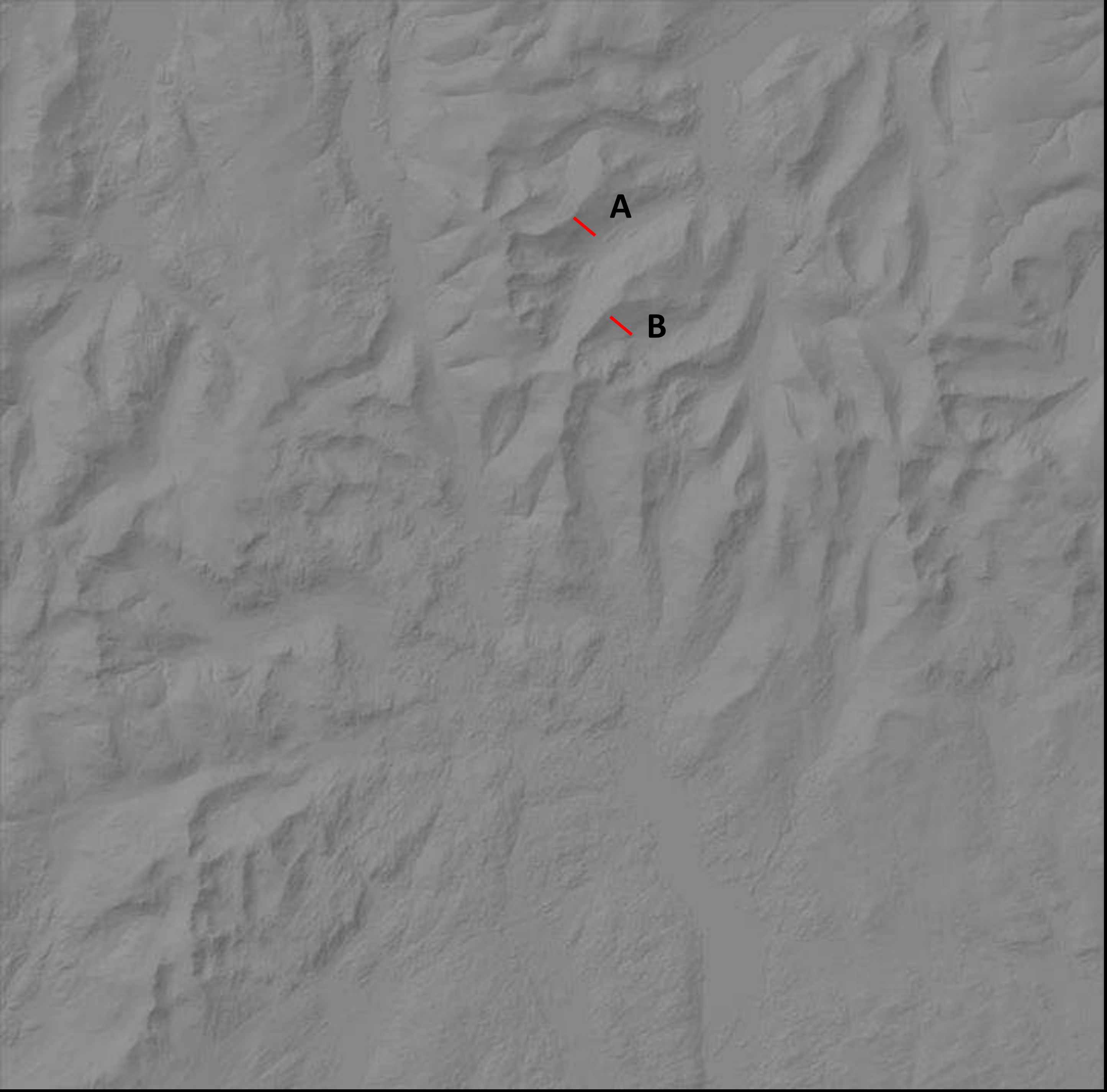
313



From which point is the red location visible?

A or B

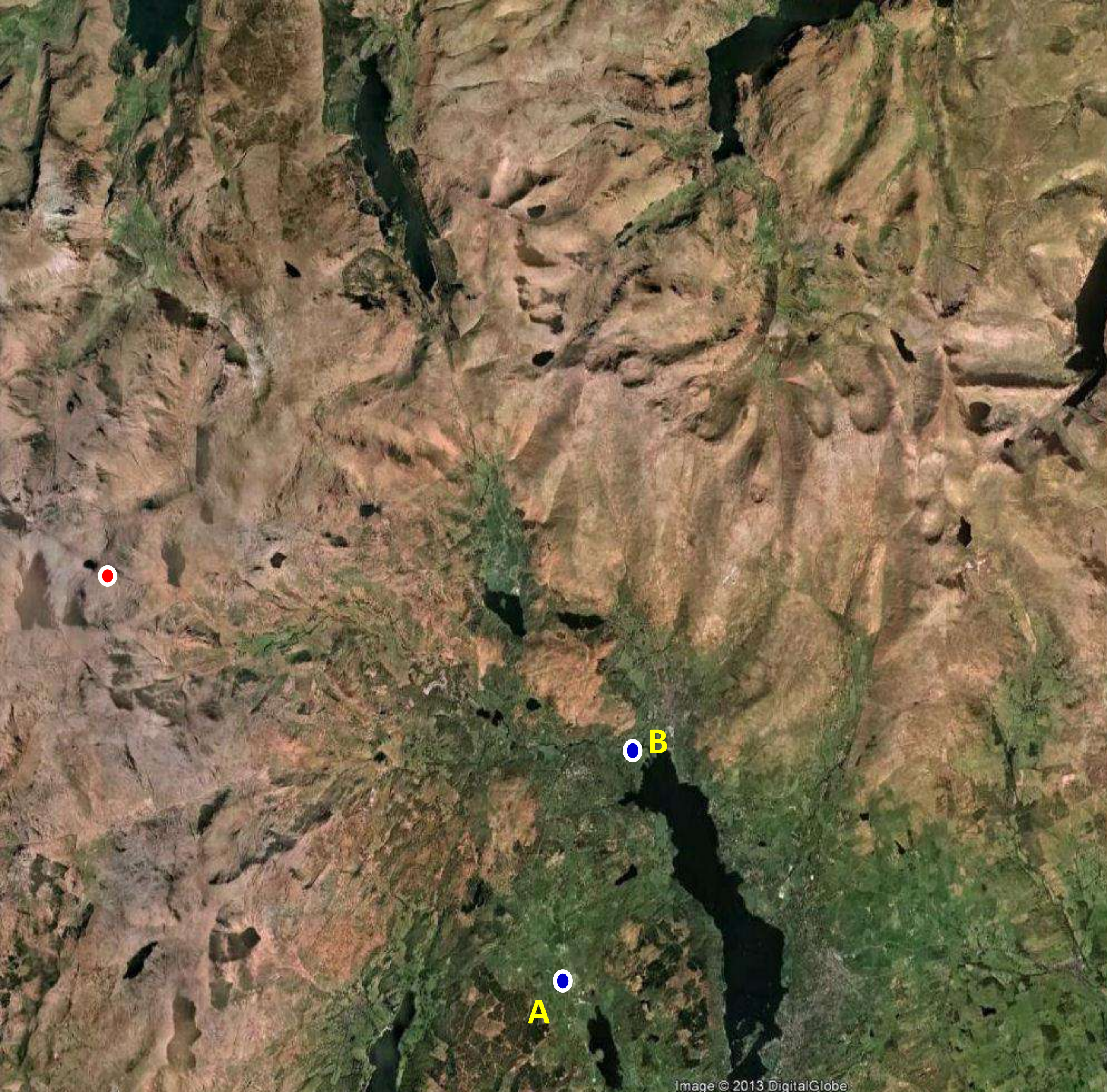
404



Which line follows the steepest path?

A or B

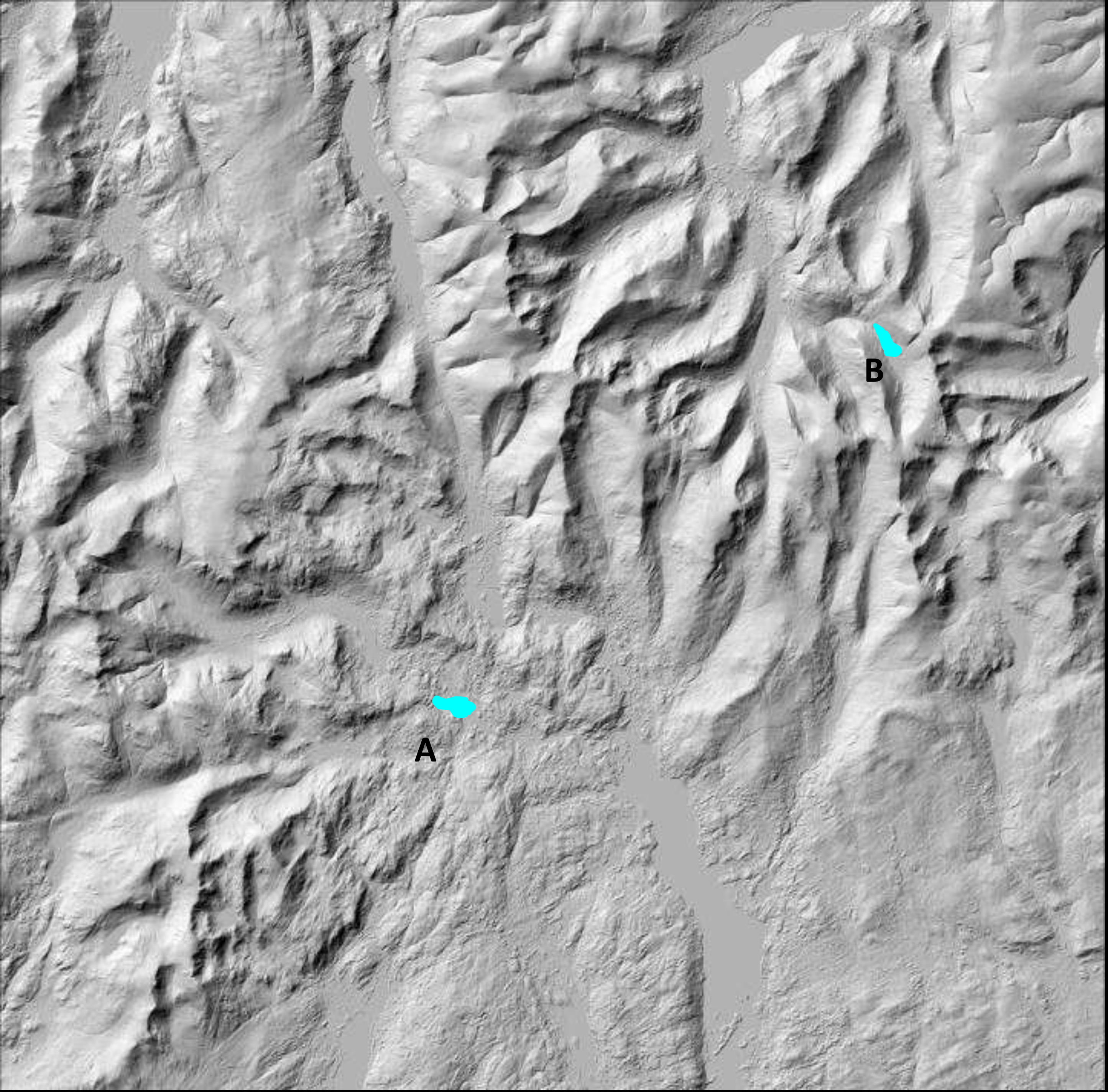
515



To which point would water flow from the red location?

A or B

612

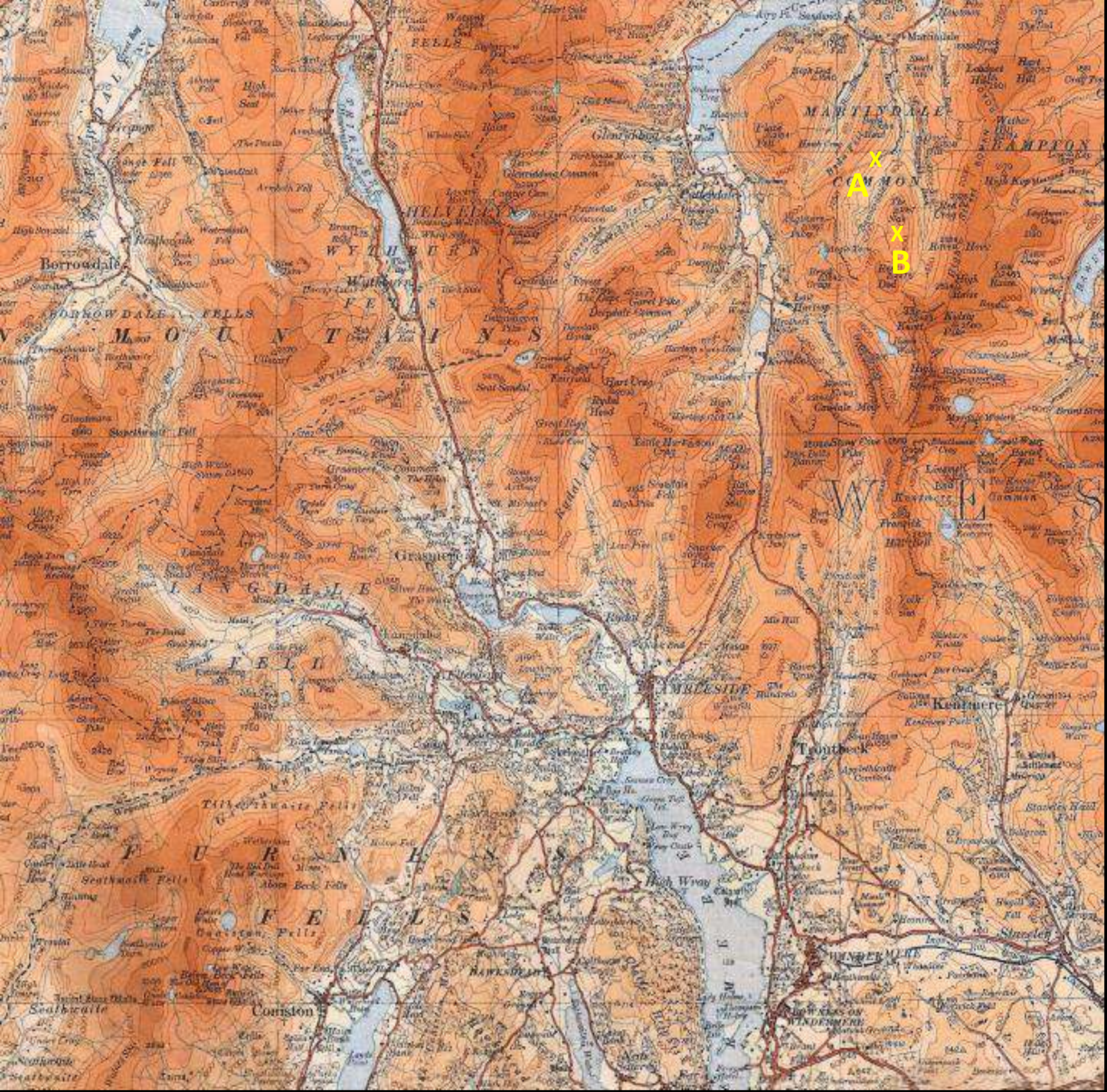


Notice both lakes (blue area).

Which is the highest lake?

A or B

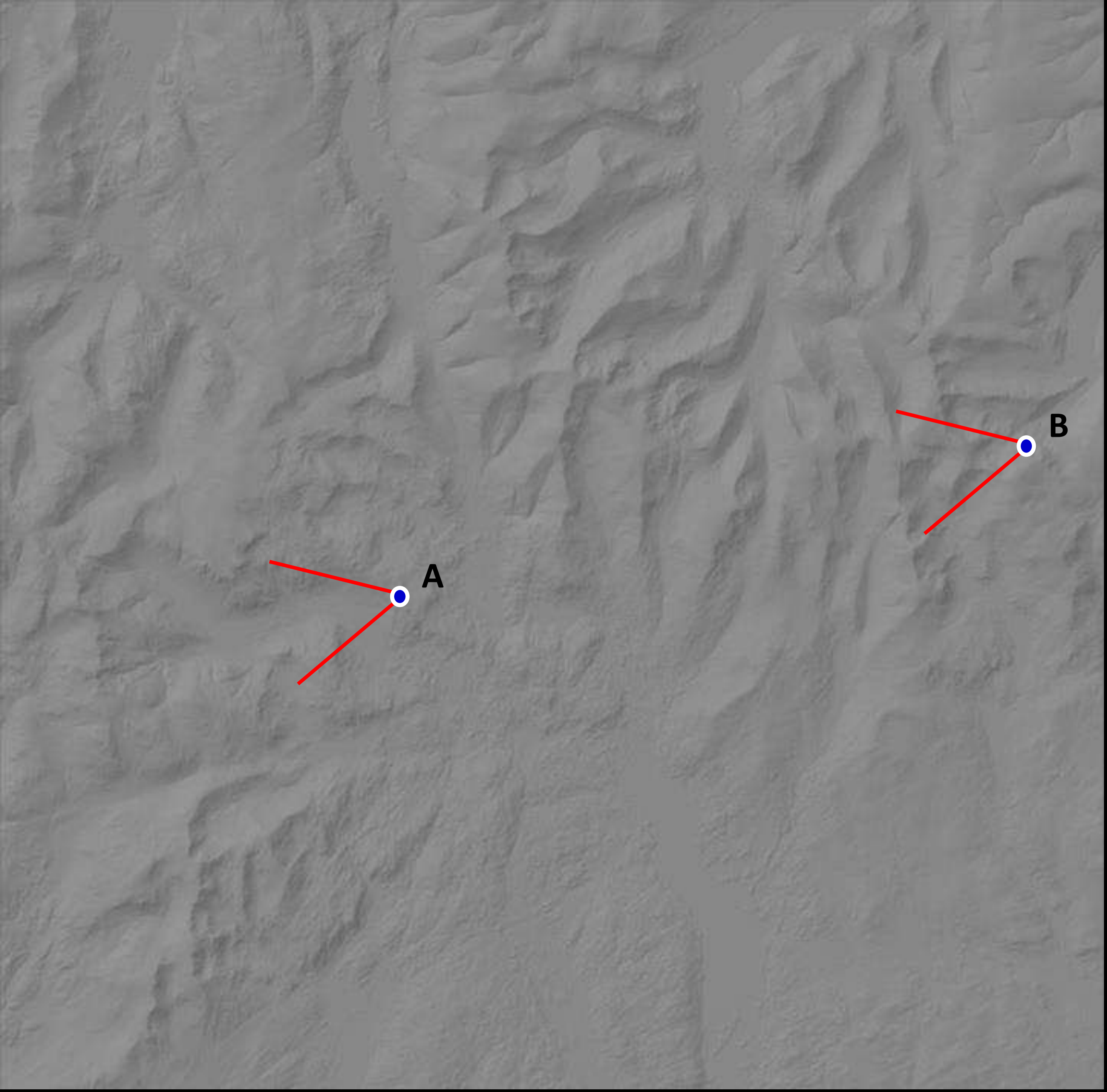
113



Notice both peaks (X sign). Which is the highest peak?

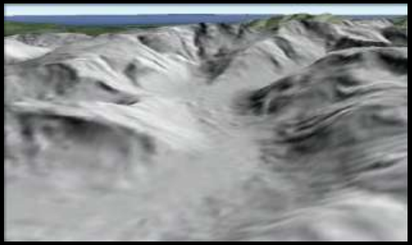
A or B

206

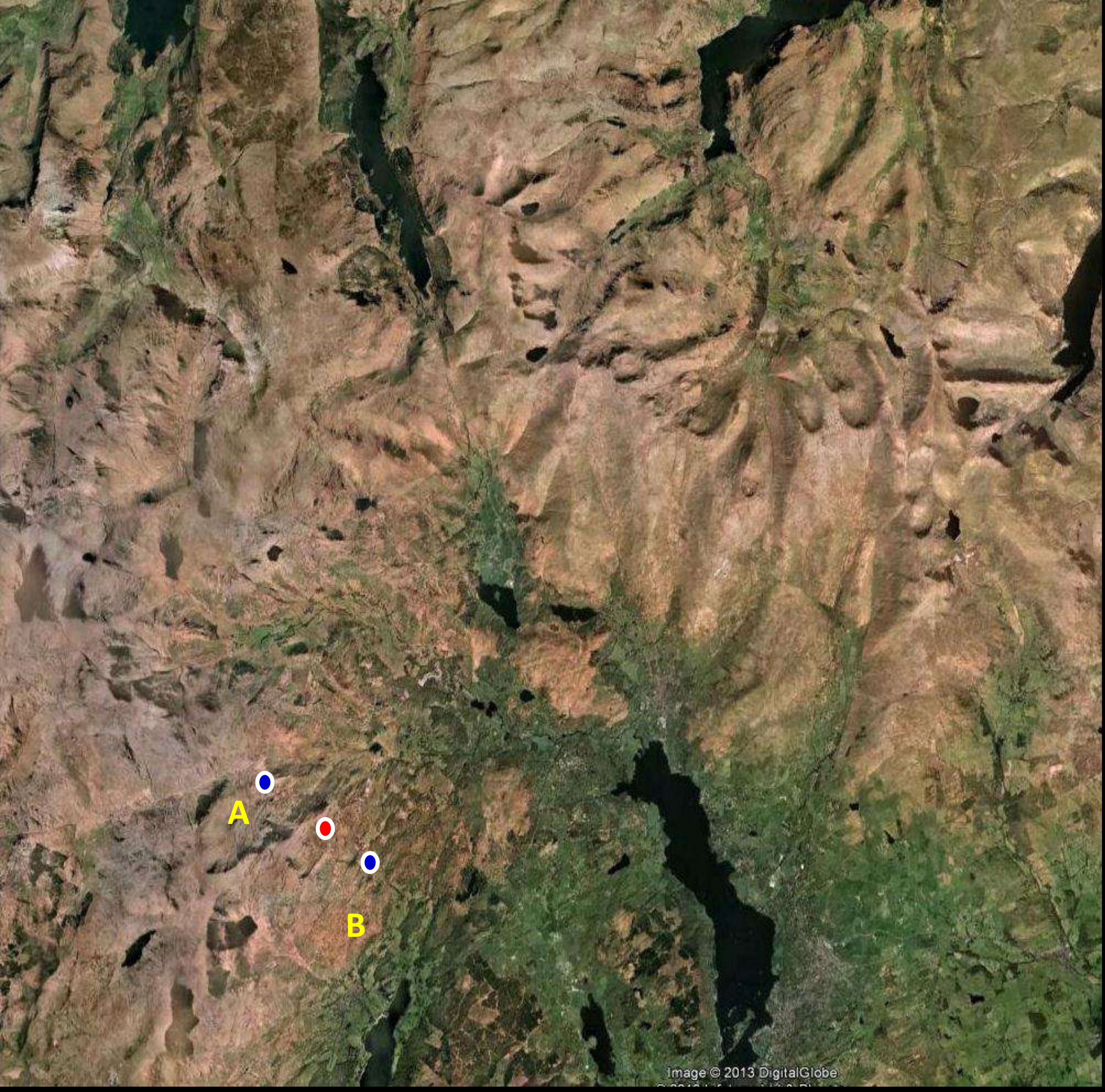


Which viewpoint matches the picture below?

A or B



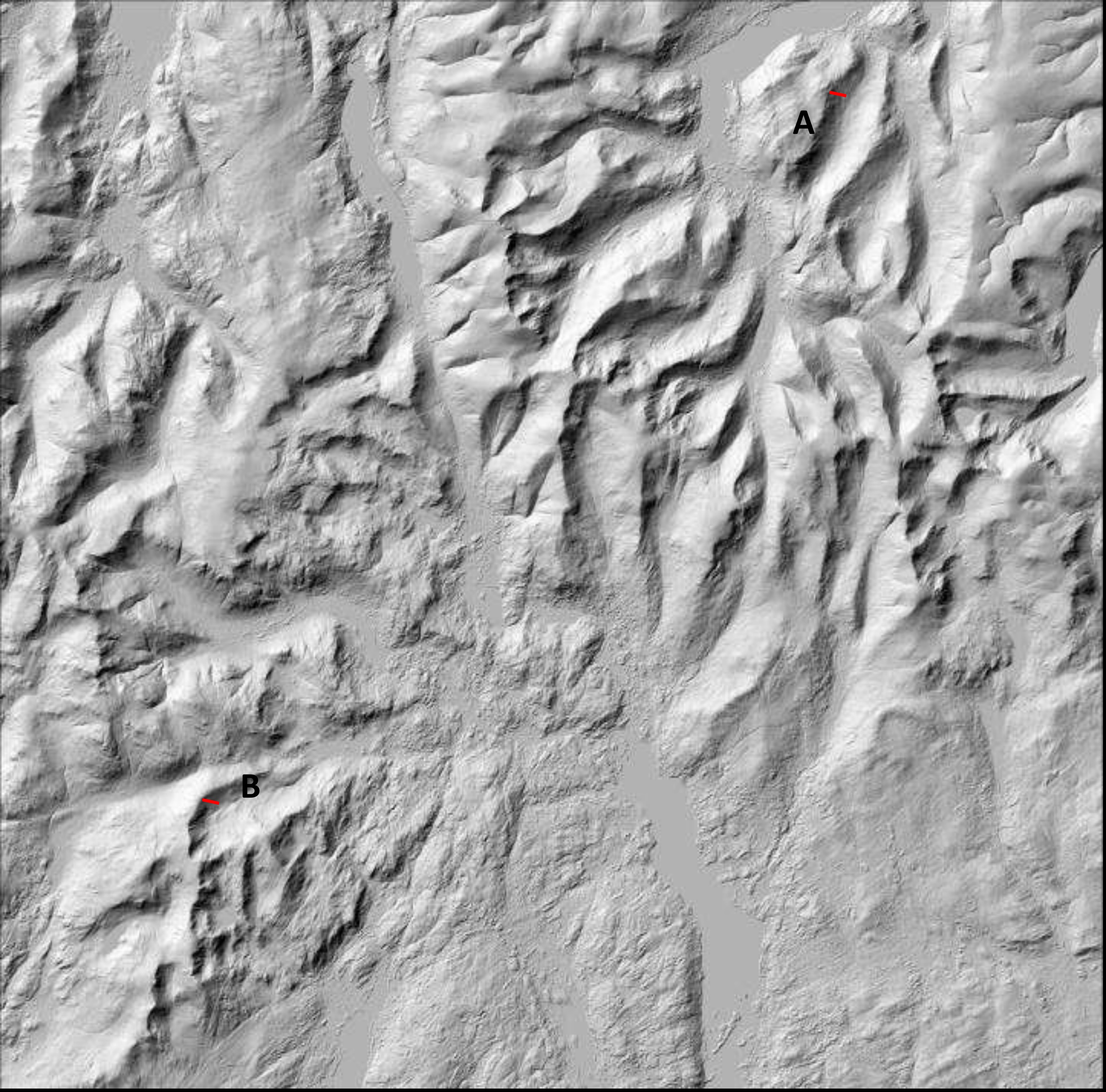
308



From which point is the red location visible?

A or B

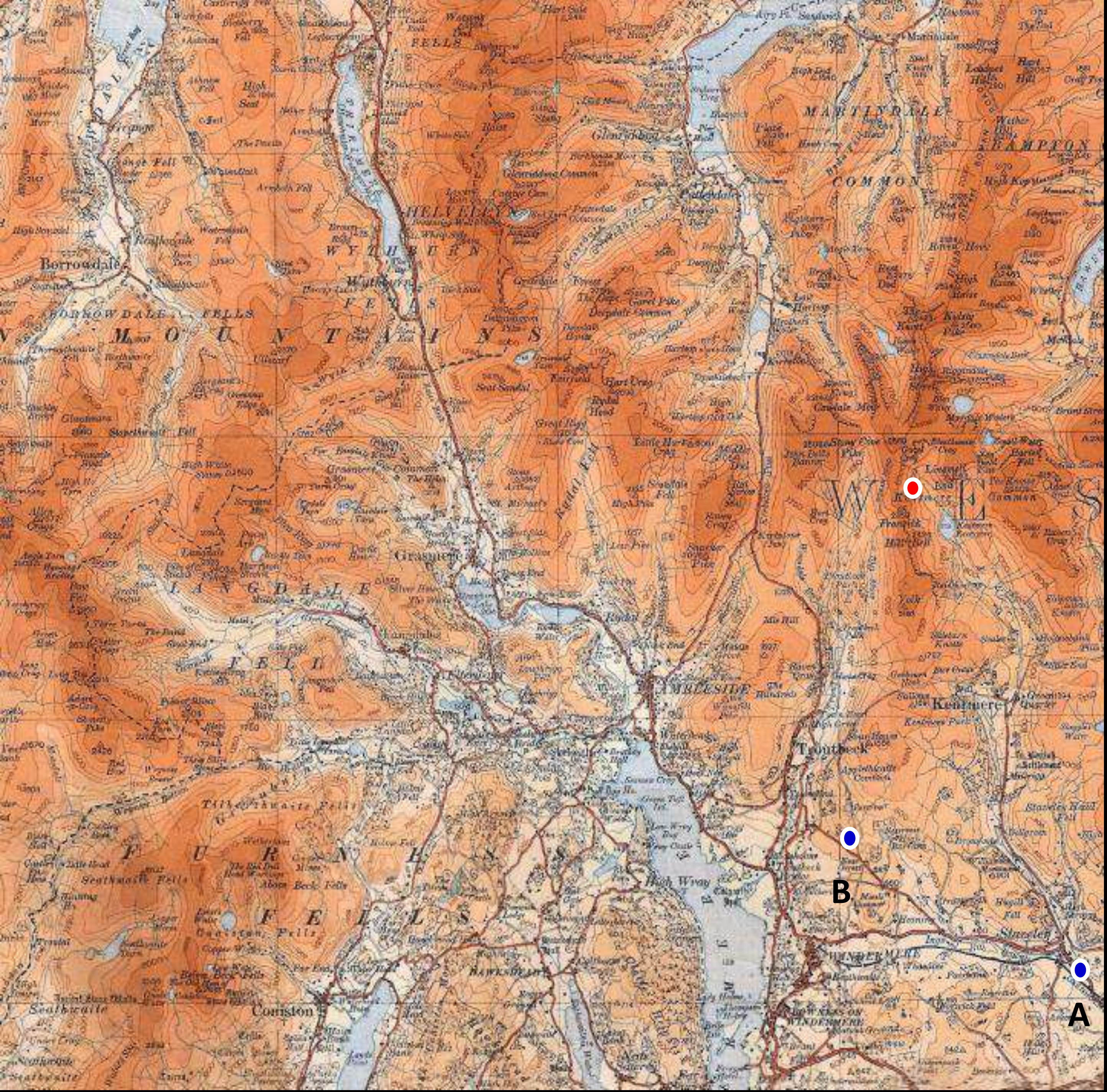
411



Which line follows the steepest path?

A or B

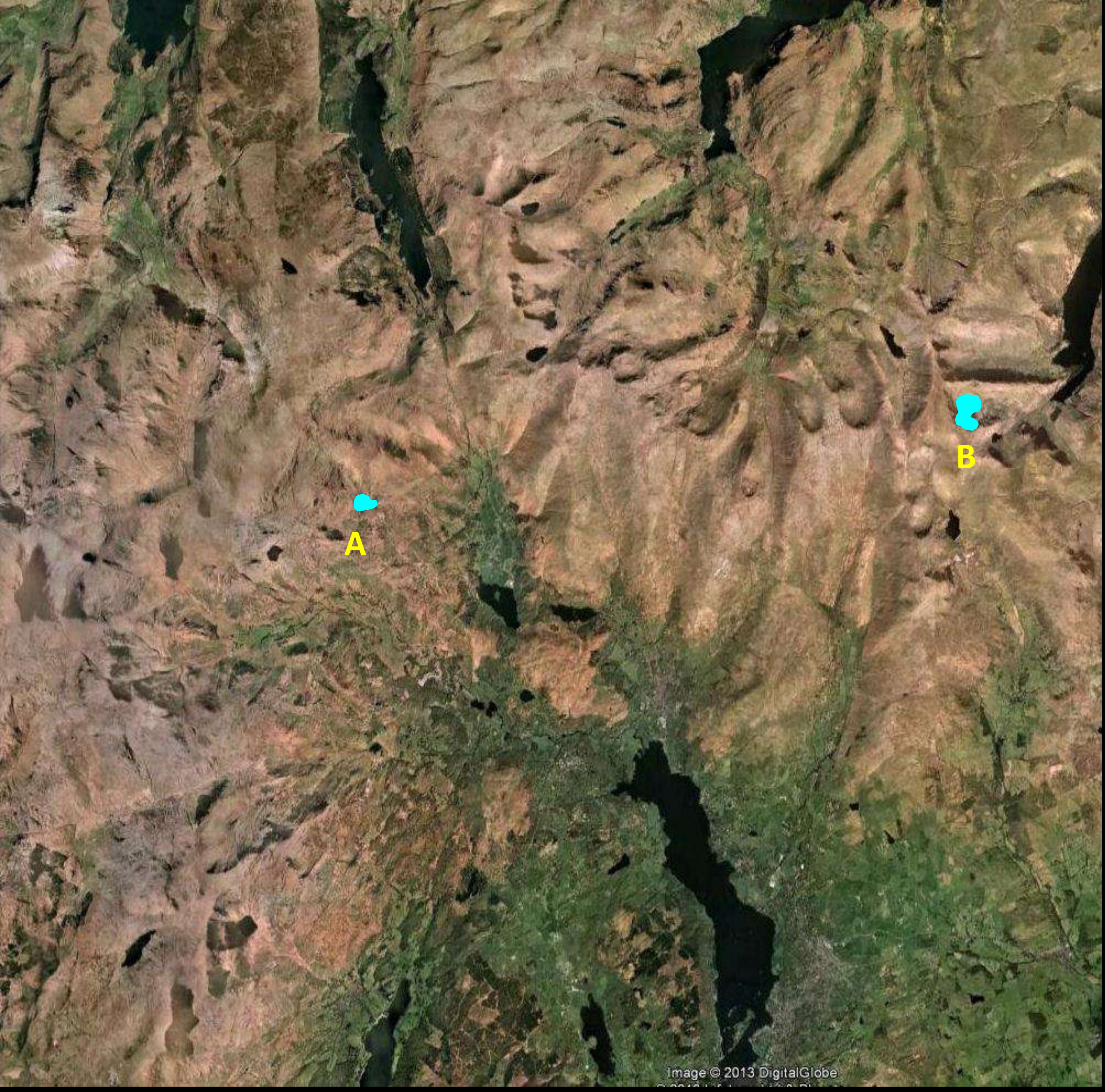
502a



To which point would water flow from the red location?

A or B

606

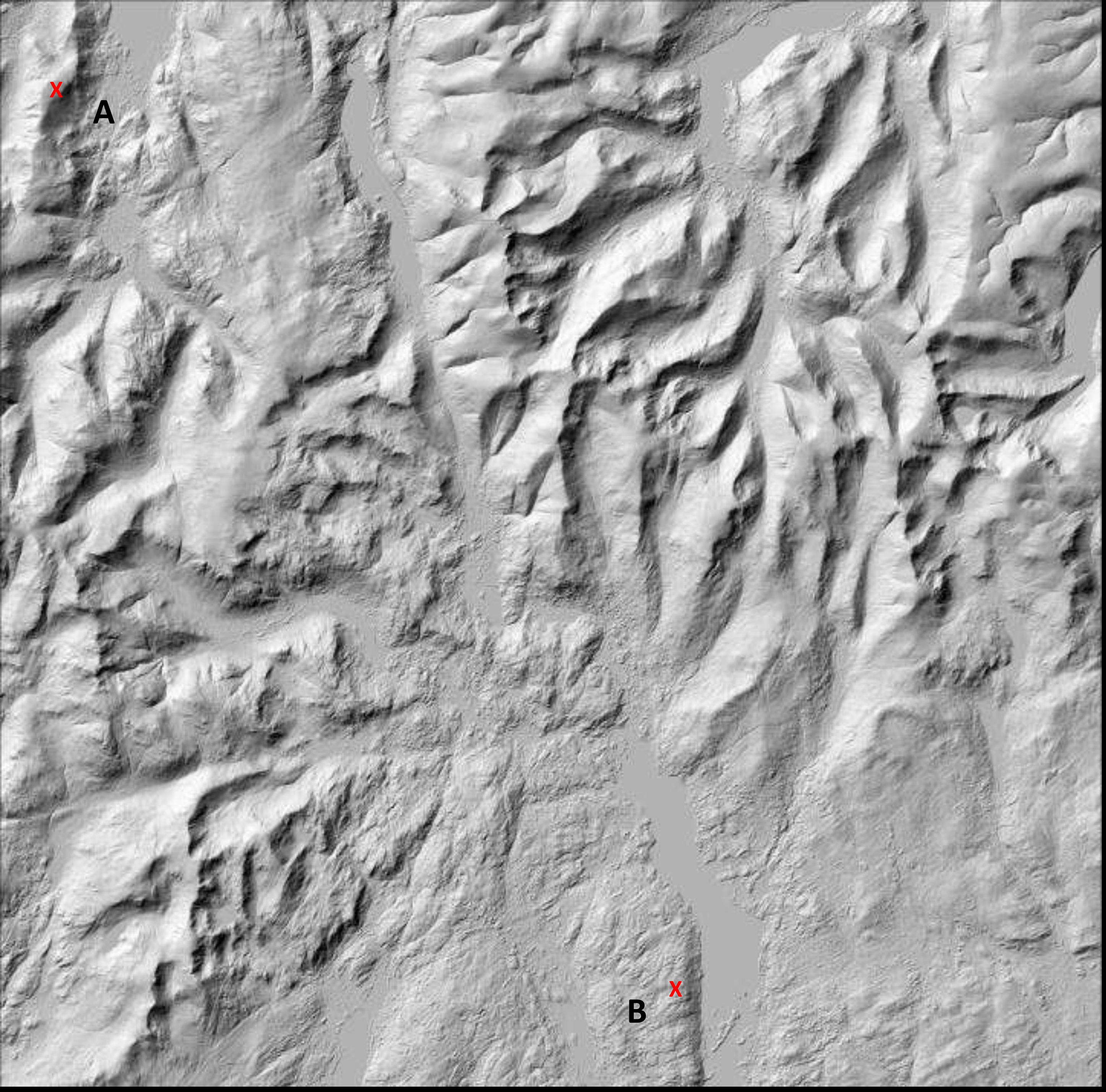


Notice both lakes (blue area).

Which is the highest lake?

A or B

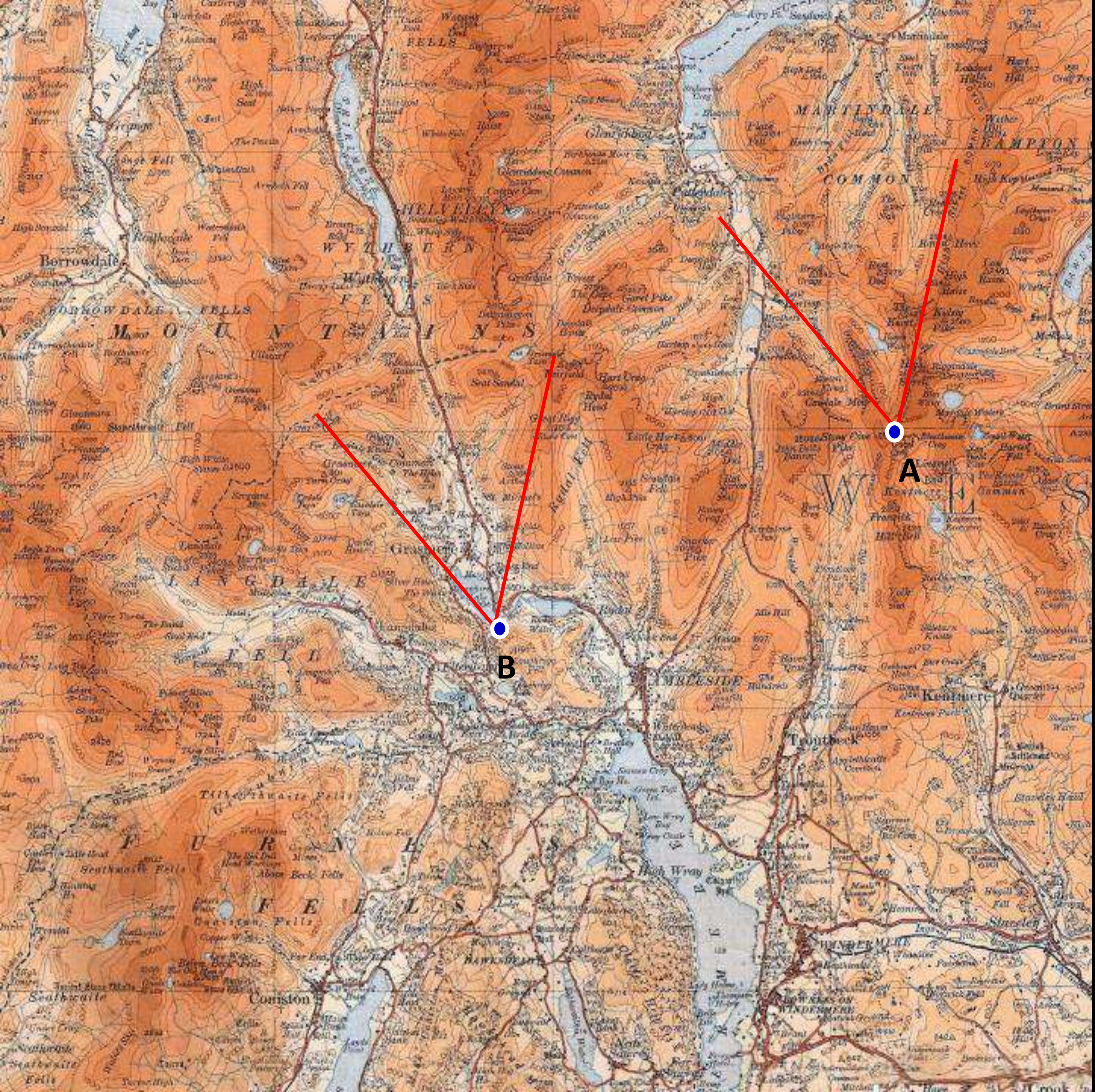
111



Notice both peaks (X sign). Which is the highest peak?

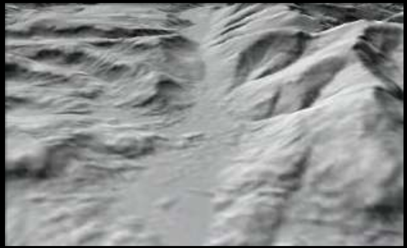
A or B

201

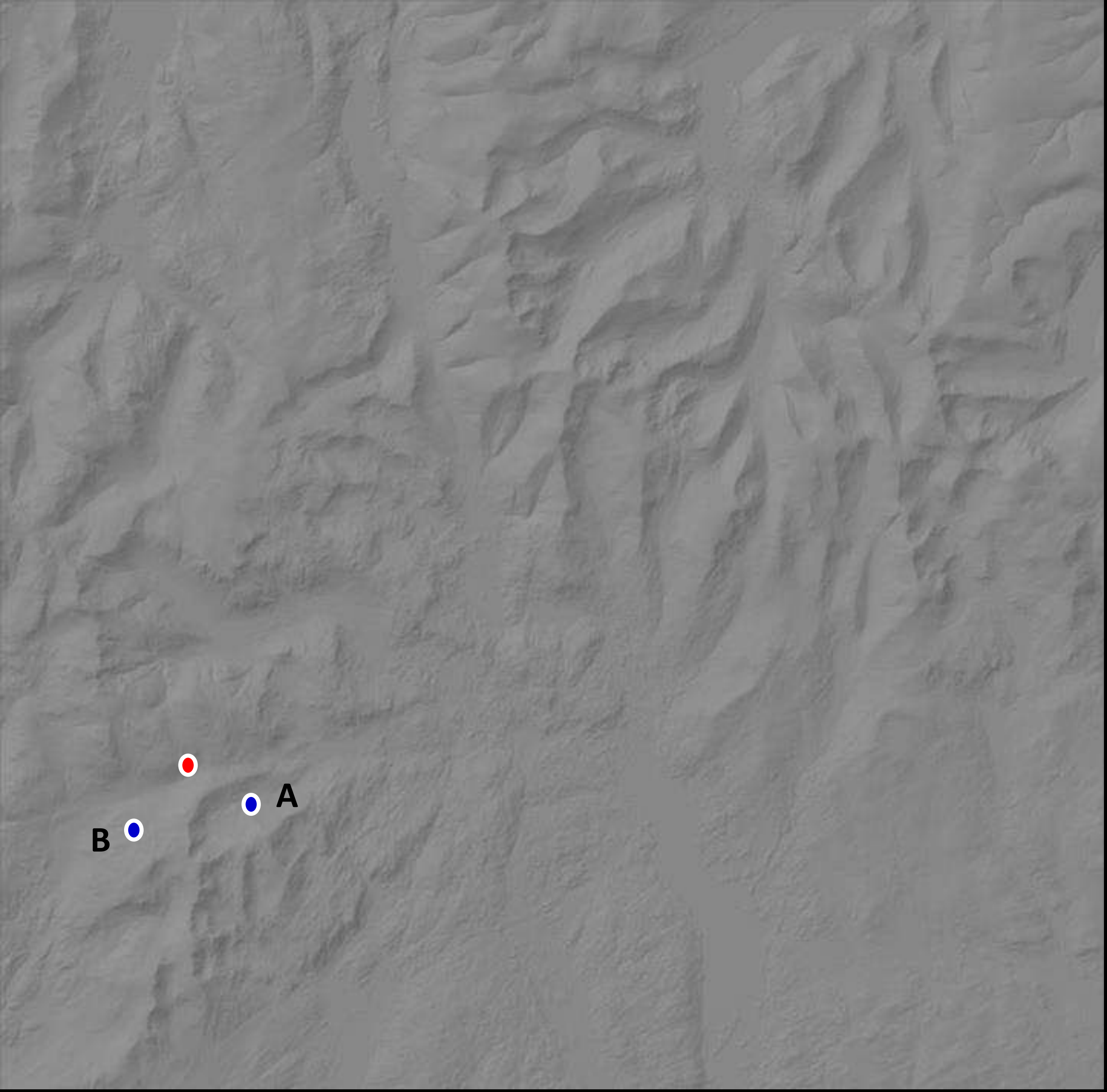


Which viewpoint matches the picture below?

A or B



314



From which point is the red location visible?

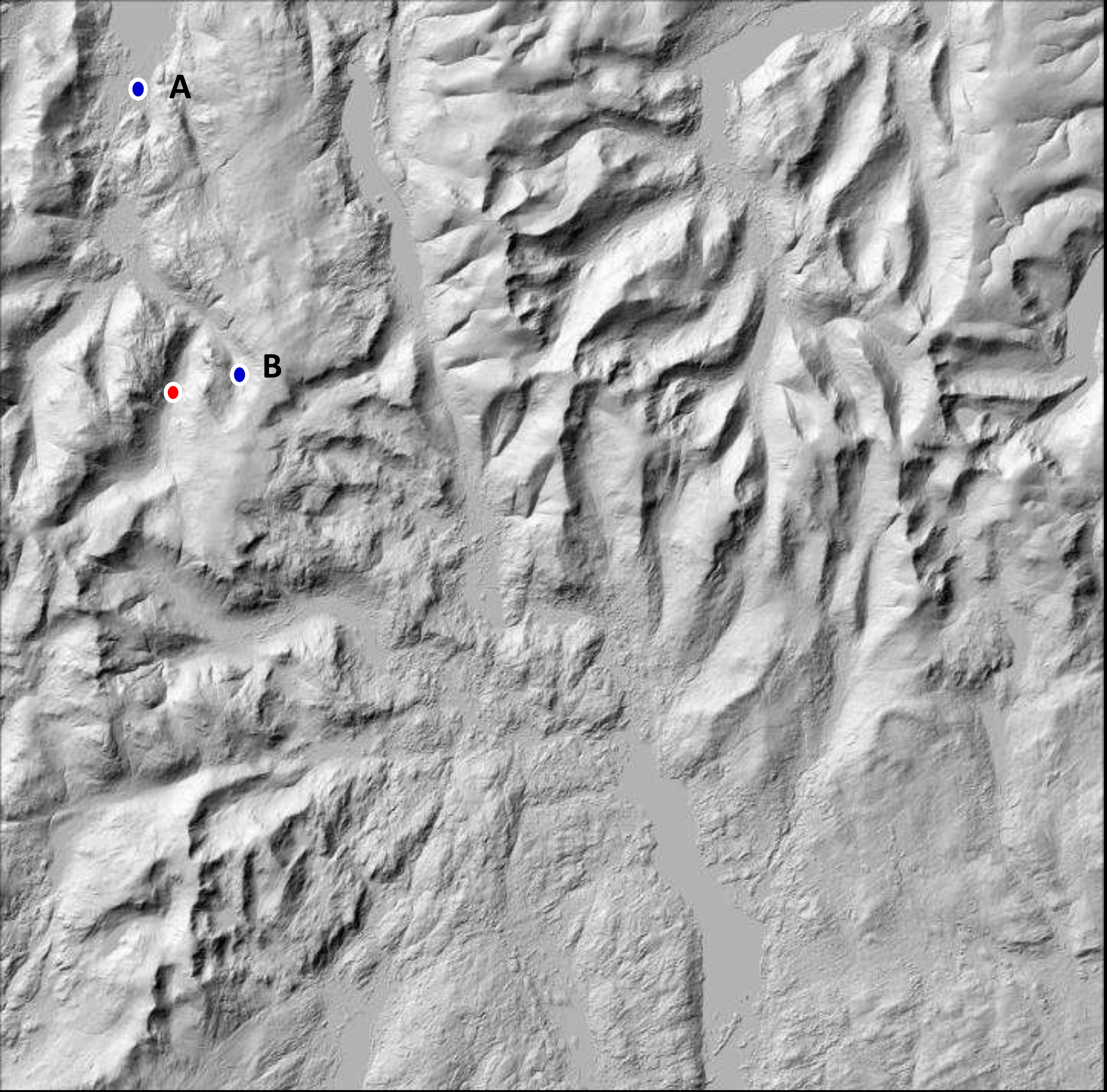
A or B

407

Which line follows the steepest path?

A or B

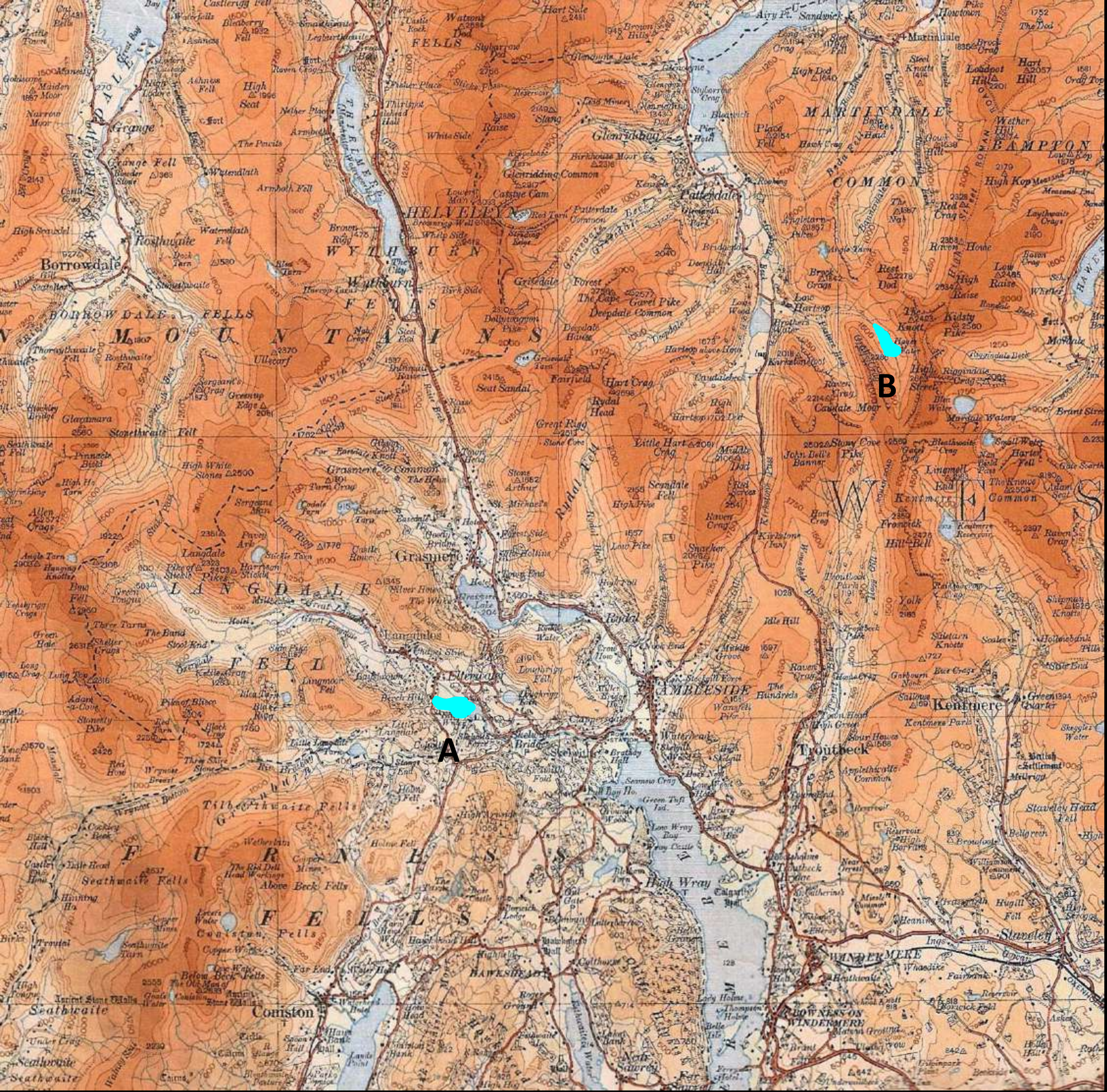
516



To which point would water flow from the red location?

A or B

602



Notice both lakes (blue area).

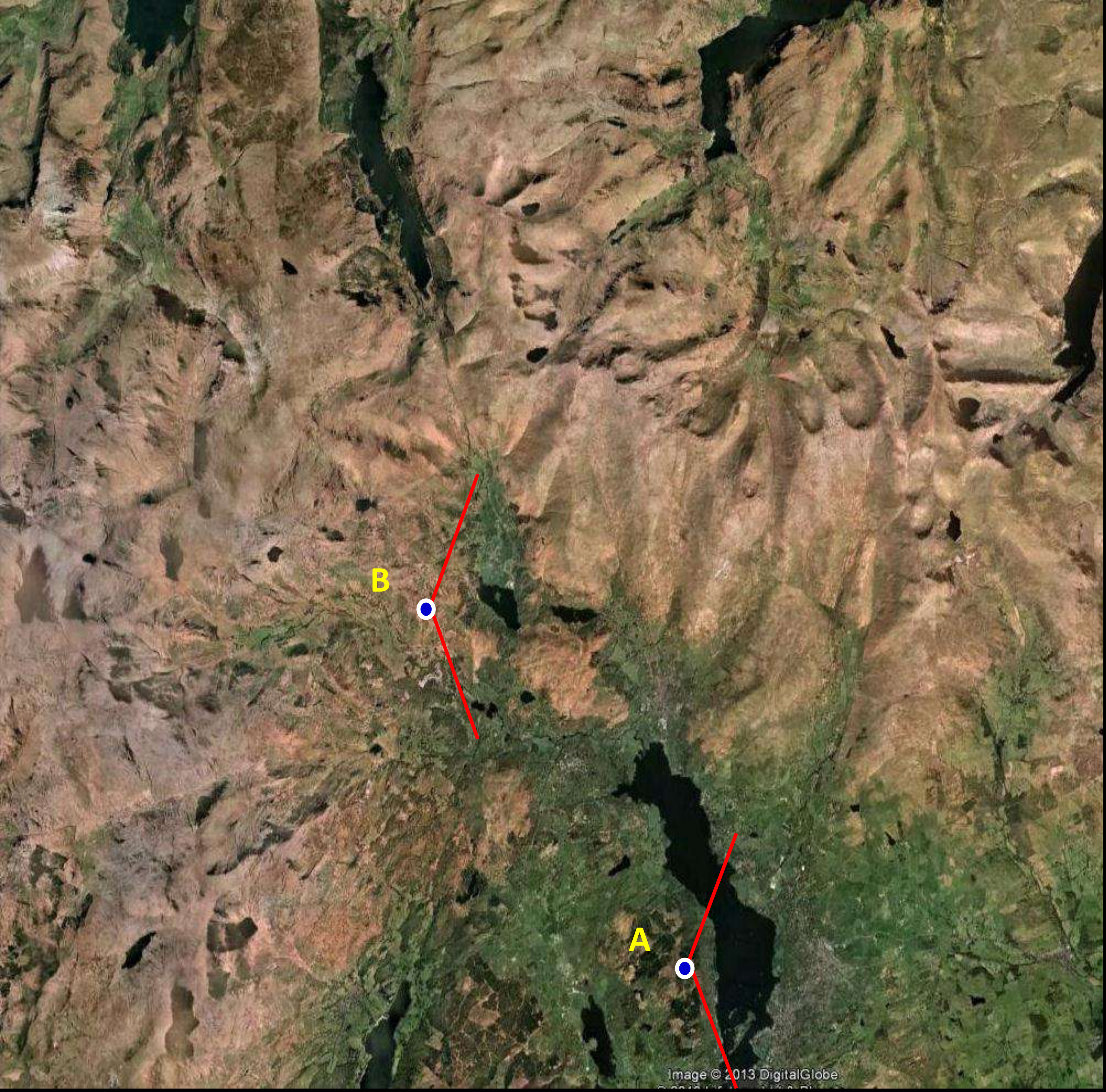
Which is the highest lake?

A or B

Notice both peaks (X sign). Which is the highest peak?

A or B

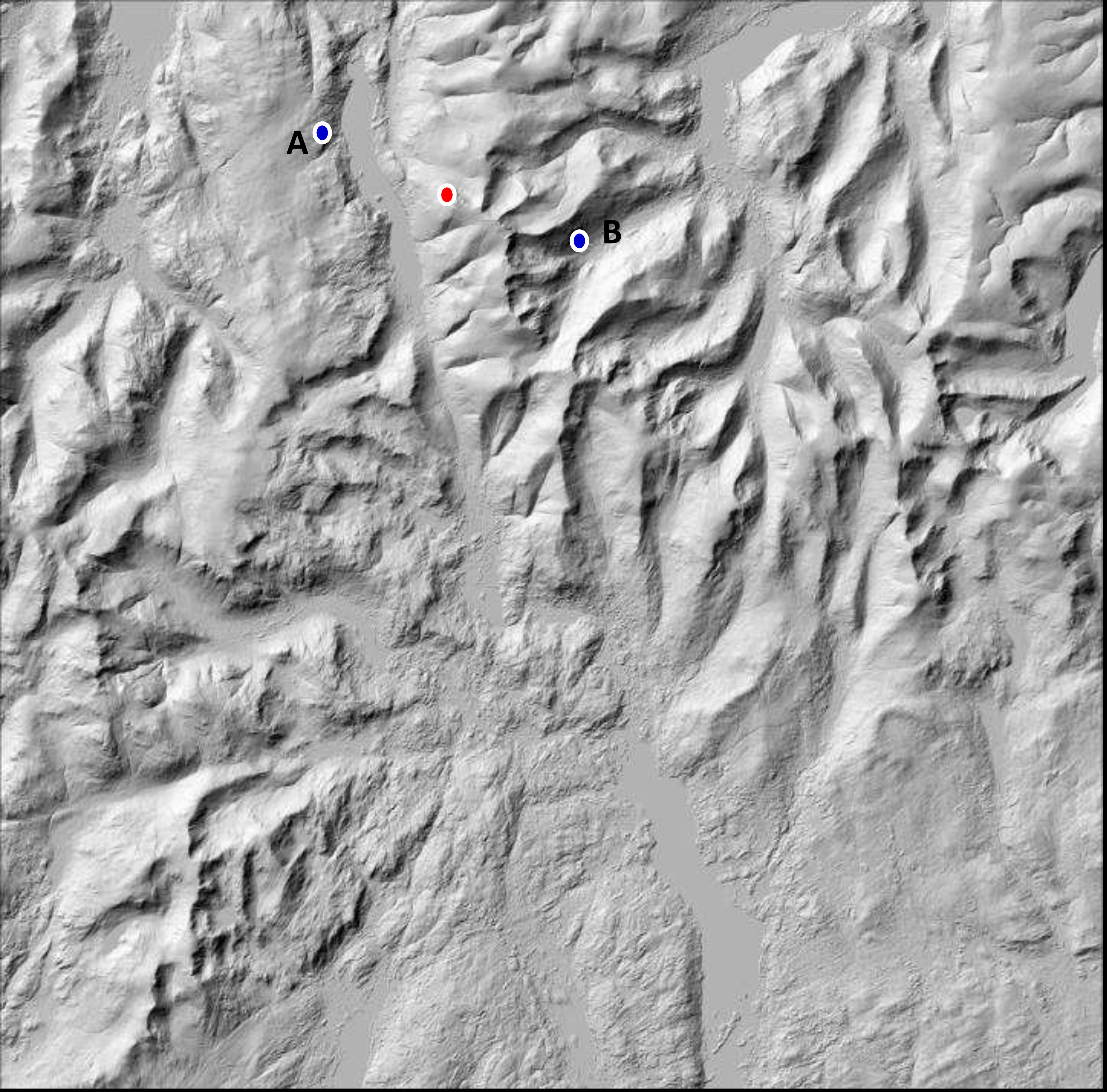
215



Which viewpoint matches the picture below?

A or B

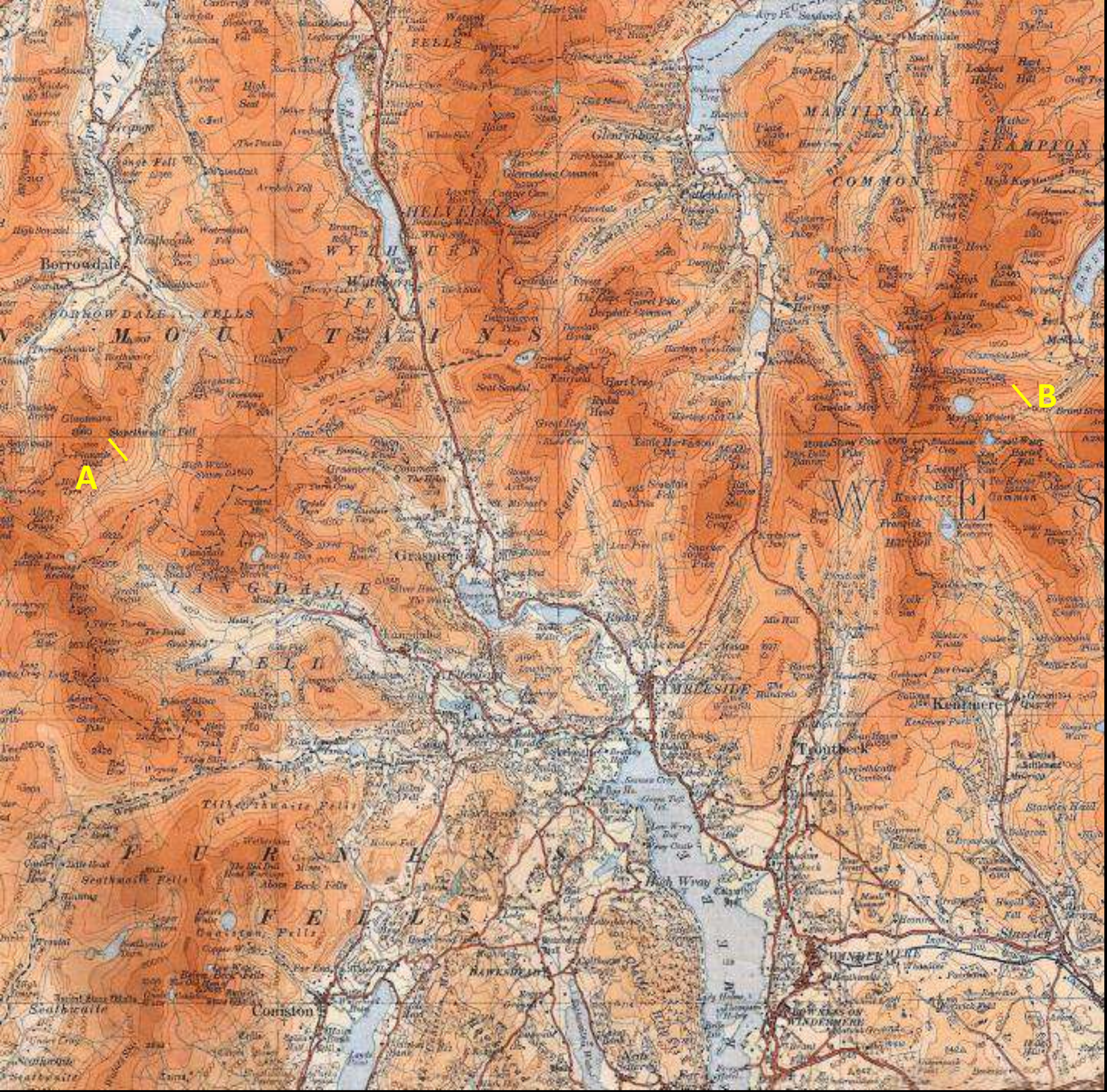
312



From which point is the red location visible?

A or B

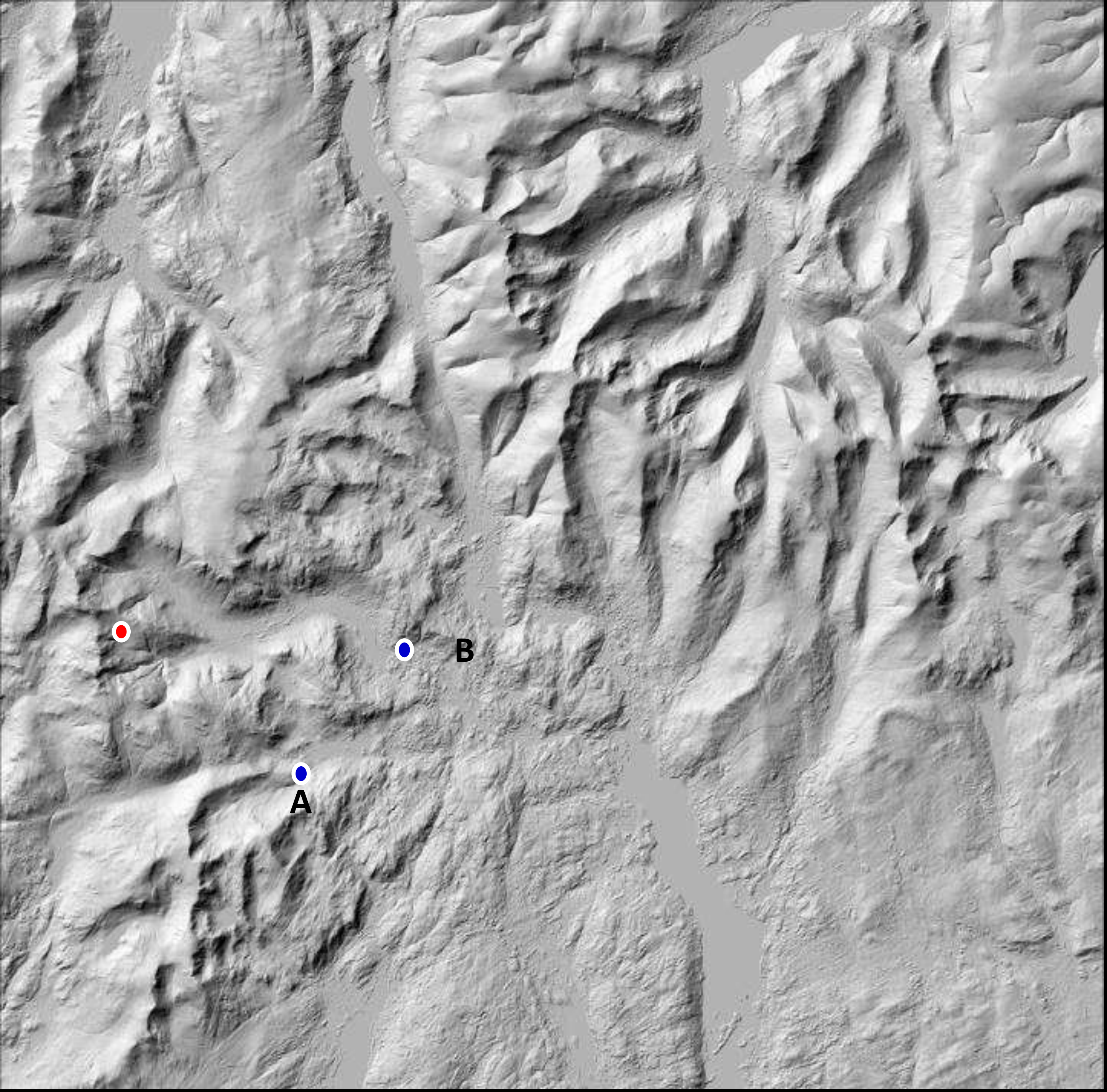
402



Which line follows the steepest path?

A or B

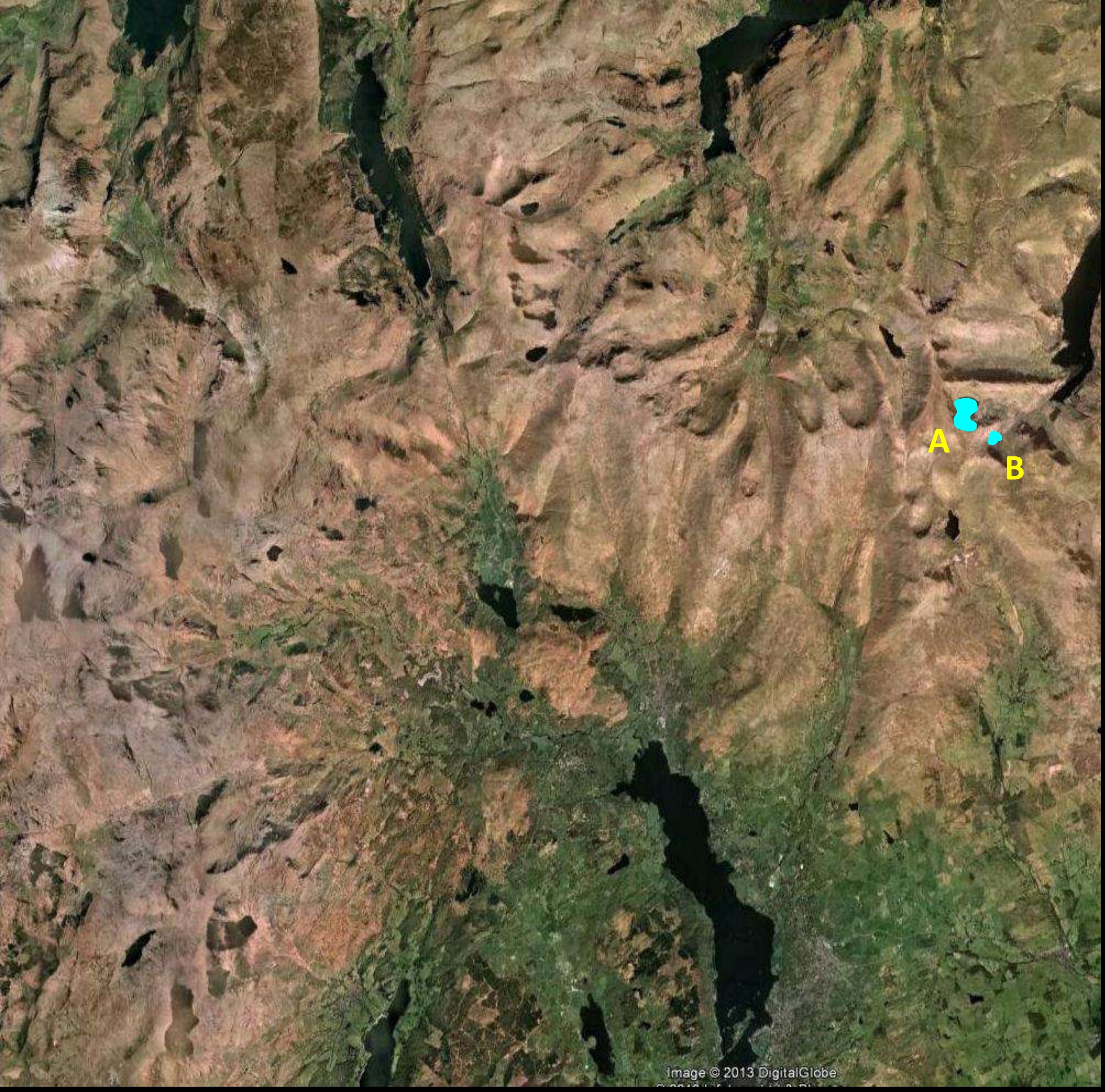
506c



To which point would water flow from the red location?

A or B

613

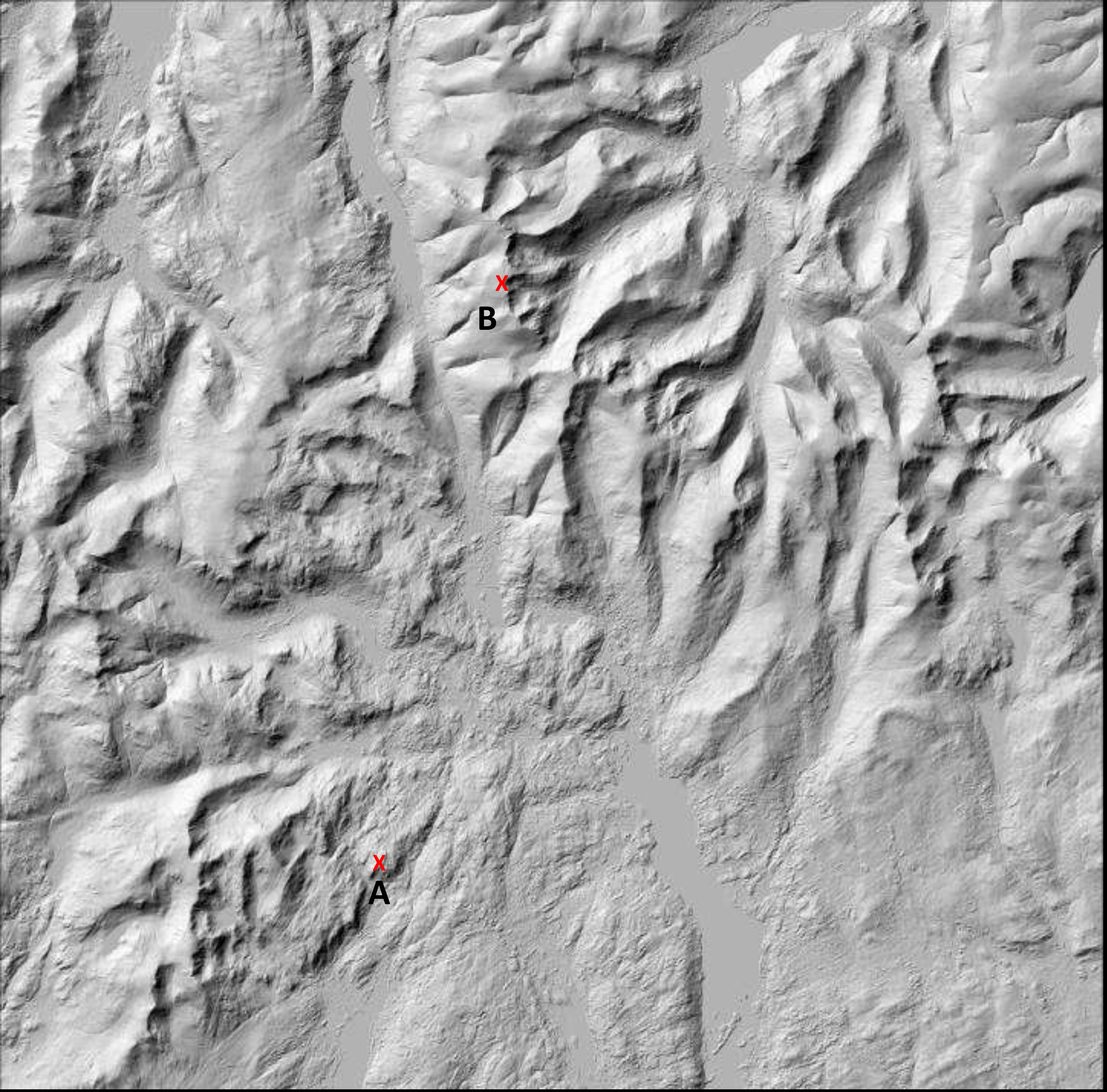


Notice both lakes
(blue area).

Which is the highest lake?

A or B

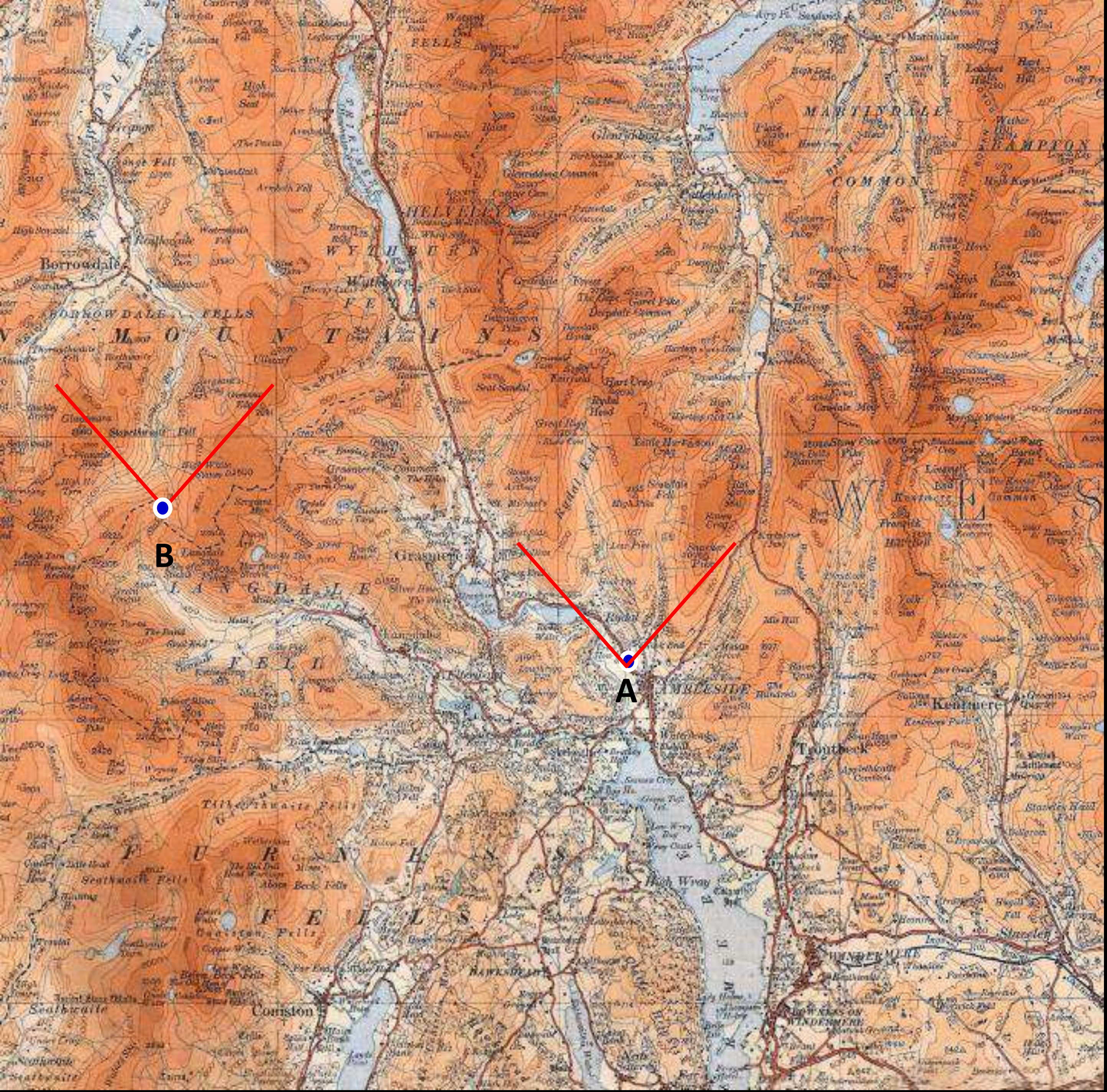
112



Notice both peaks (X sign). Which is the highest peak?

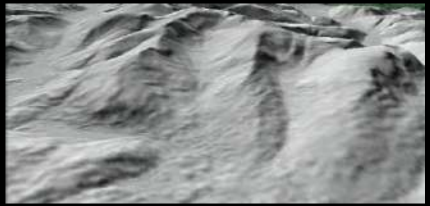
A or B

202

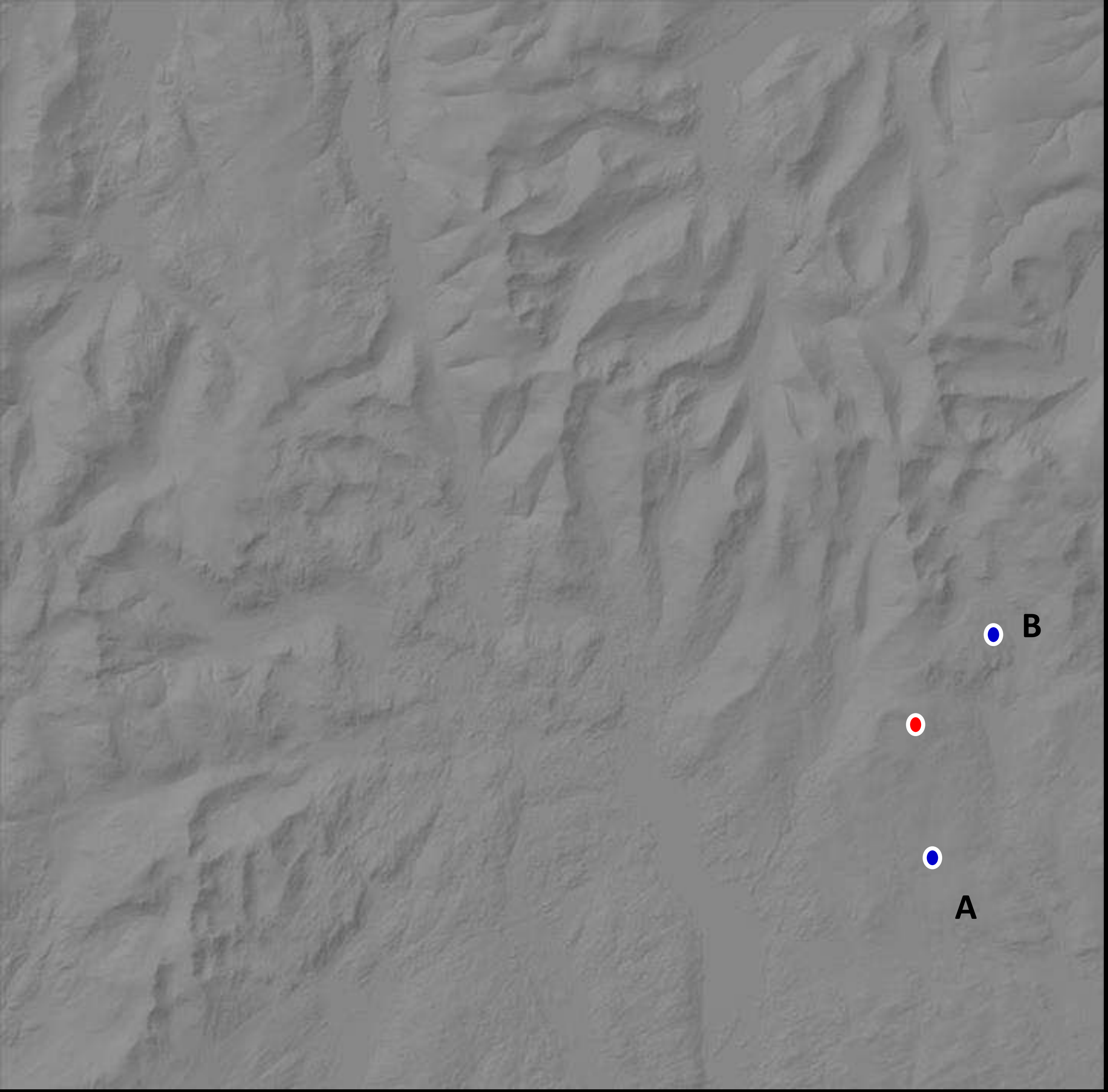


Which viewpoint matches the picture below?

A or B



305a



From which point is the red location visible?

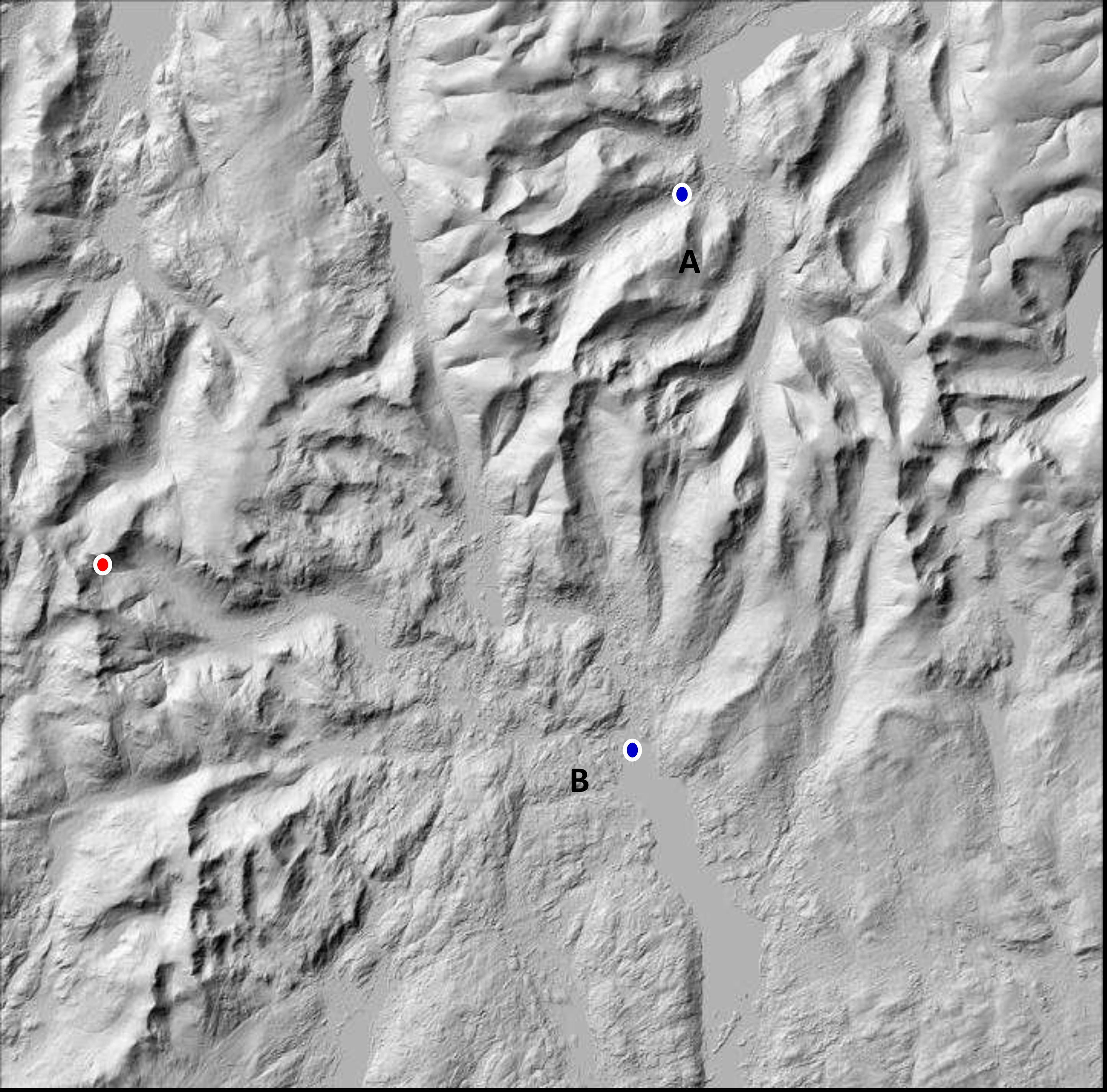
A or B

408

Which line follows the steepest path?

A or B

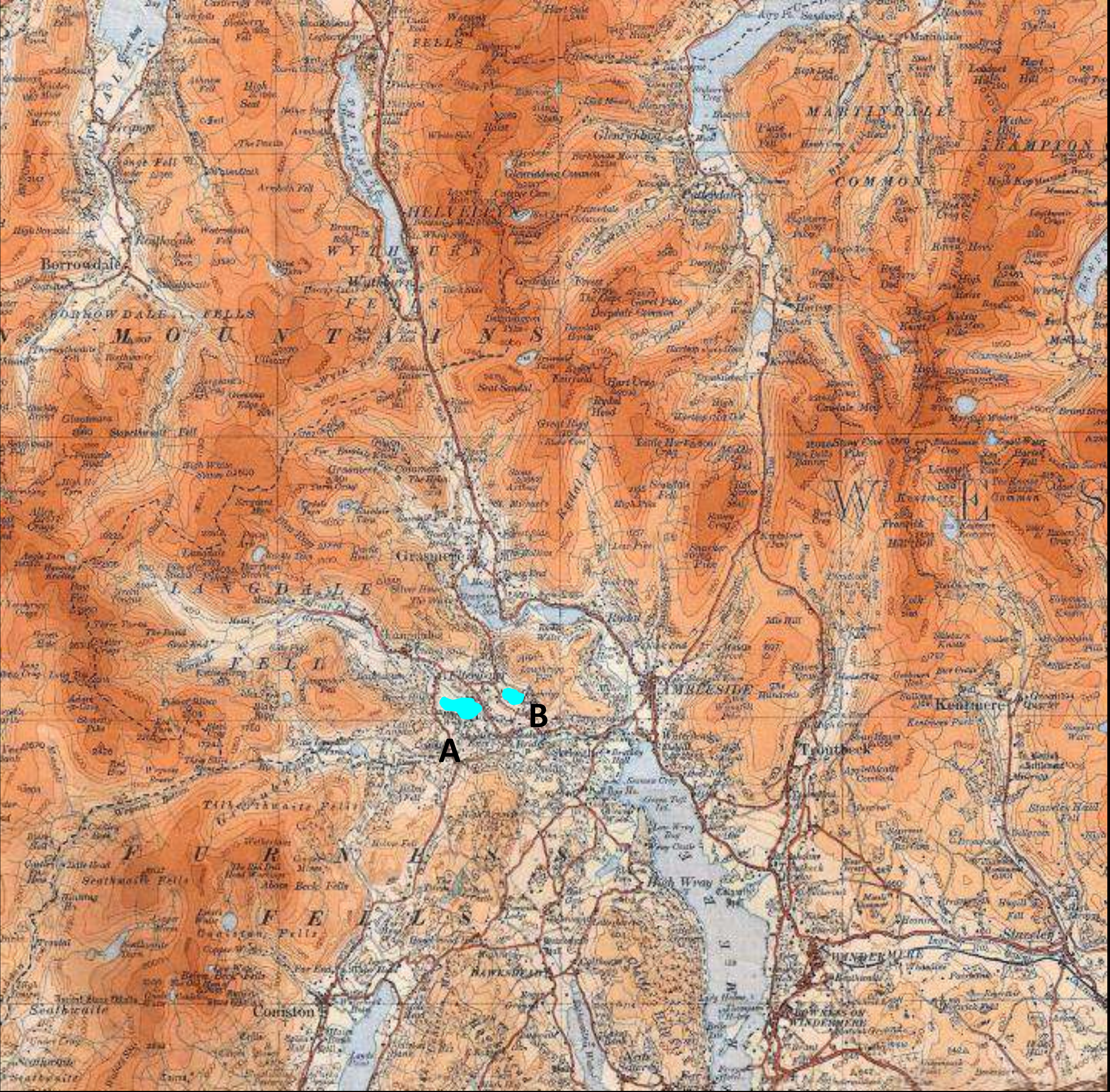
511



To which point would water flow from the red location?

A or B

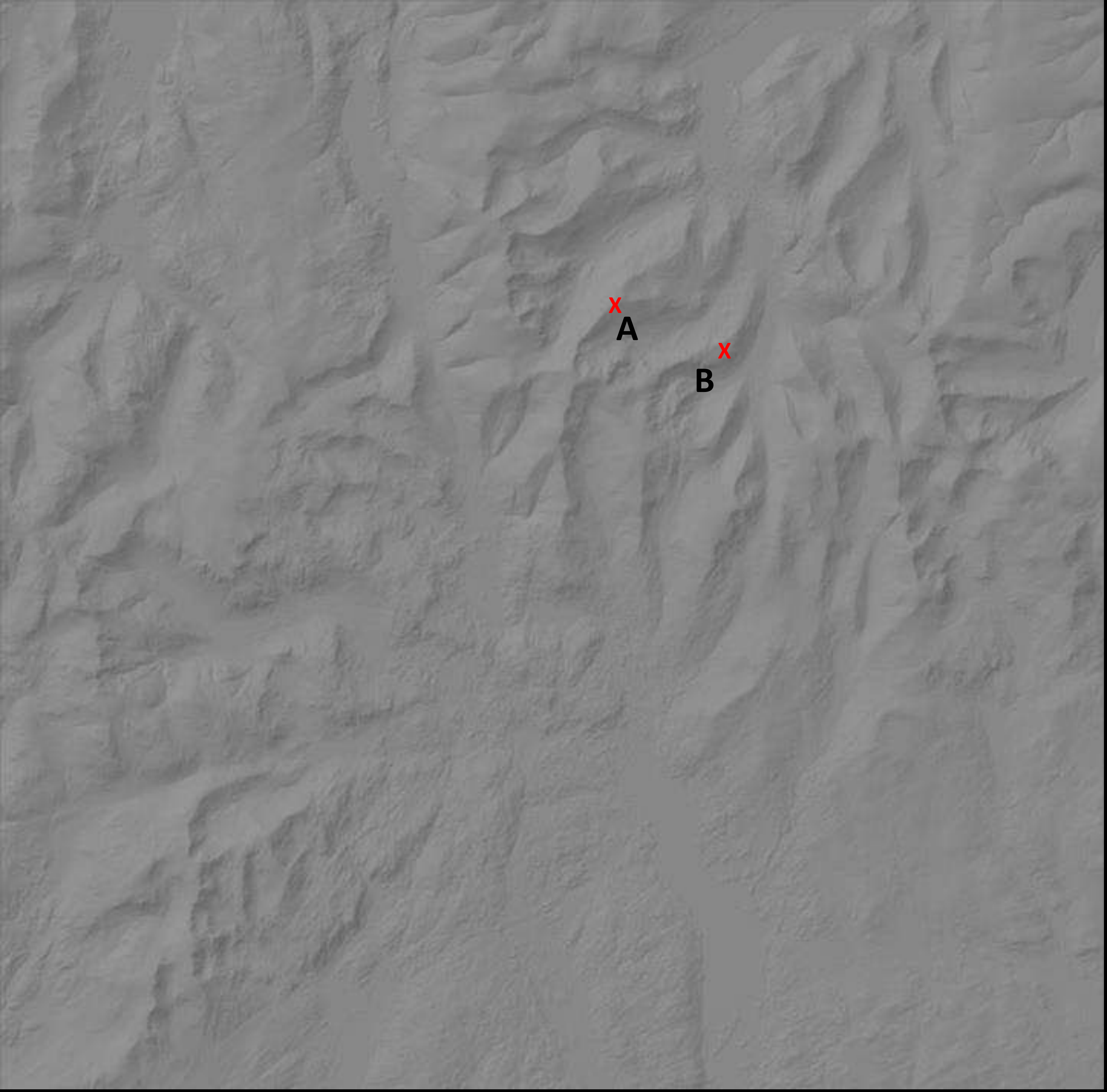
603



Notice both lakes (blue area).

Which is the highest lake?

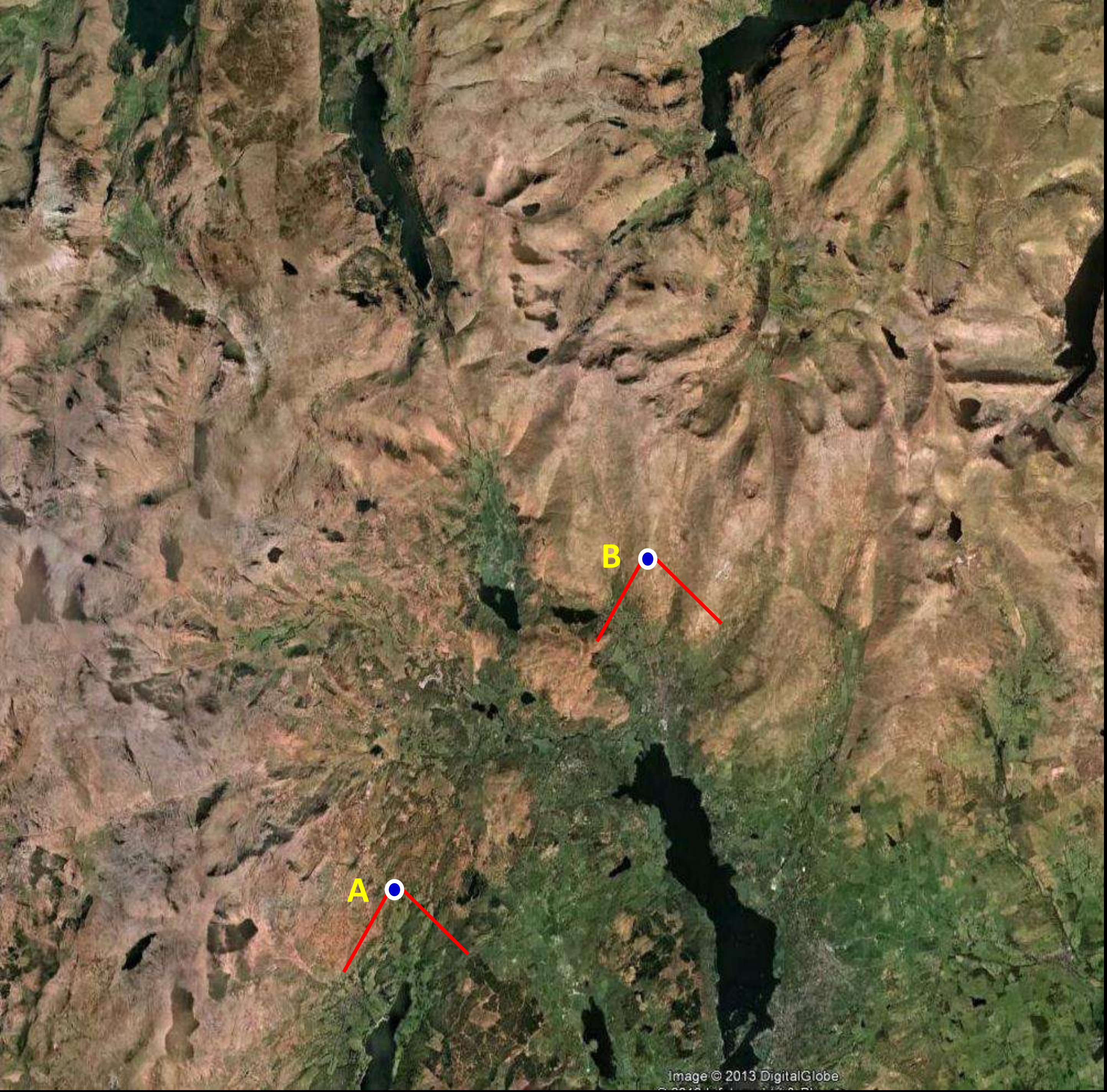
A or B



Notice both peaks (X sign). Which is the highest peak?

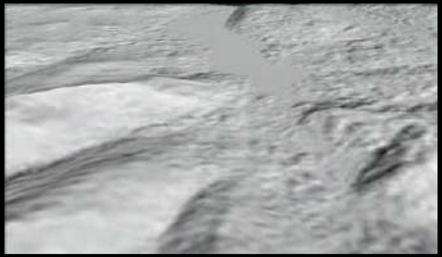
A or B

209

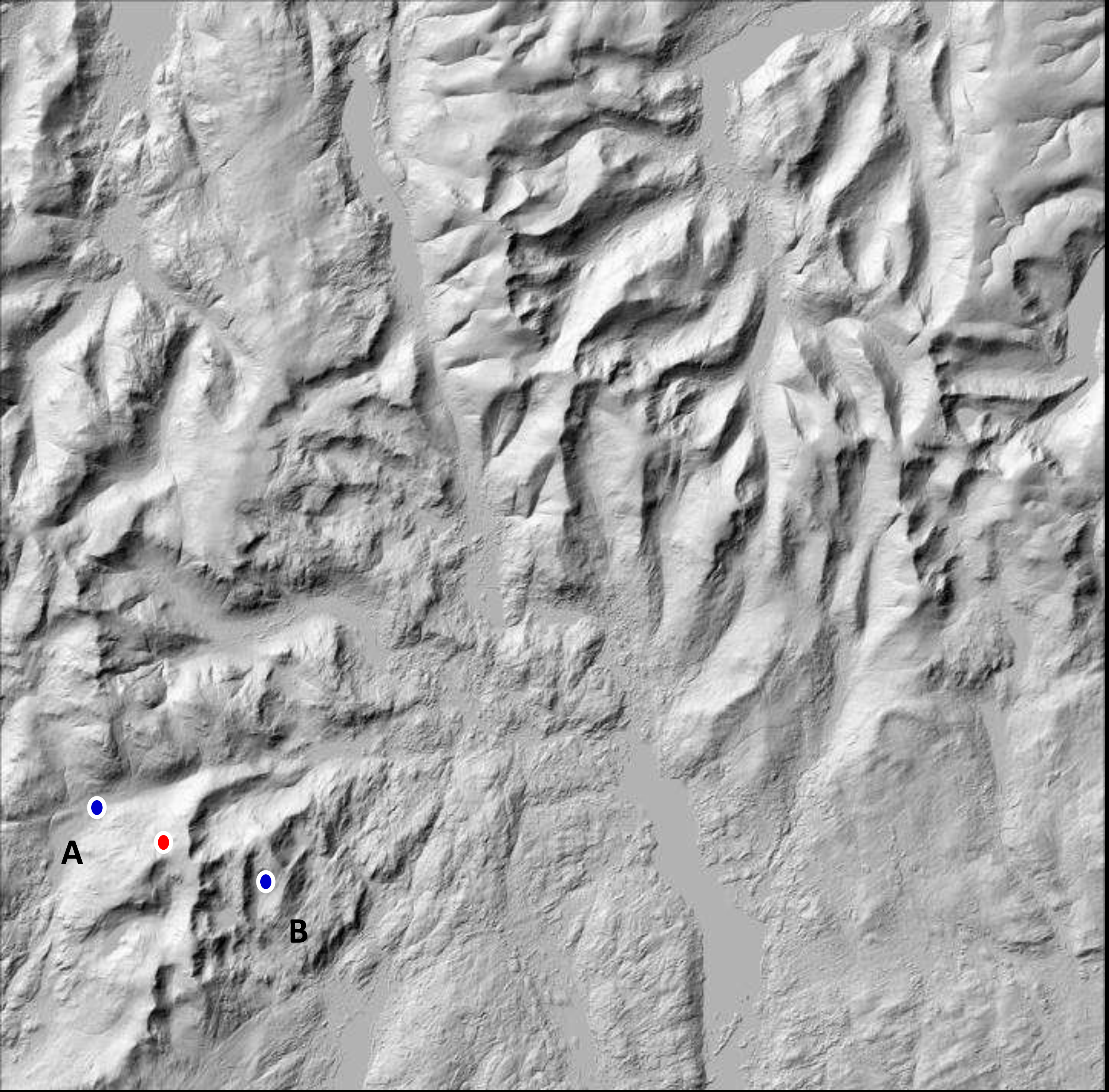


Which viewpoint matches the picture below?

A or B



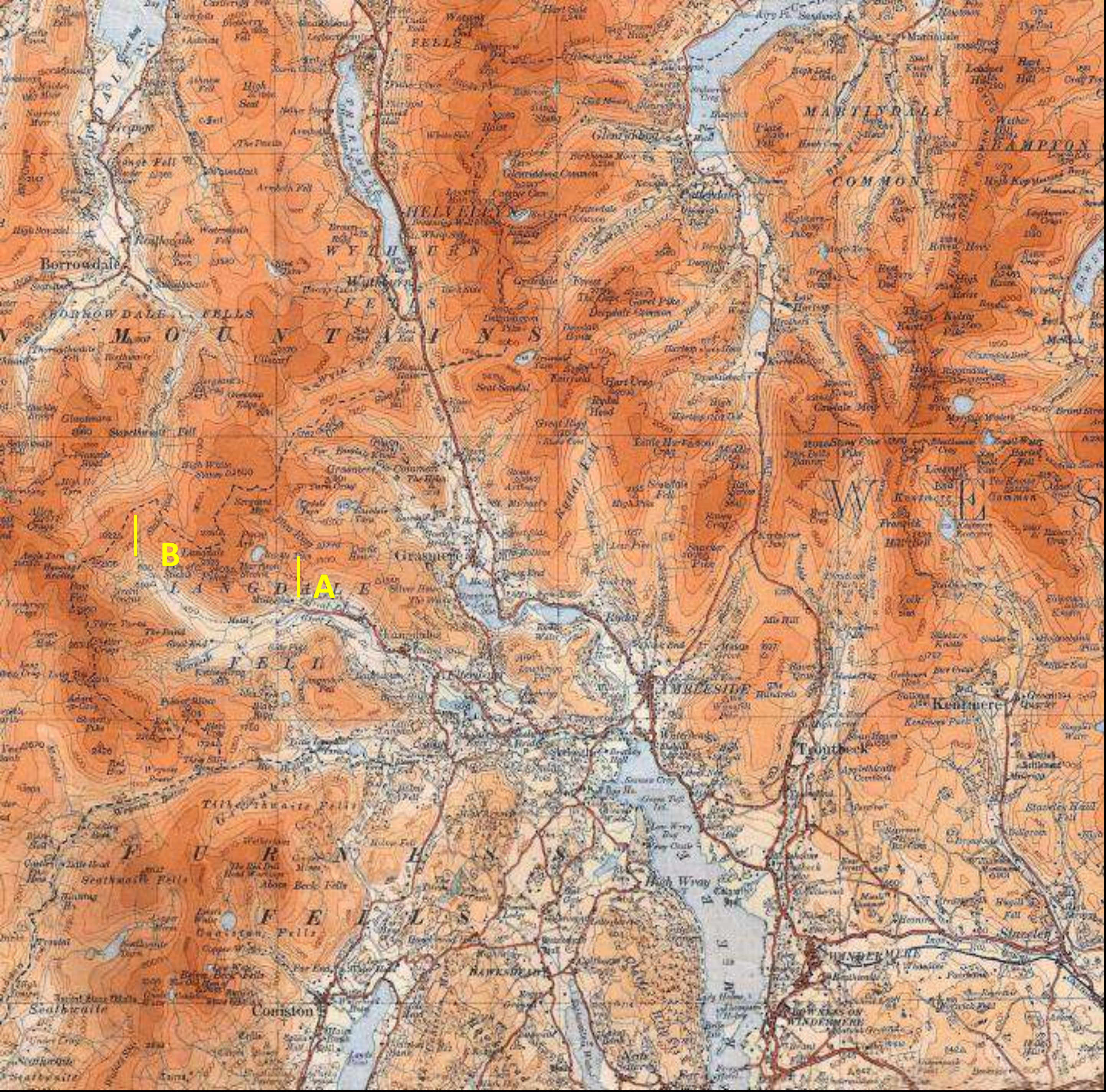
311



From which point is the red location visible?

A or B

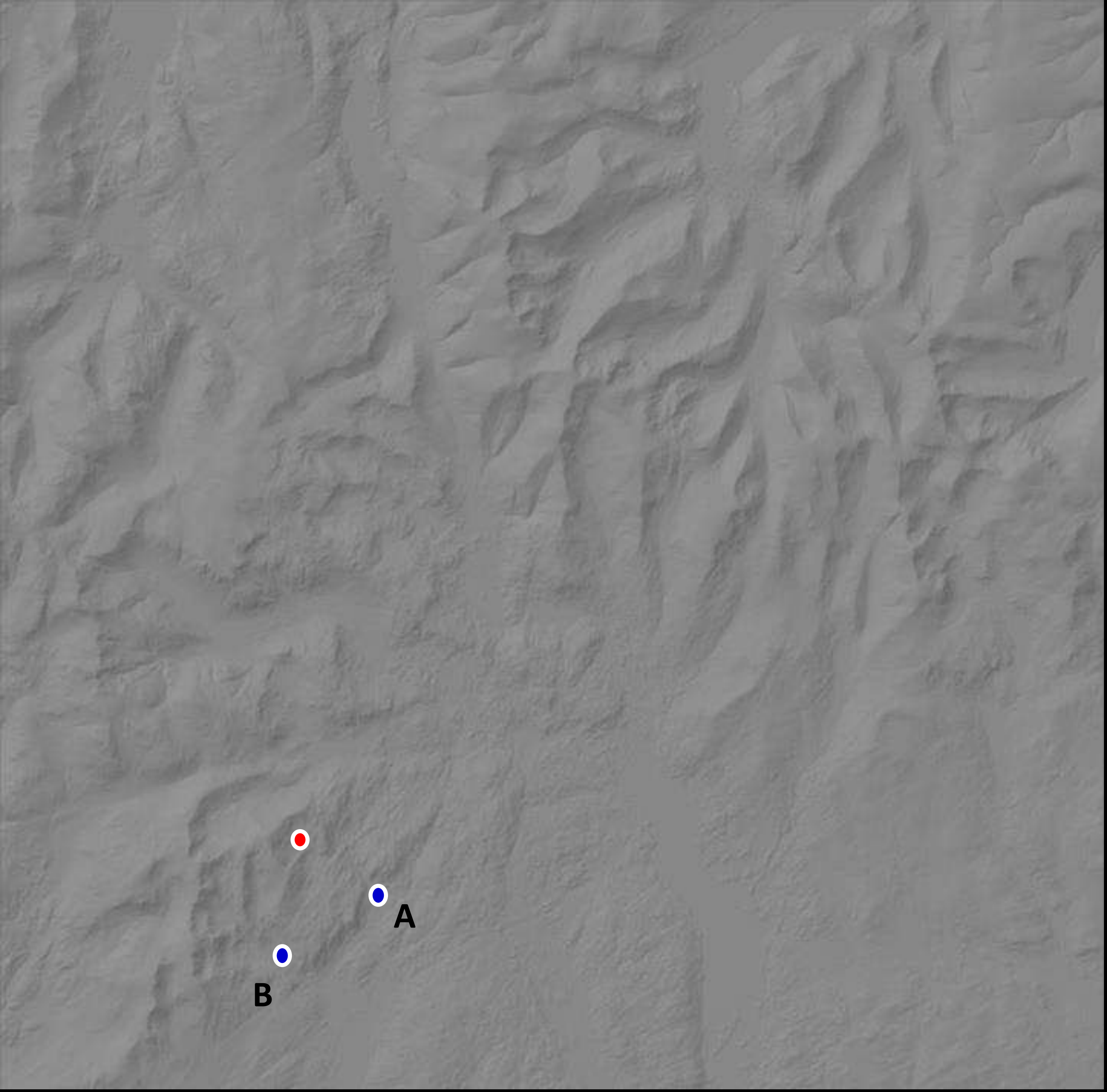
403



Which line follows the steepest path?

A or B

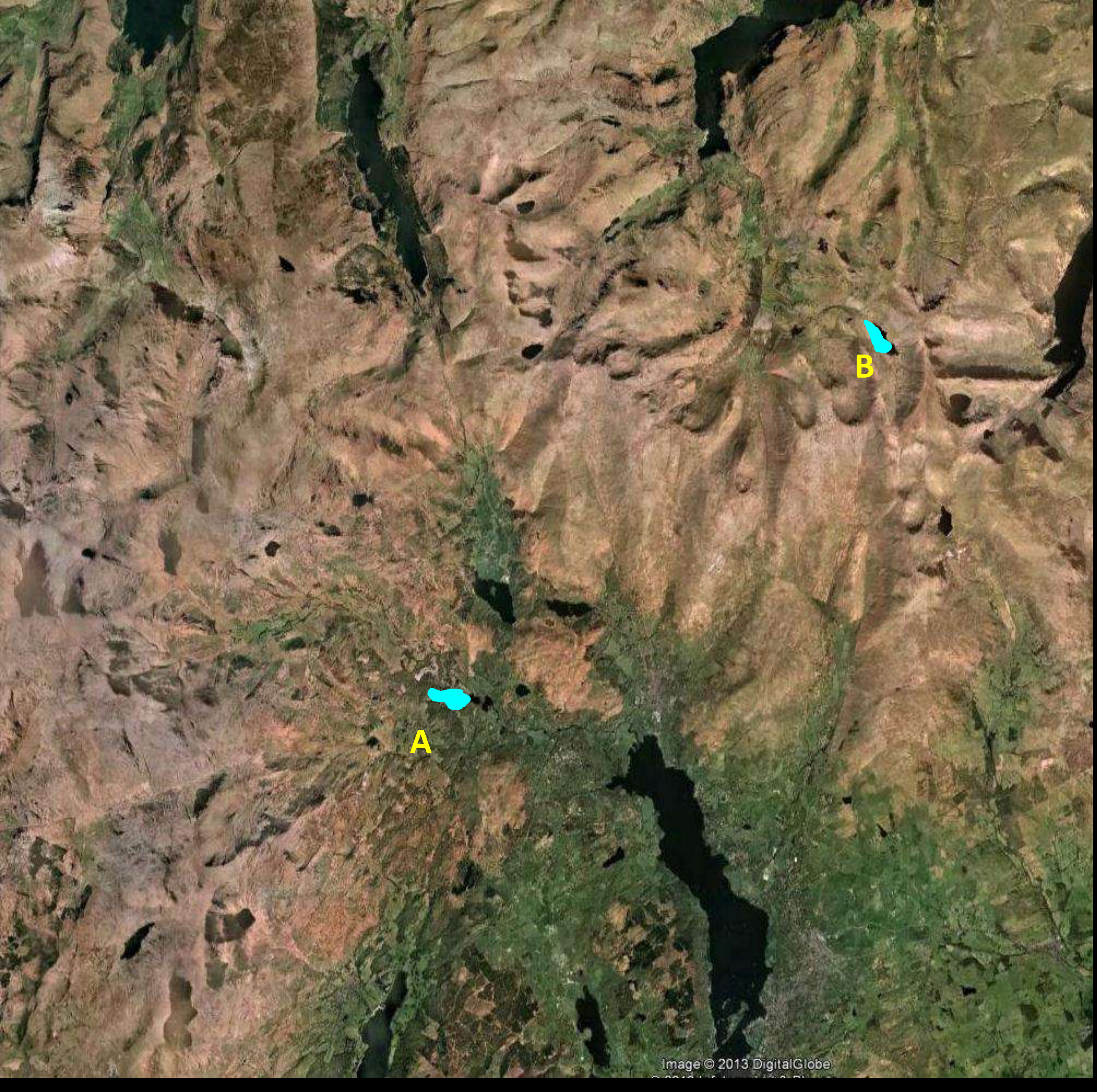
504c



To which point would water flow from the red location?

A or B

608

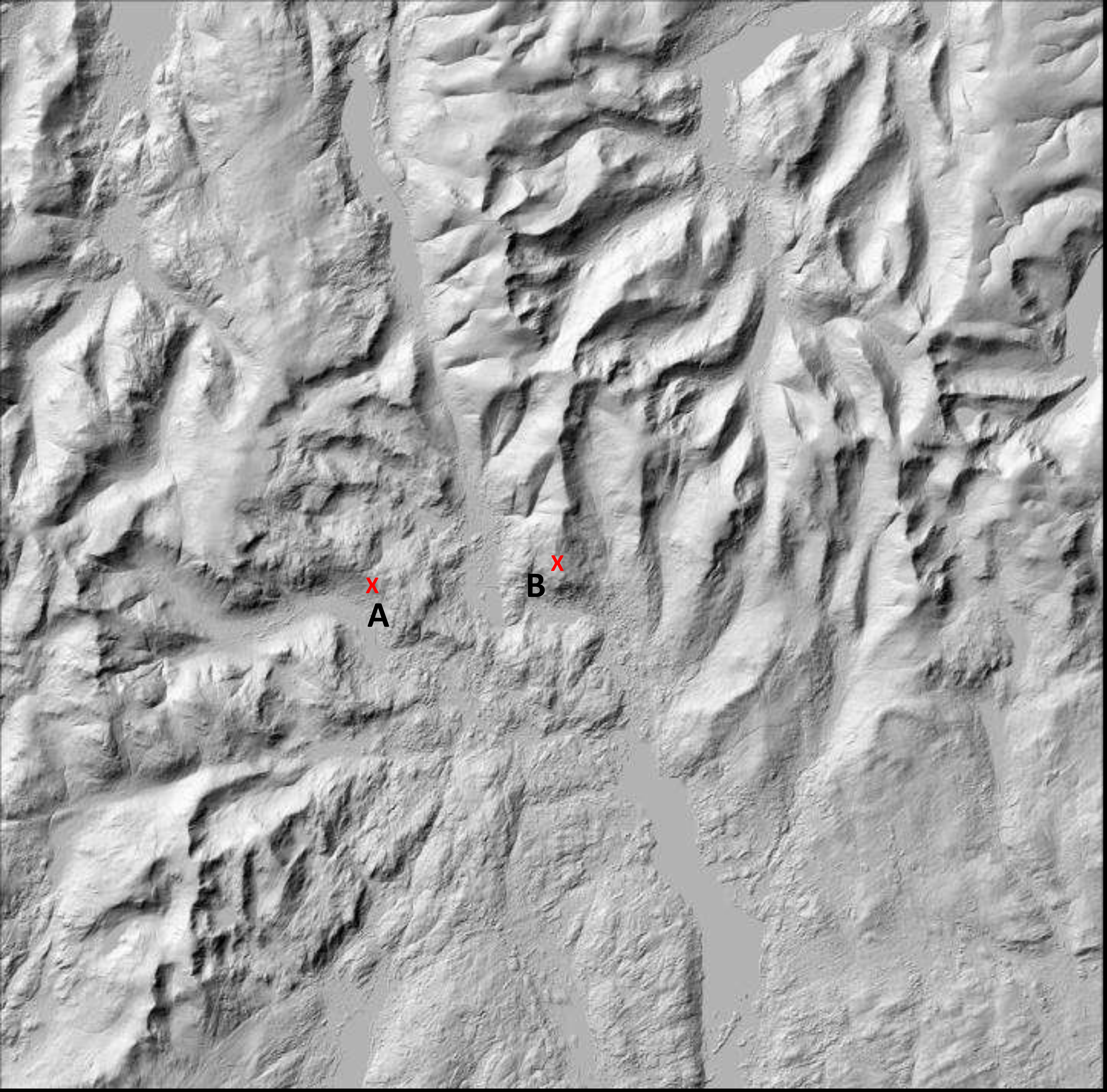


Notice both lakes (blue area).

Which is the highest lake?

A or B

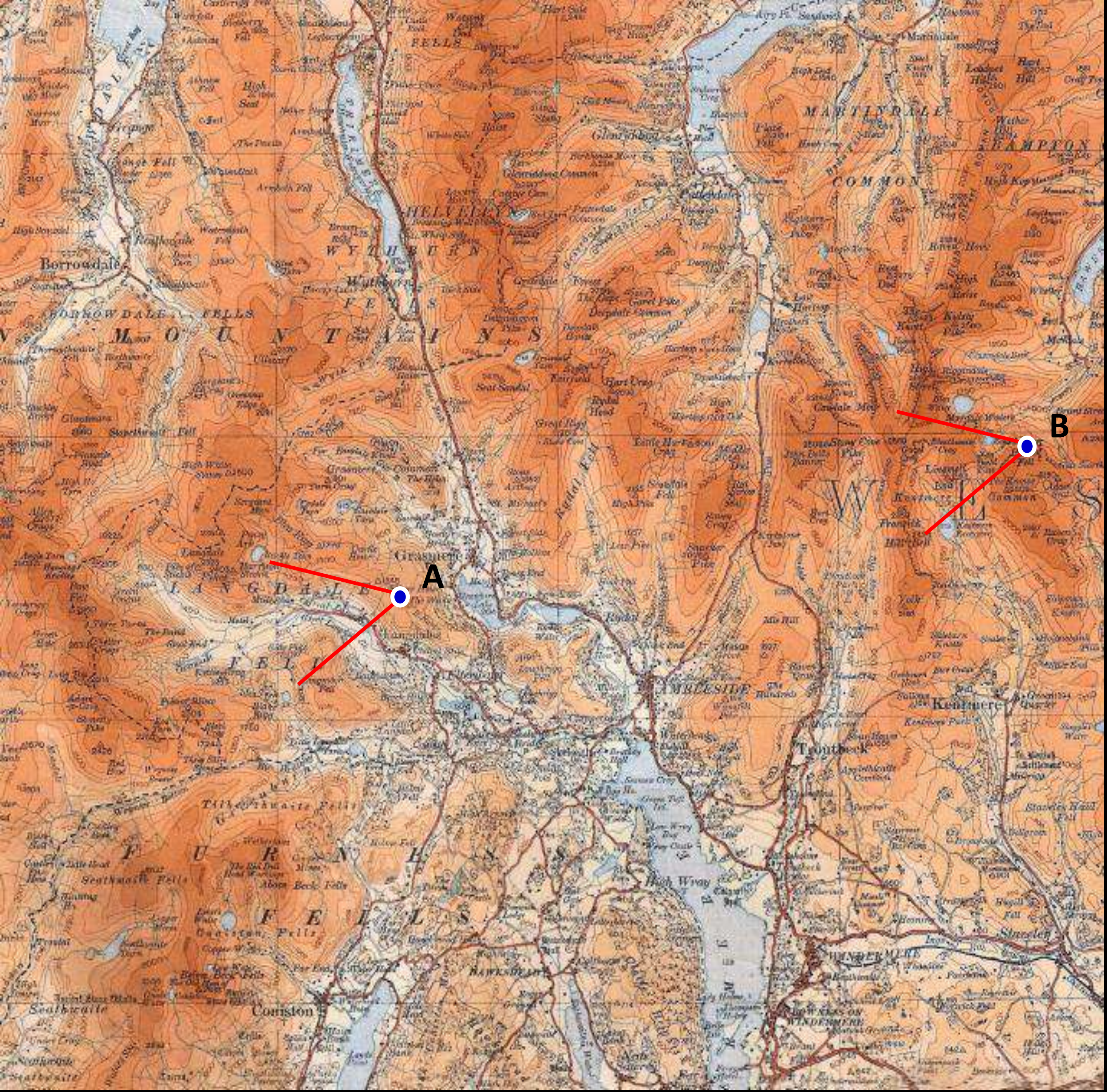
116



Notice both peaks (X sign). Which is the highest peak?

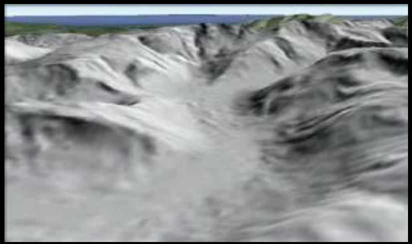
A or B

203

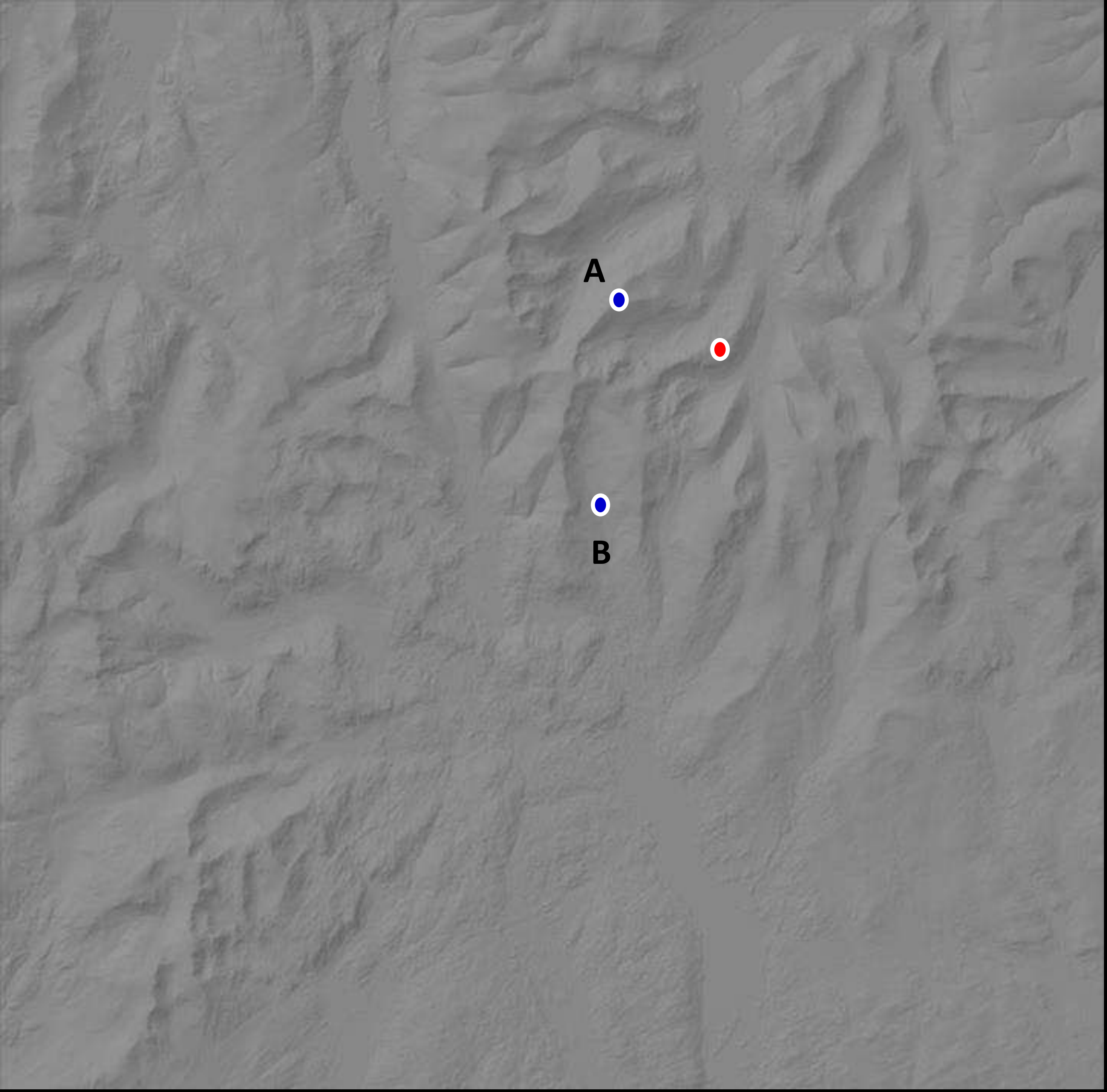


Which viewpoint matches the picture below?

A or B



306a



From which point is the red location visible?

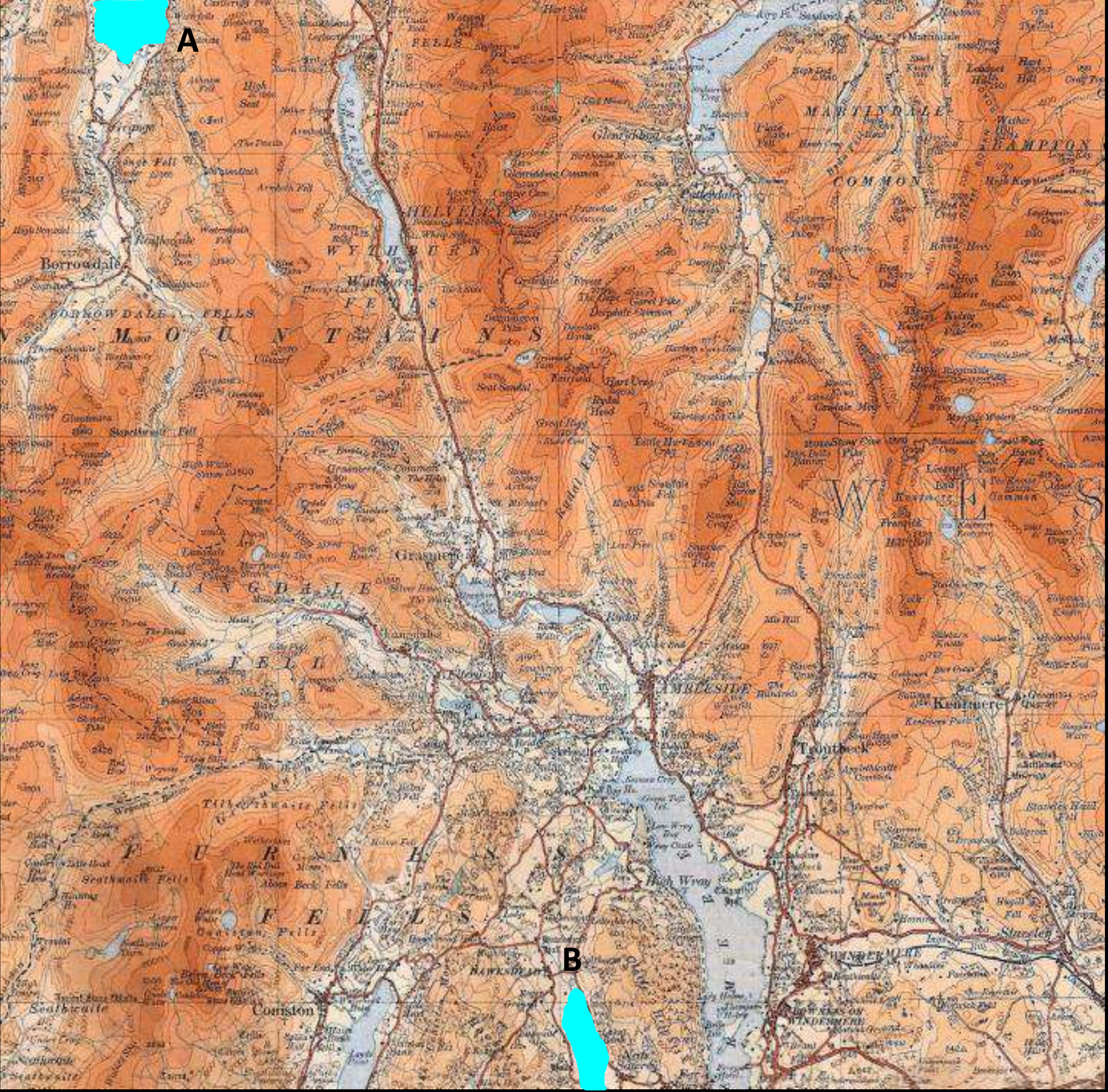
A or B

409

Which line follows the steepest path?

A or B

512



Notice both lakes (blue area).

Which is the highest lake?

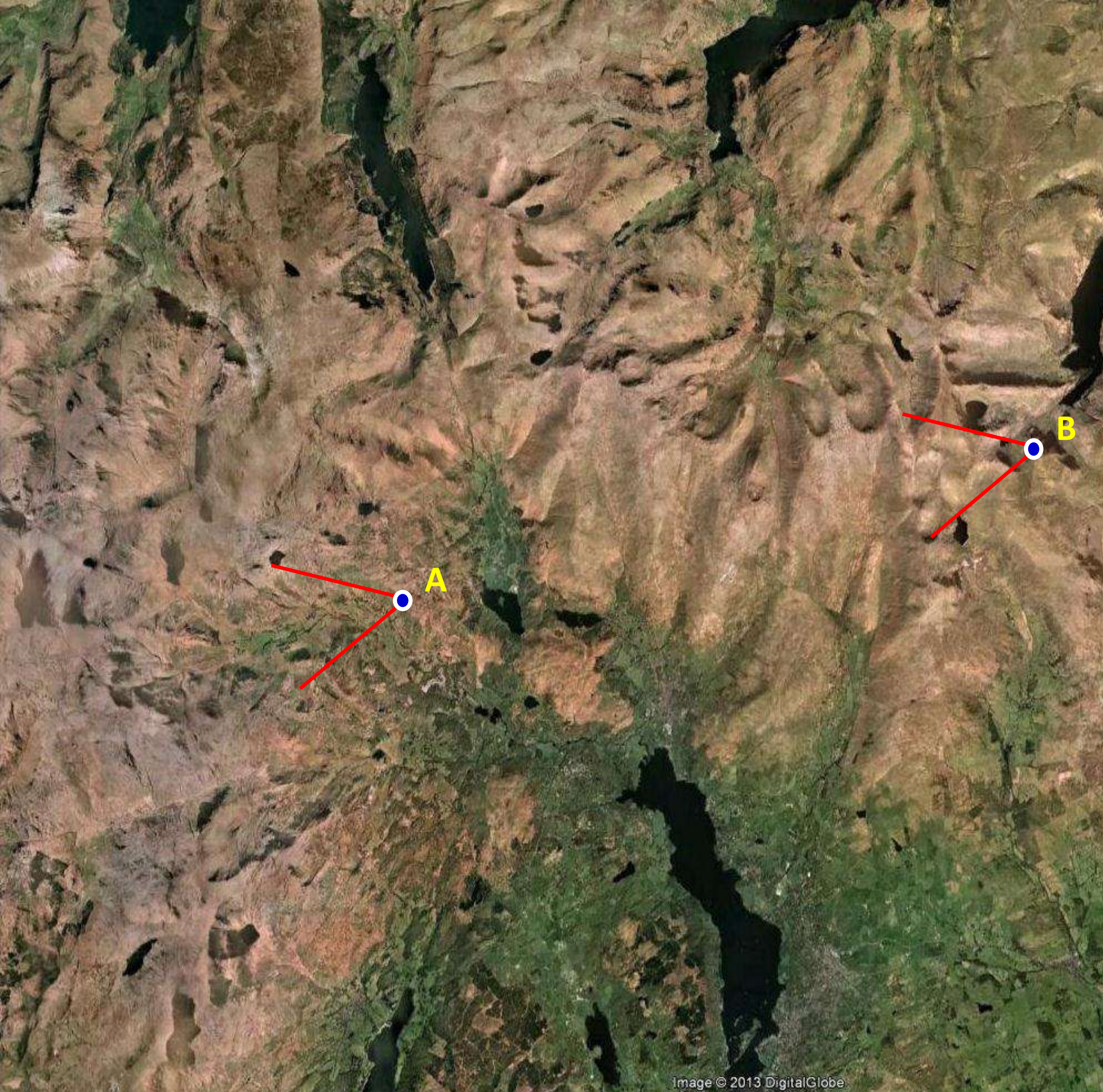
A or B

104

Notice both peaks (X sign). Which is the highest peak?

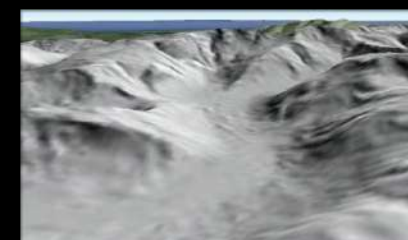
A or B

207

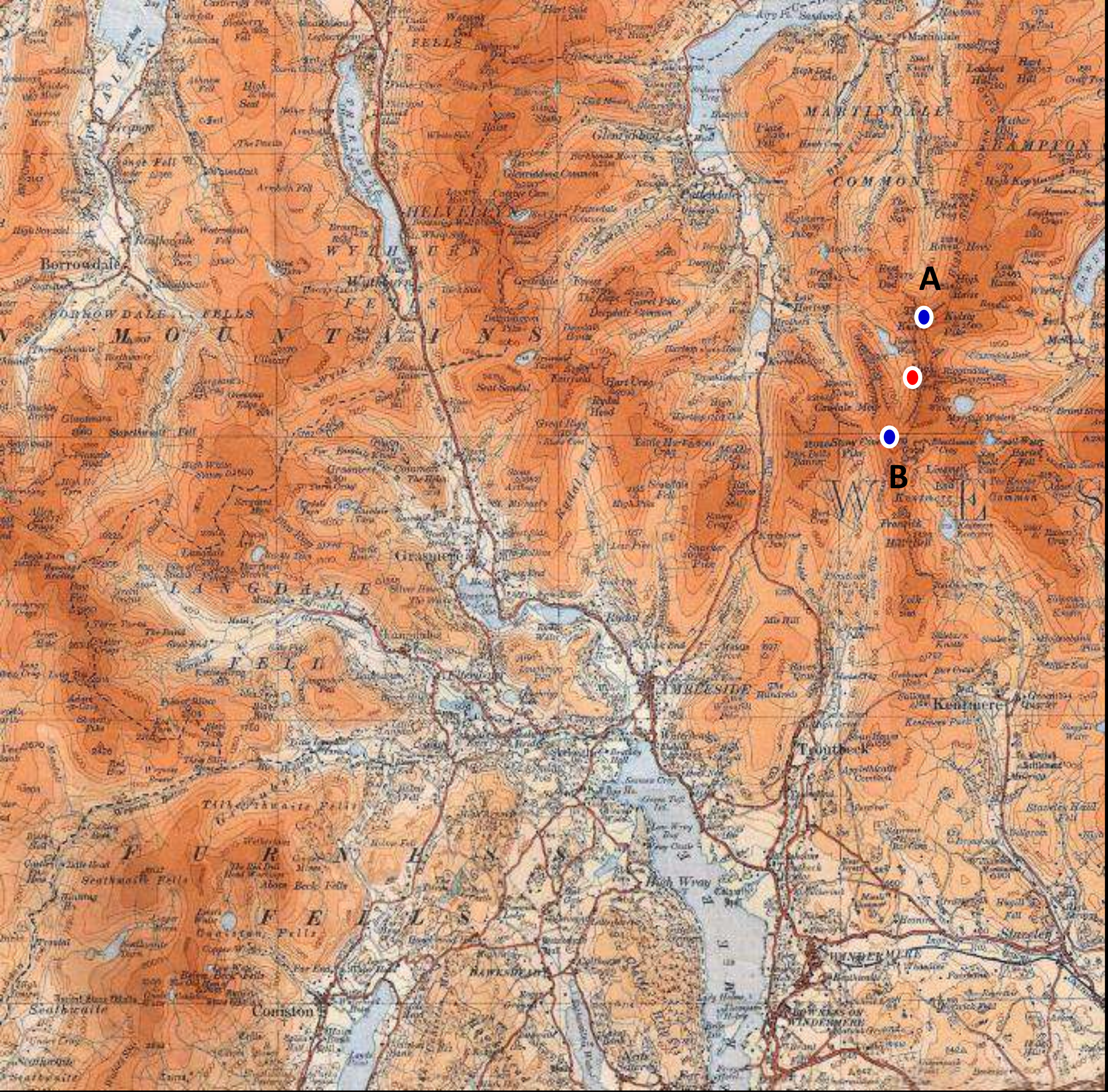


Which viewpoint matches the picture below?

A or B



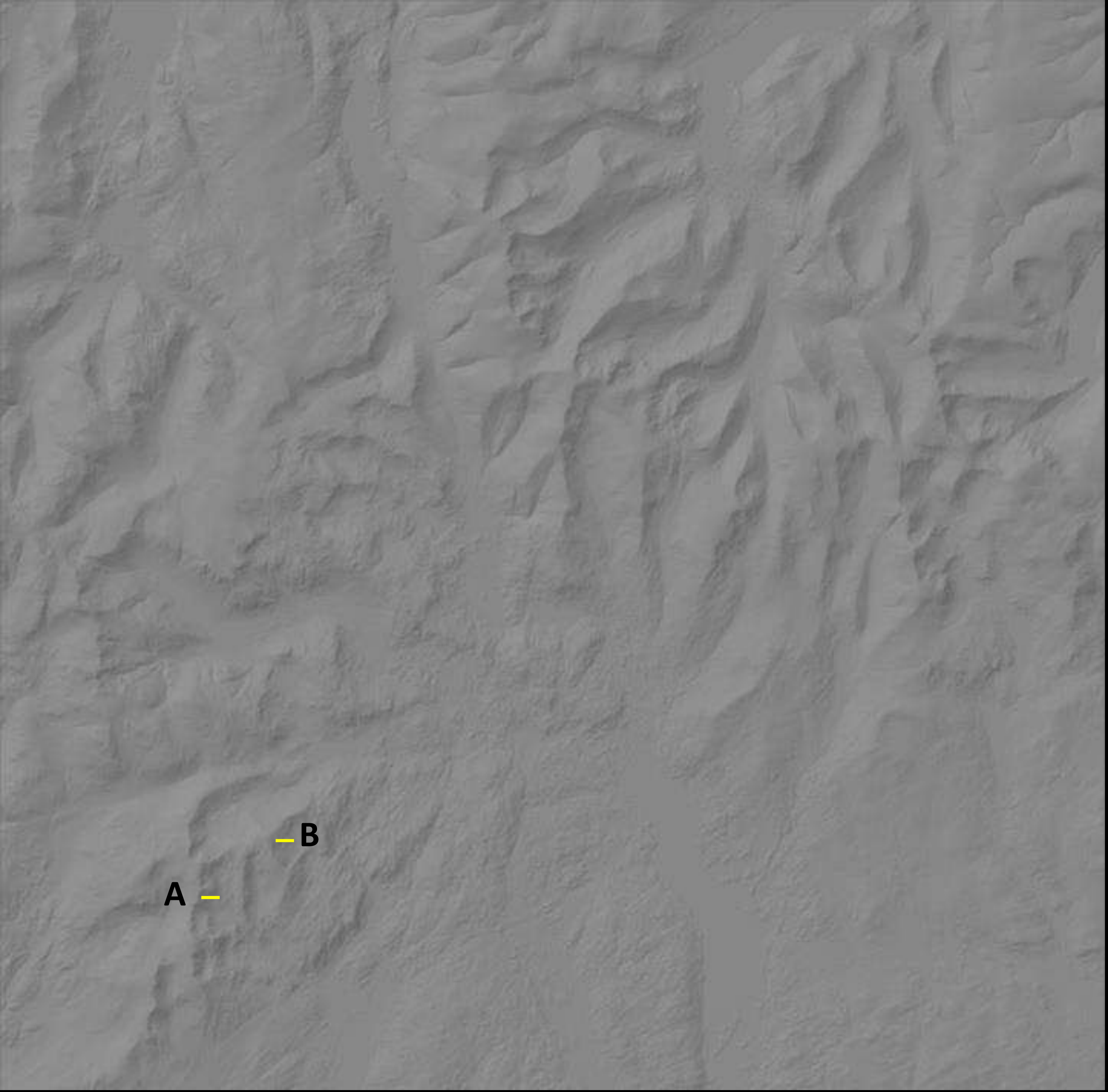
310



From which point is the red location visible?

A or B

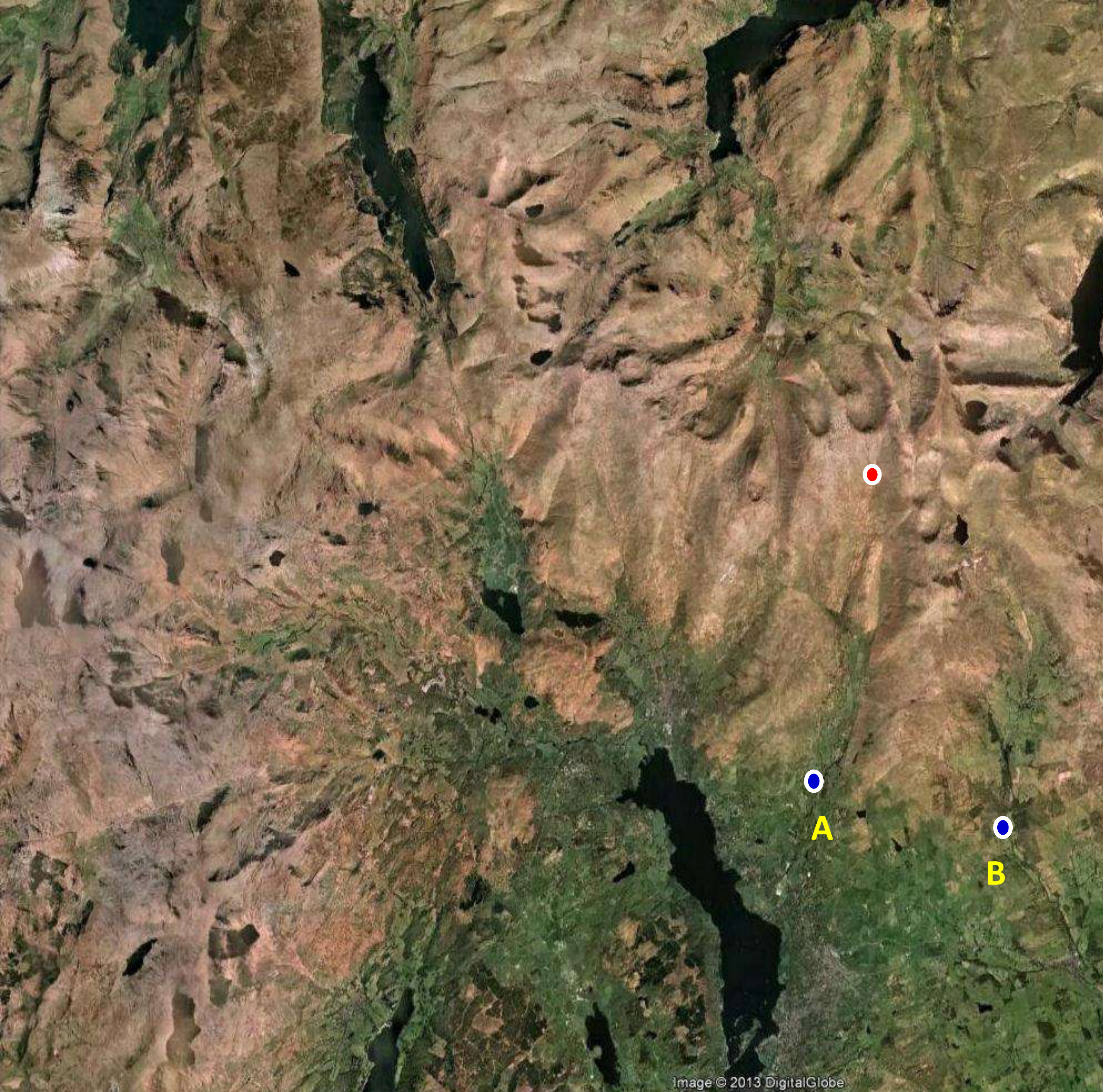
405



Which line follows the steepest path?

A or B

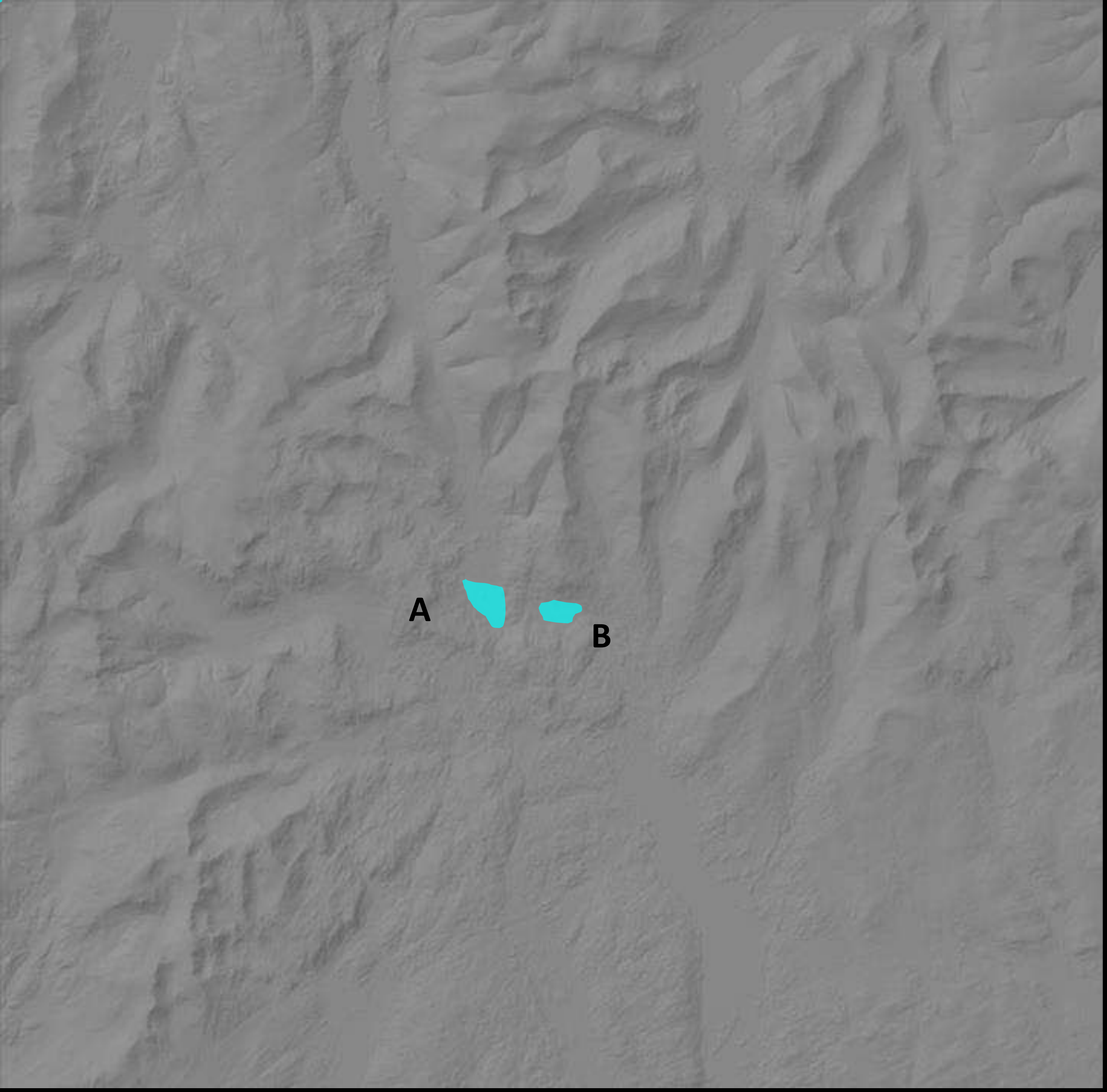
507



To which point would water flow from the red location?

A or B

611



Notice both lakes (blue area).

Which is the highest lake?

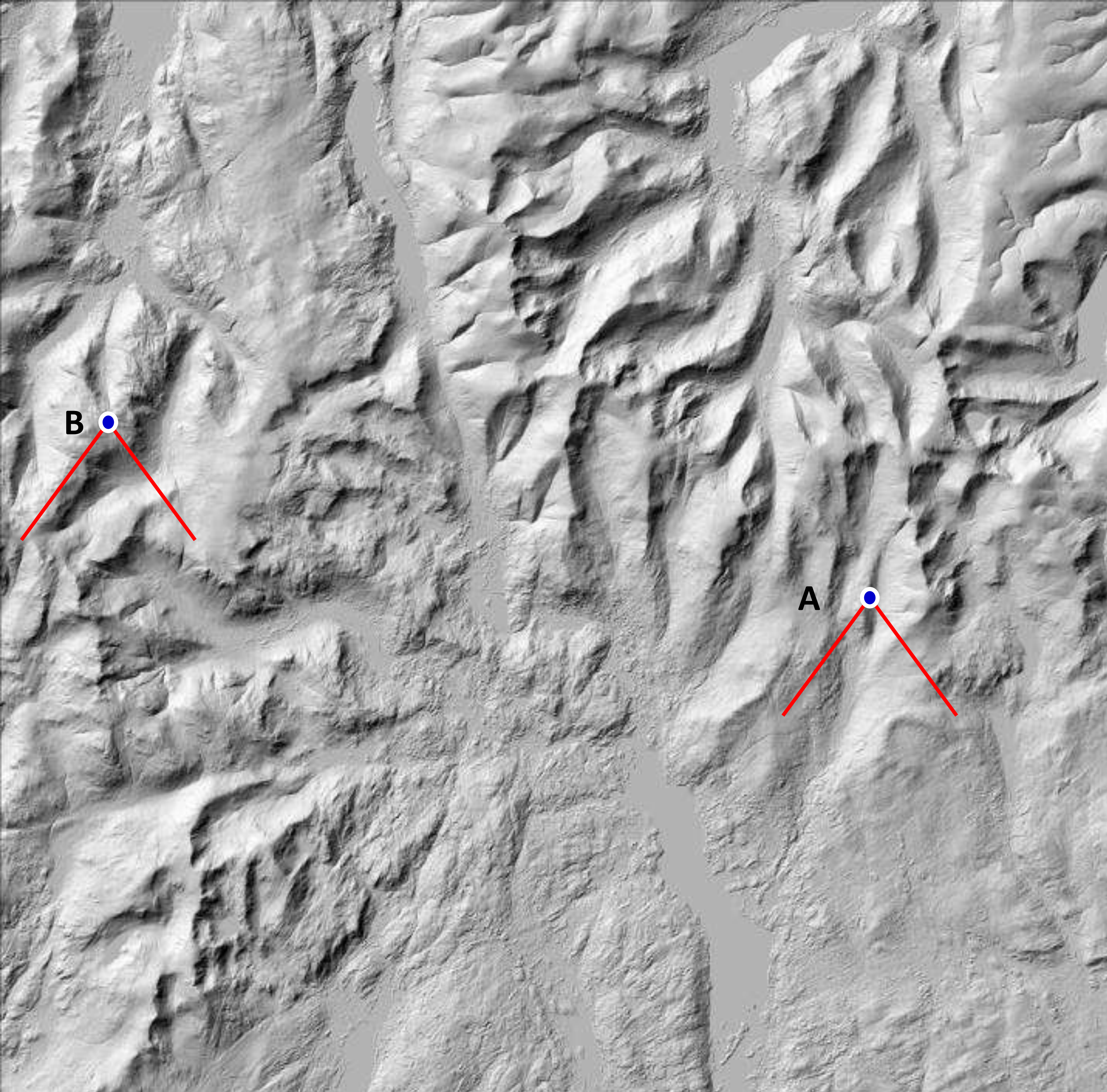
A or B

109

Notice both peaks (X sign). Which is the highest peak?

A or B

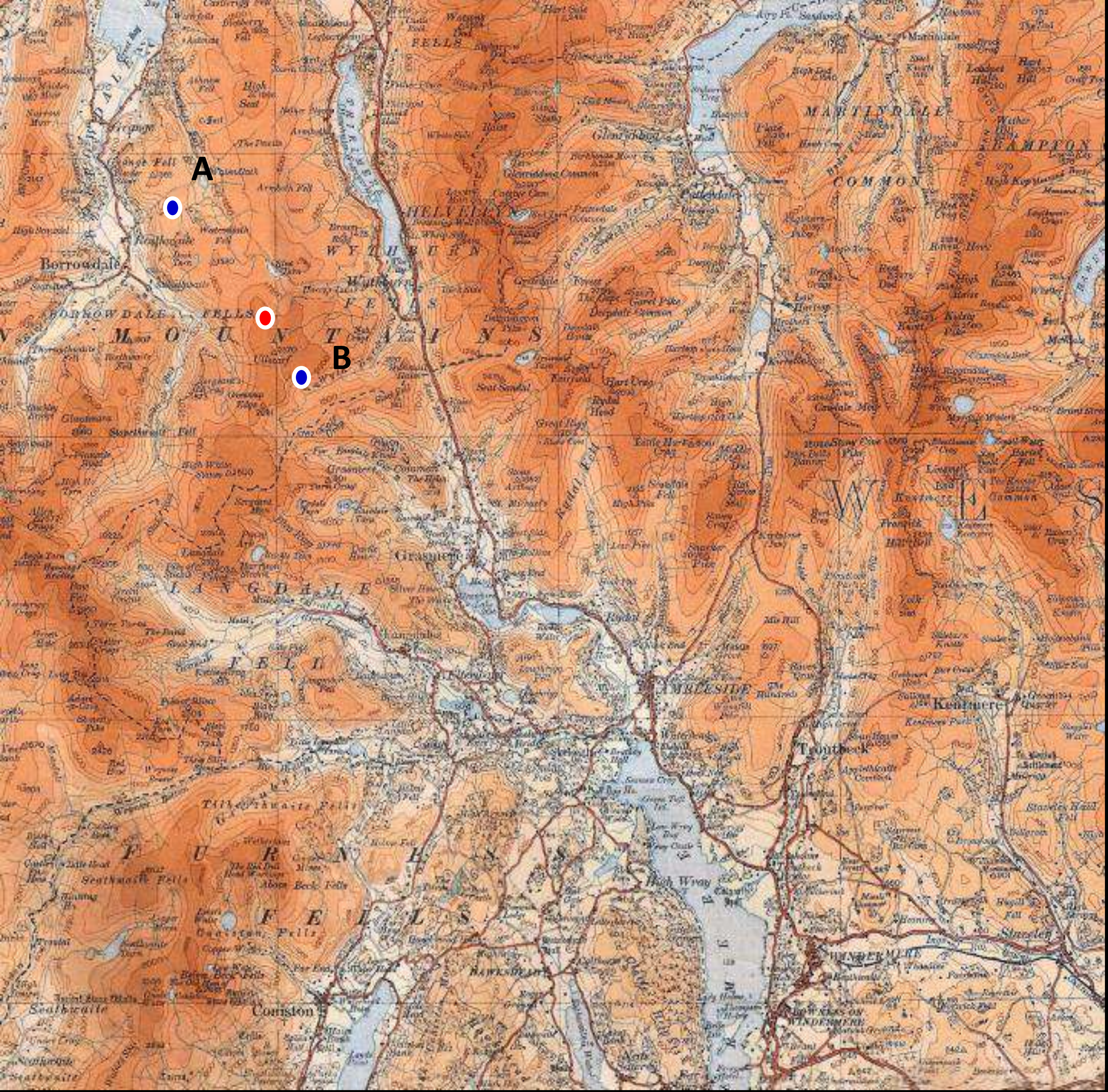
210



Which viewpoint matches the picture below?

A or B

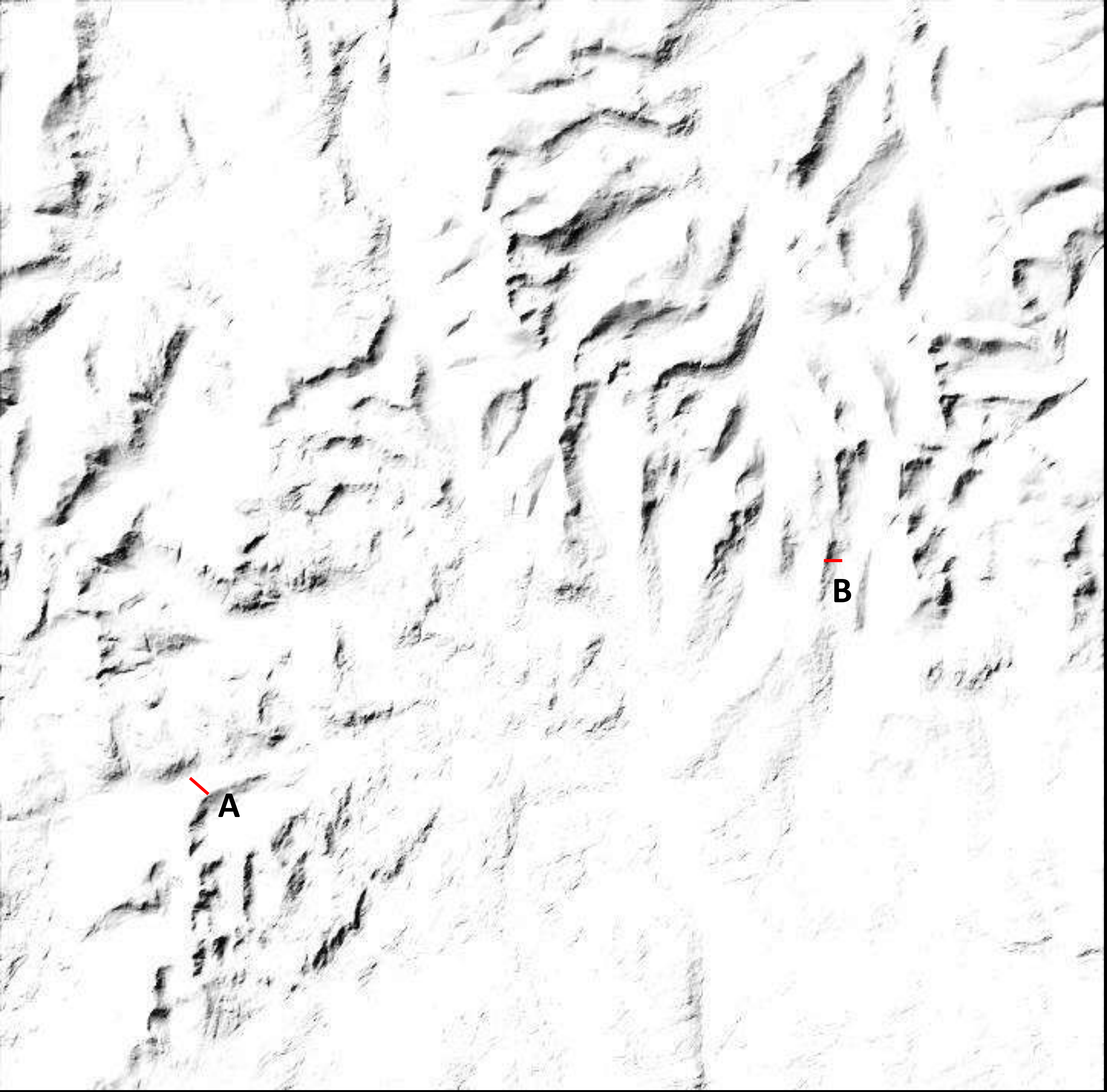
302b



From which point is the red location visible?

A or B

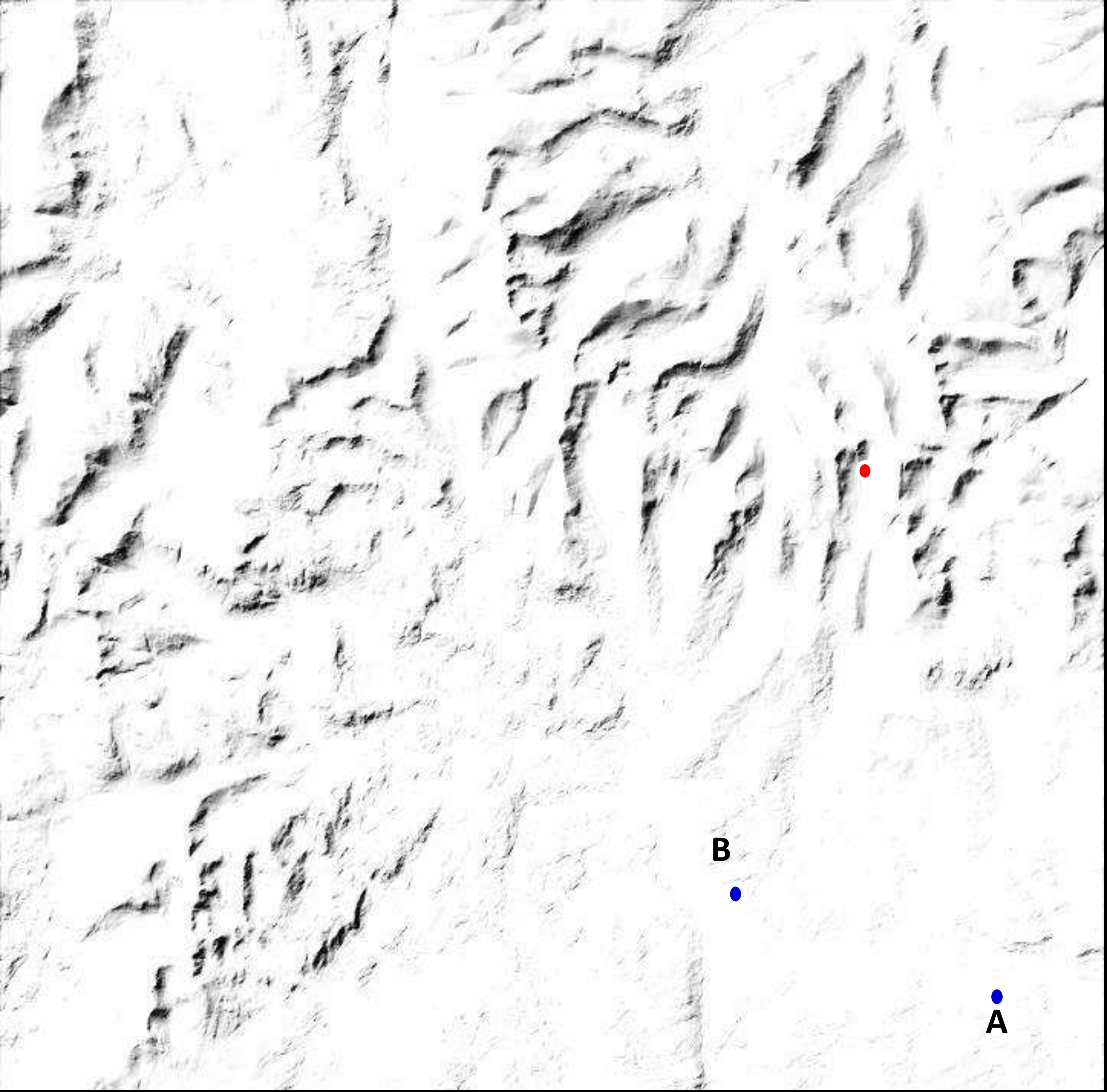
406



Which line follows the steepest path?

A or B

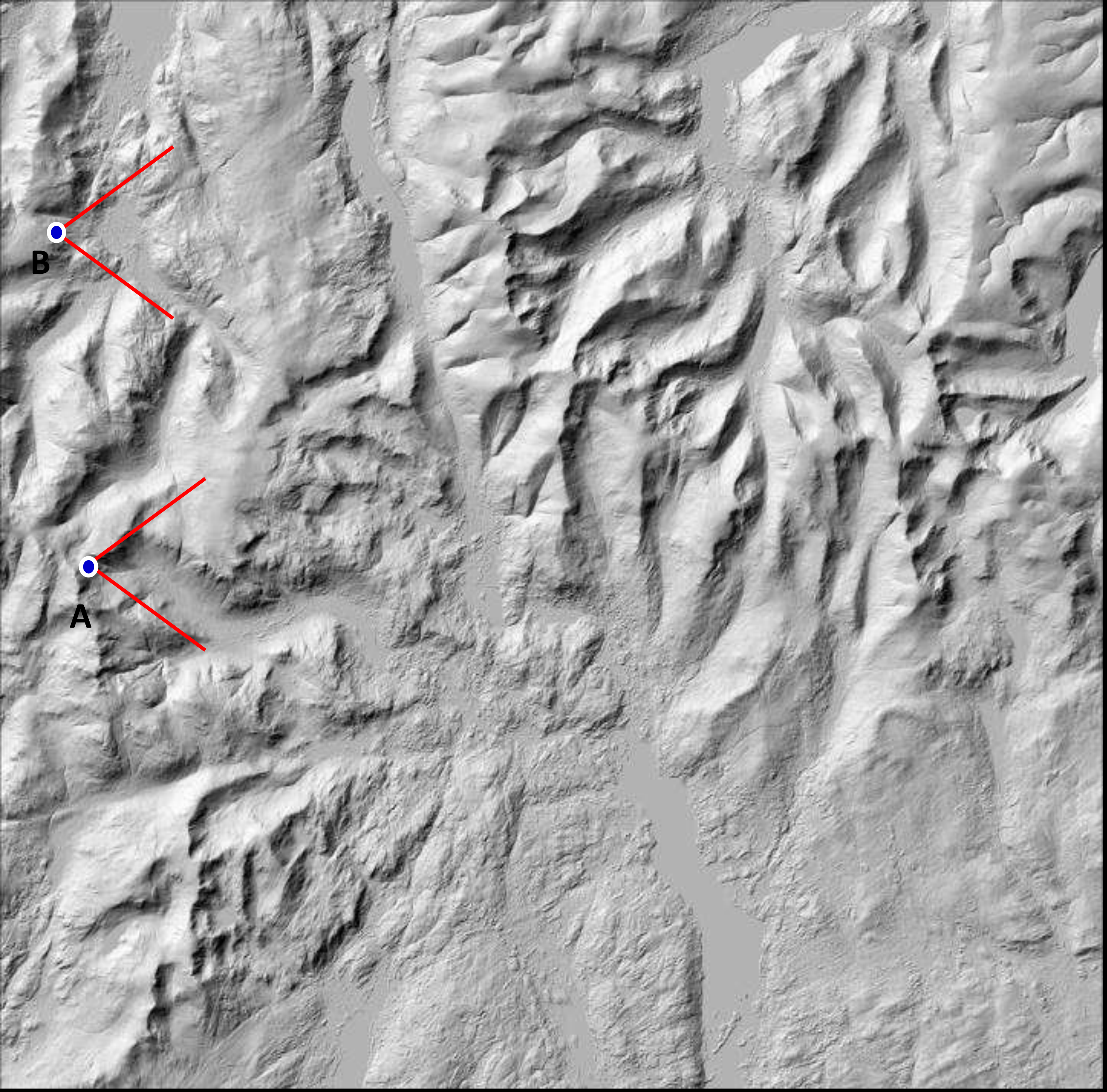
508



To which point would water flow from the red location?

A or B

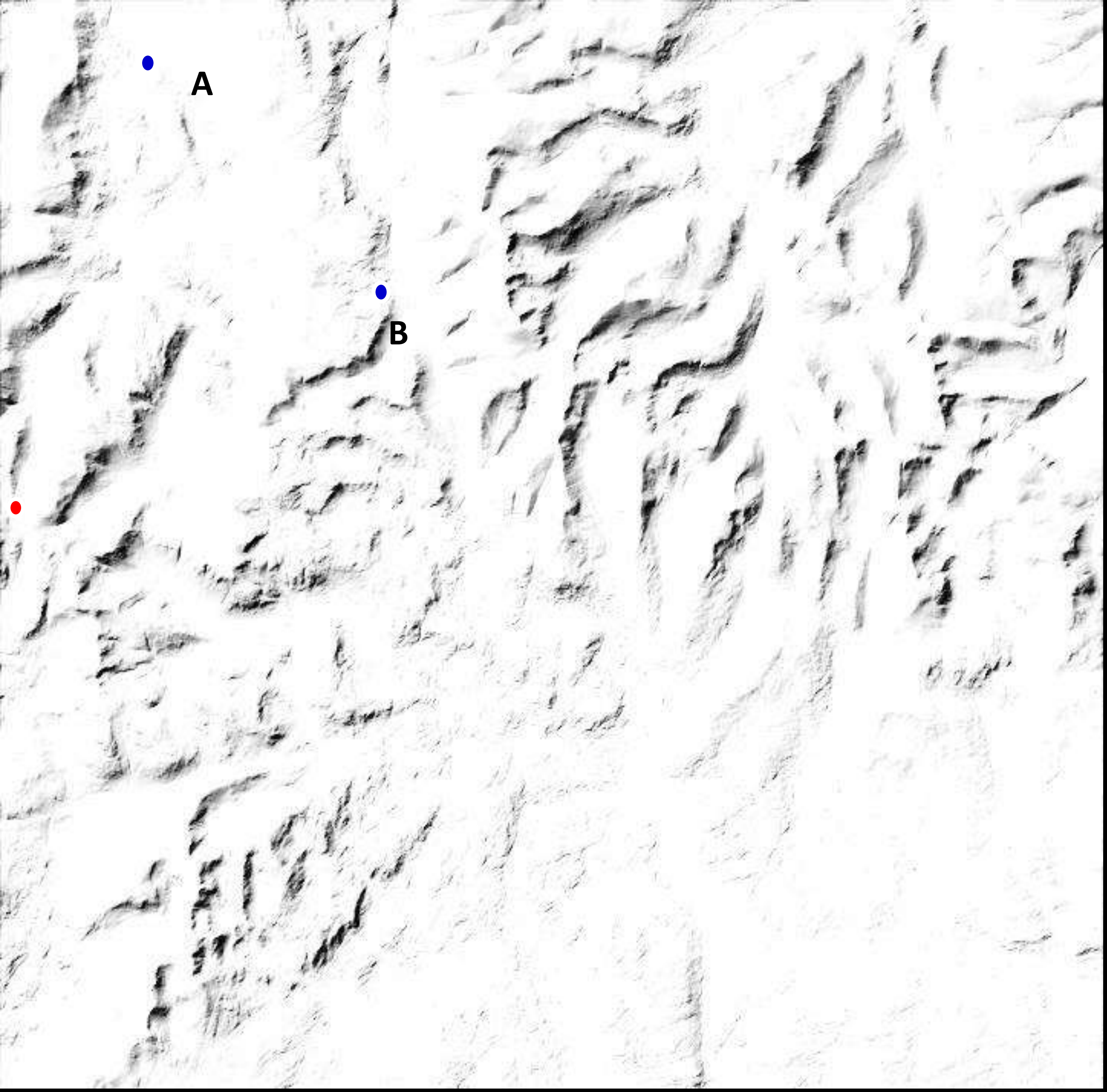
607



Which viewpoint matches the picture below?

A or B

303b



To which point would water flow from the red location?

A or B

609

PARM: 2nd Experiment

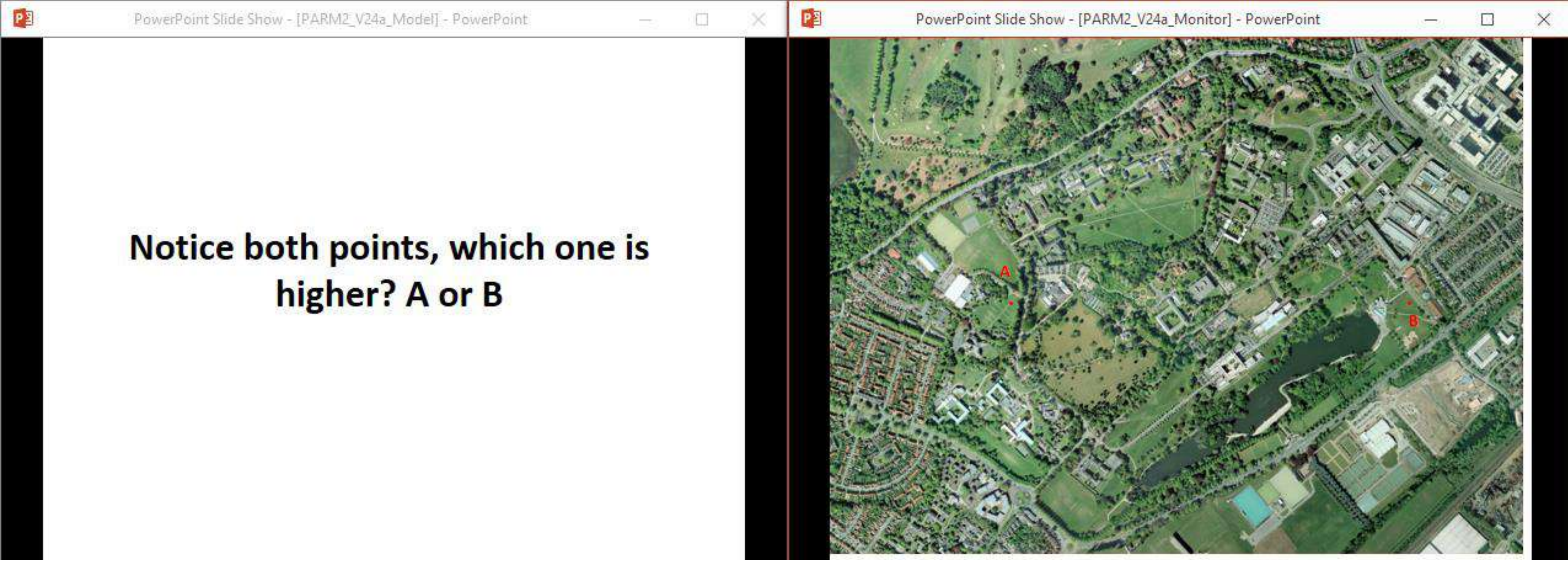
PARM: 2nd Experiment

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

Session 1

PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

Session 1


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Notice both points, which one is higher? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

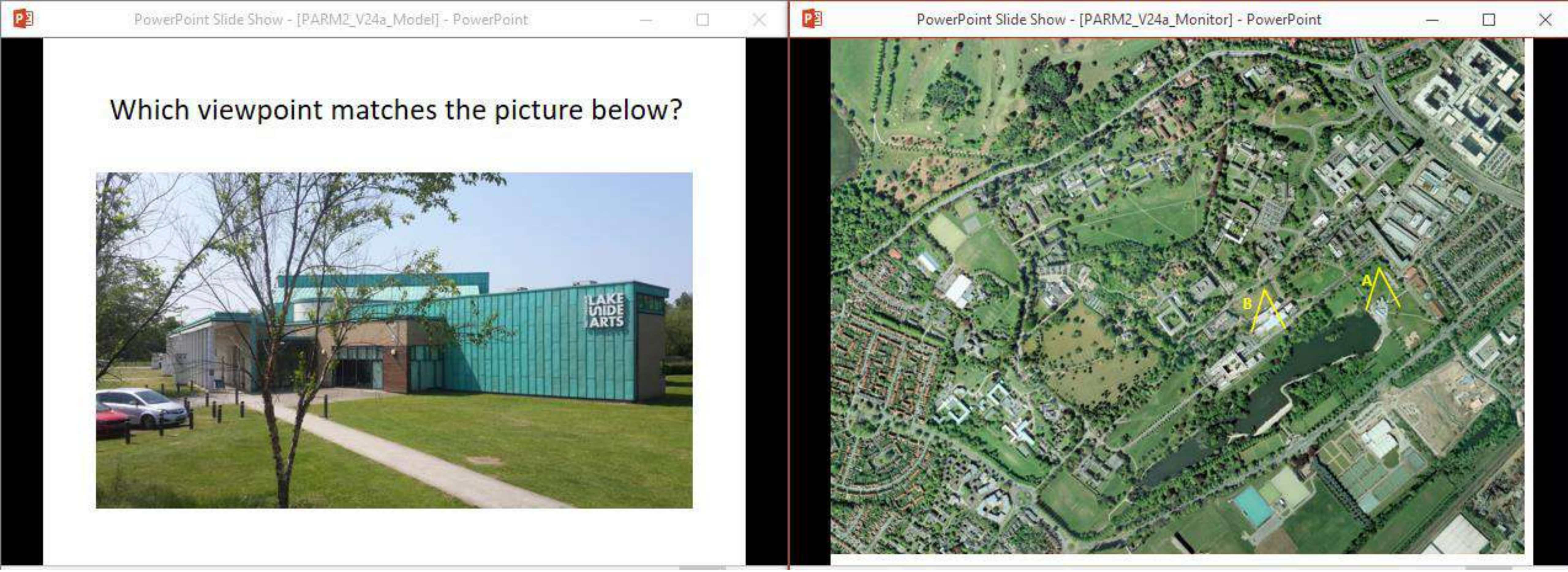
No 1

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

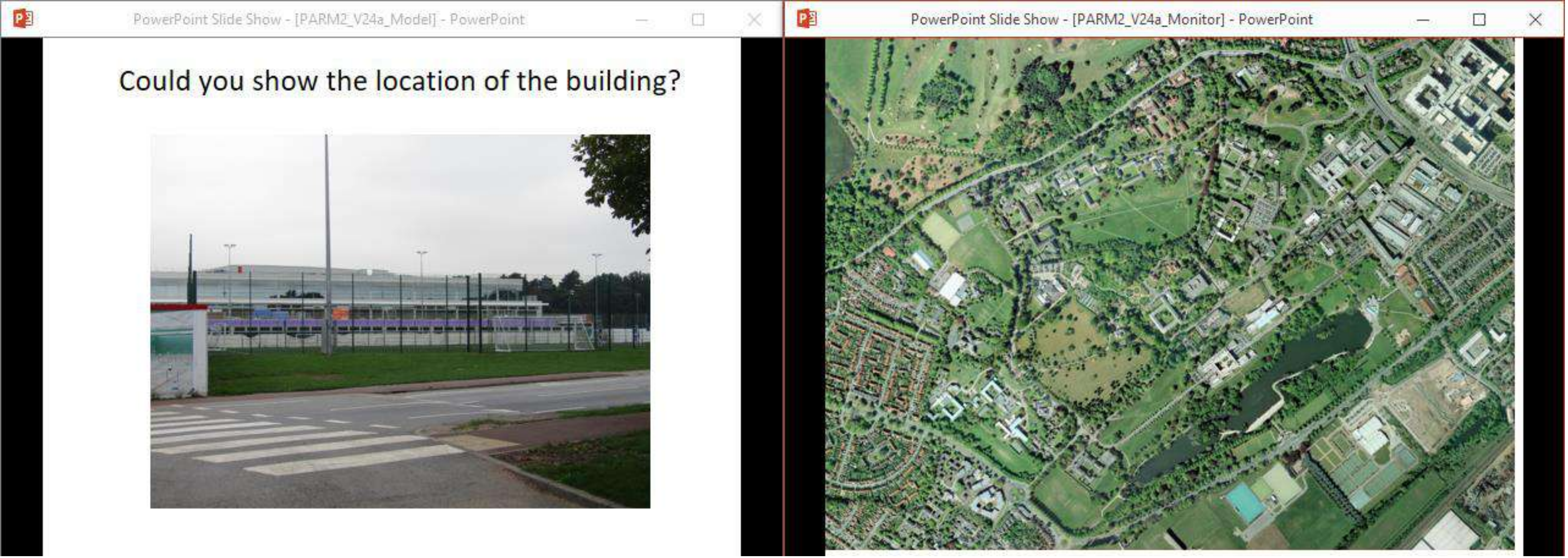
From which point is the yellow spot (building top) visible? A or B

PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

No 2


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Which viewpoint matches the picture below?
LAKE
SIDE
ARTS
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

No 3


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Could you show the location of the building?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

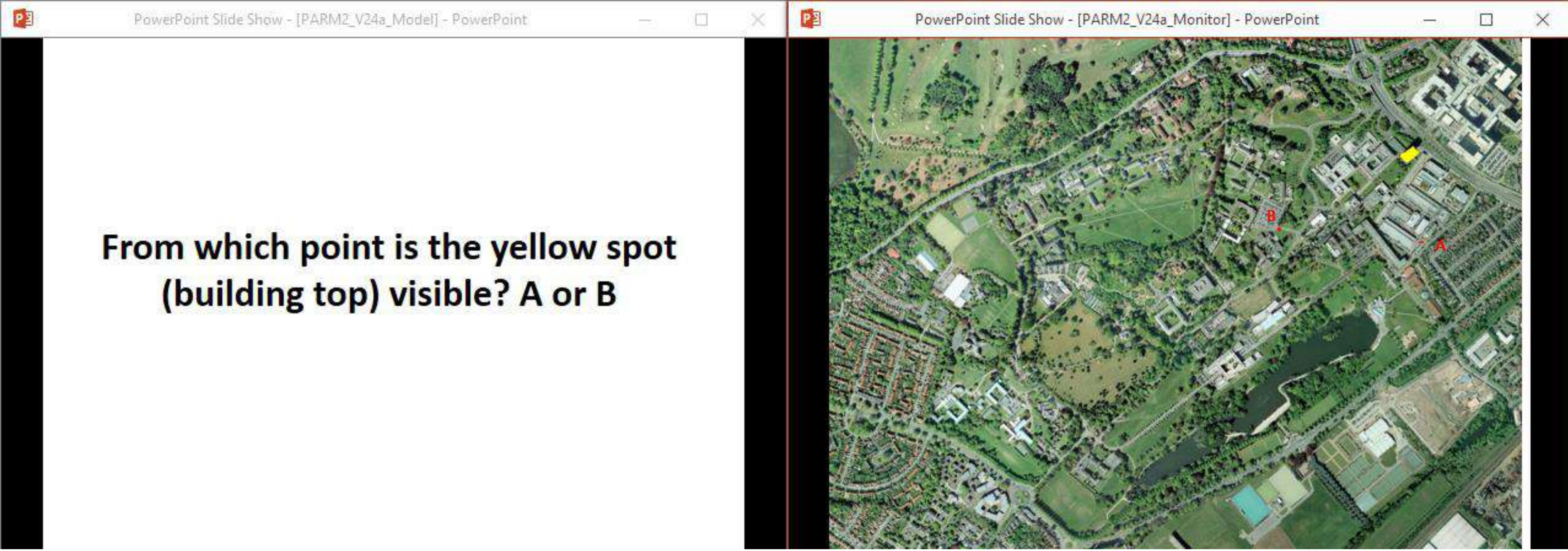
No 4

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

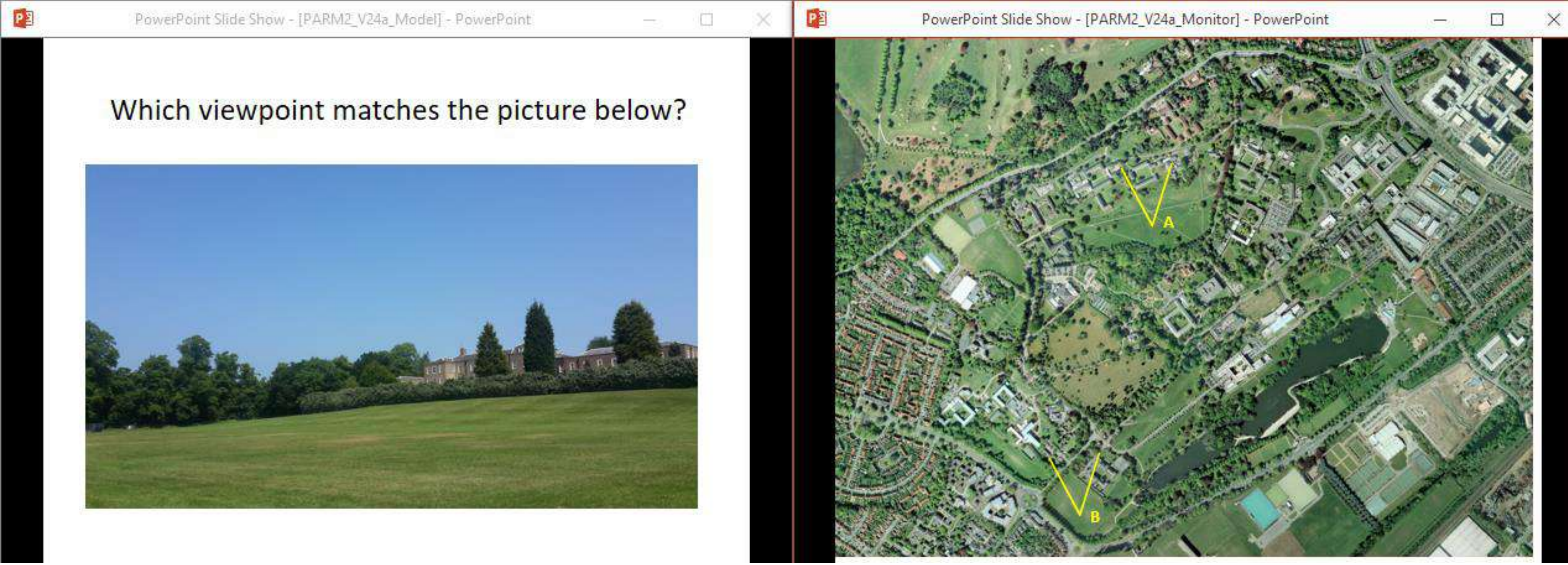
Notice both points, which one is higher? A or B

PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

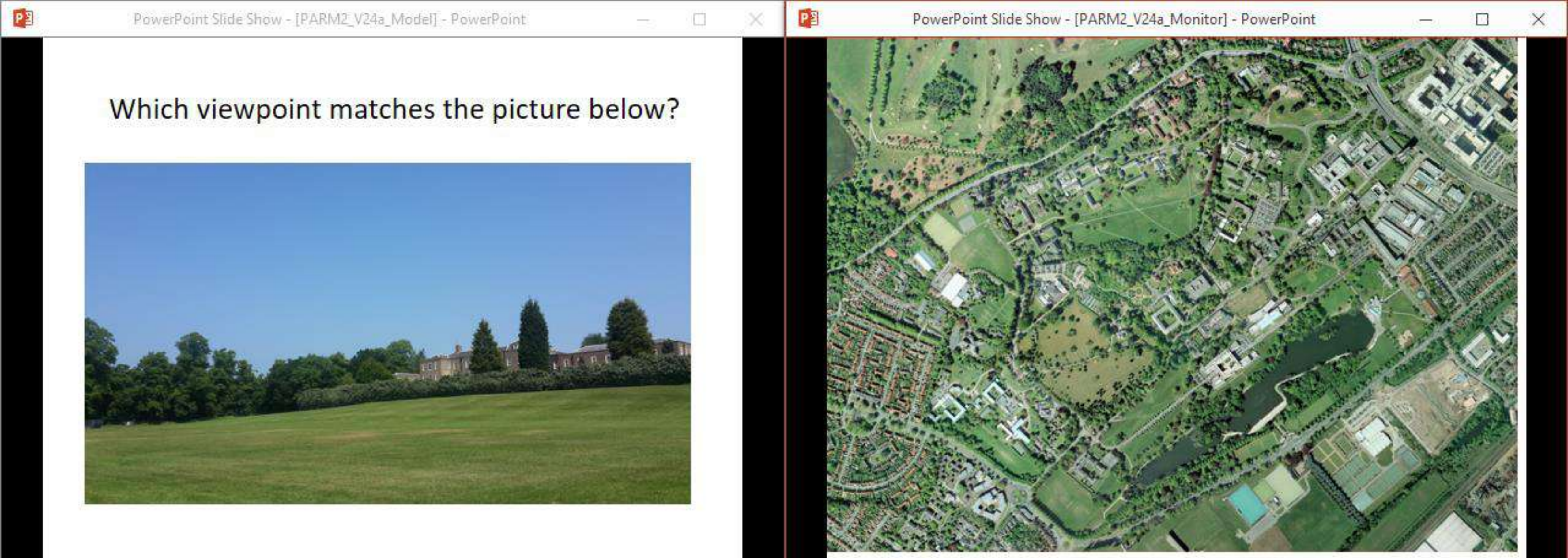
No 5


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
From which point is the yellow spot (building top) visible? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

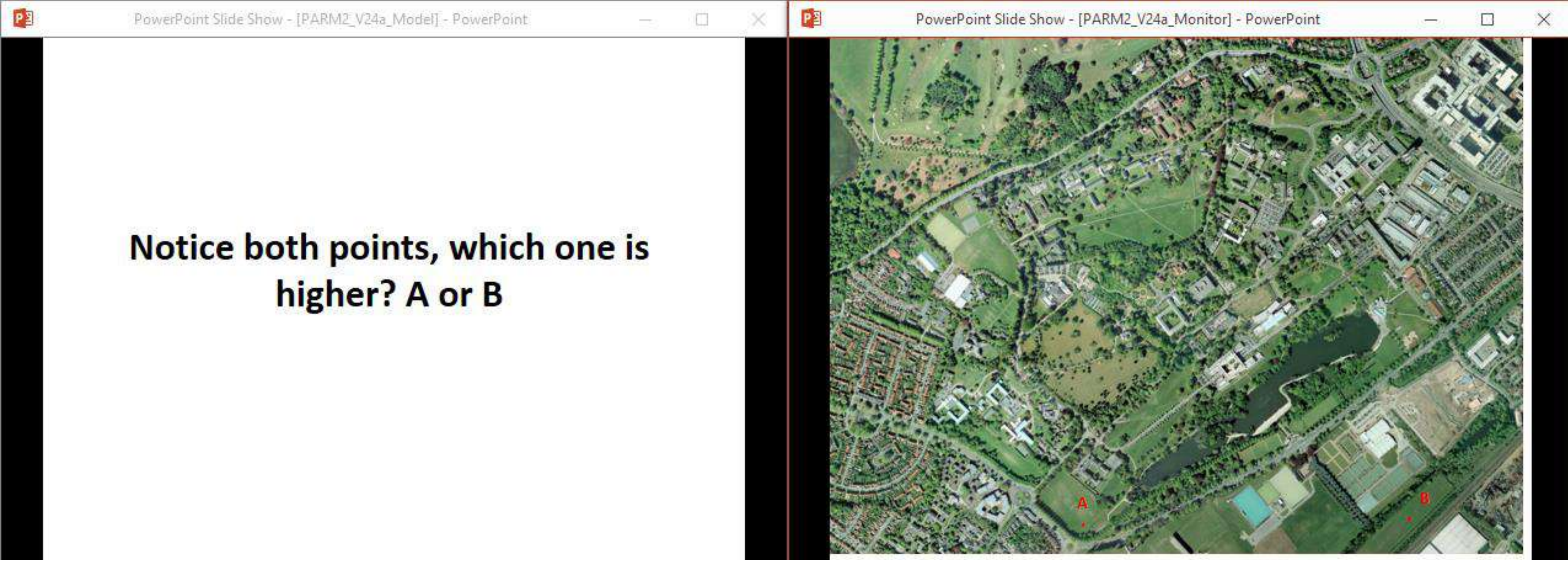
No 6


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Which viewpoint matches the picture below?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

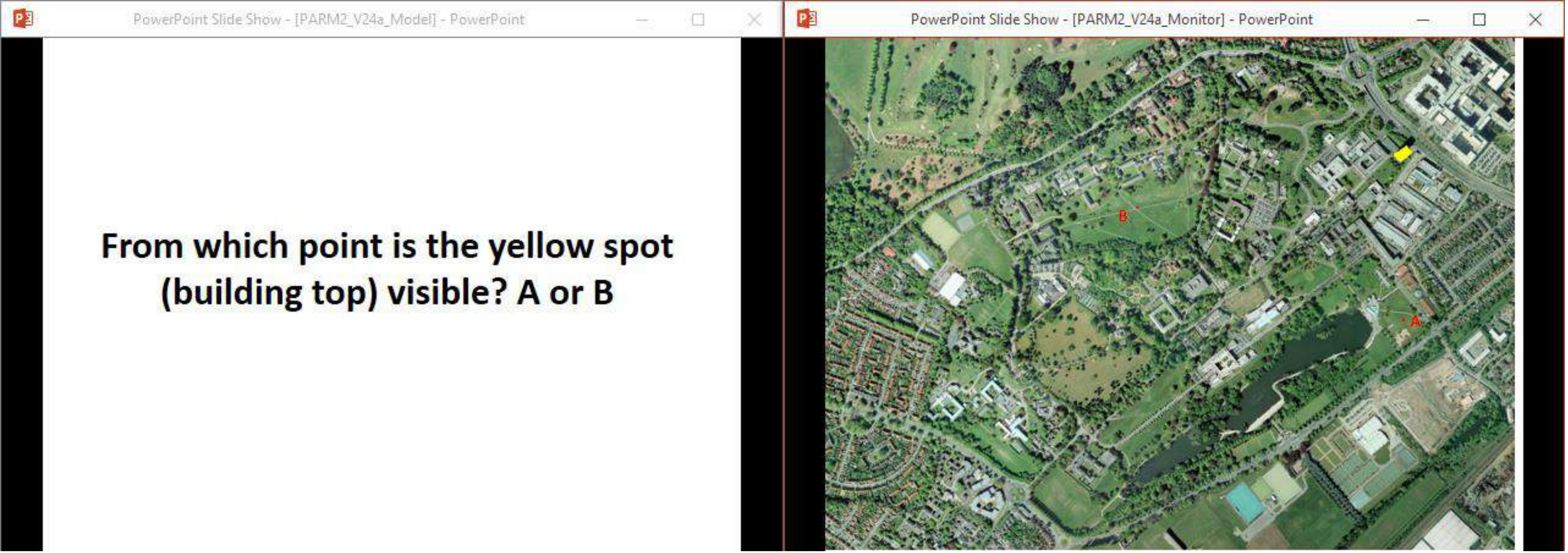
No 7


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Which viewpoint matches the picture below?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

No 8


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Notice both points, which one is higher? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

No 9

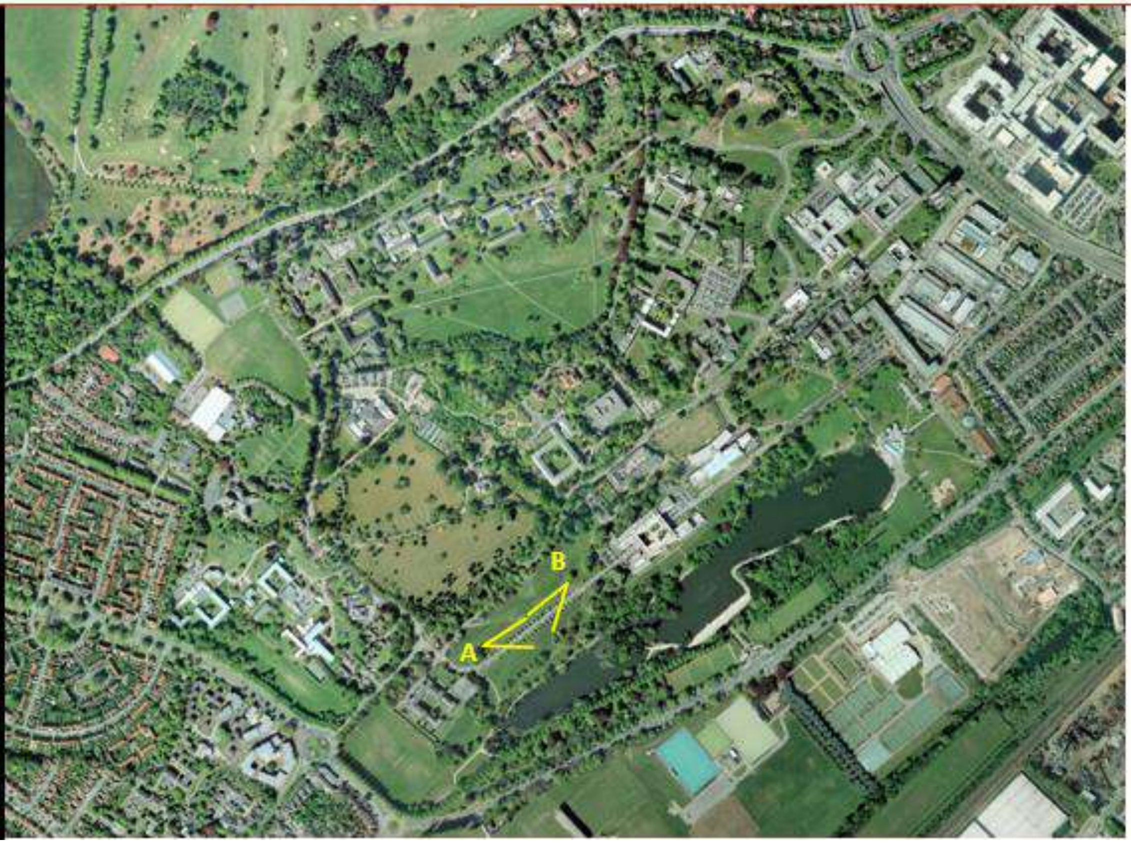

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
From which point is the yellow spot (building top) visible? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

No 10

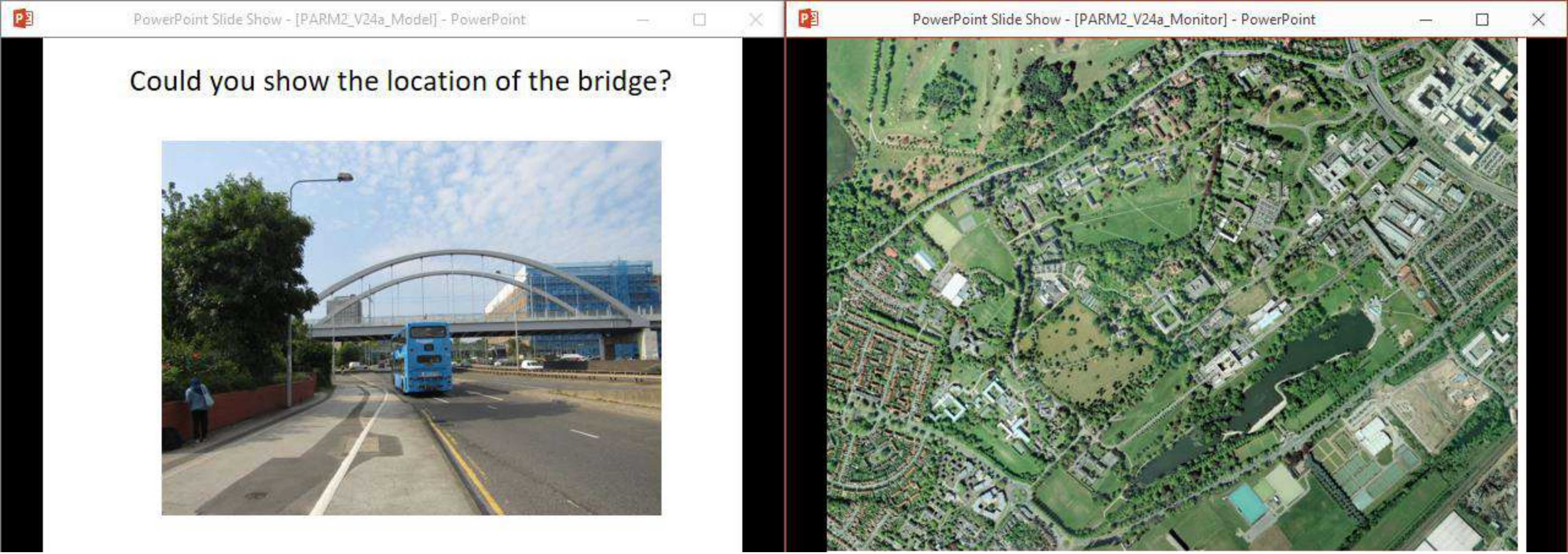
PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

Which viewpoint matches the picture below?

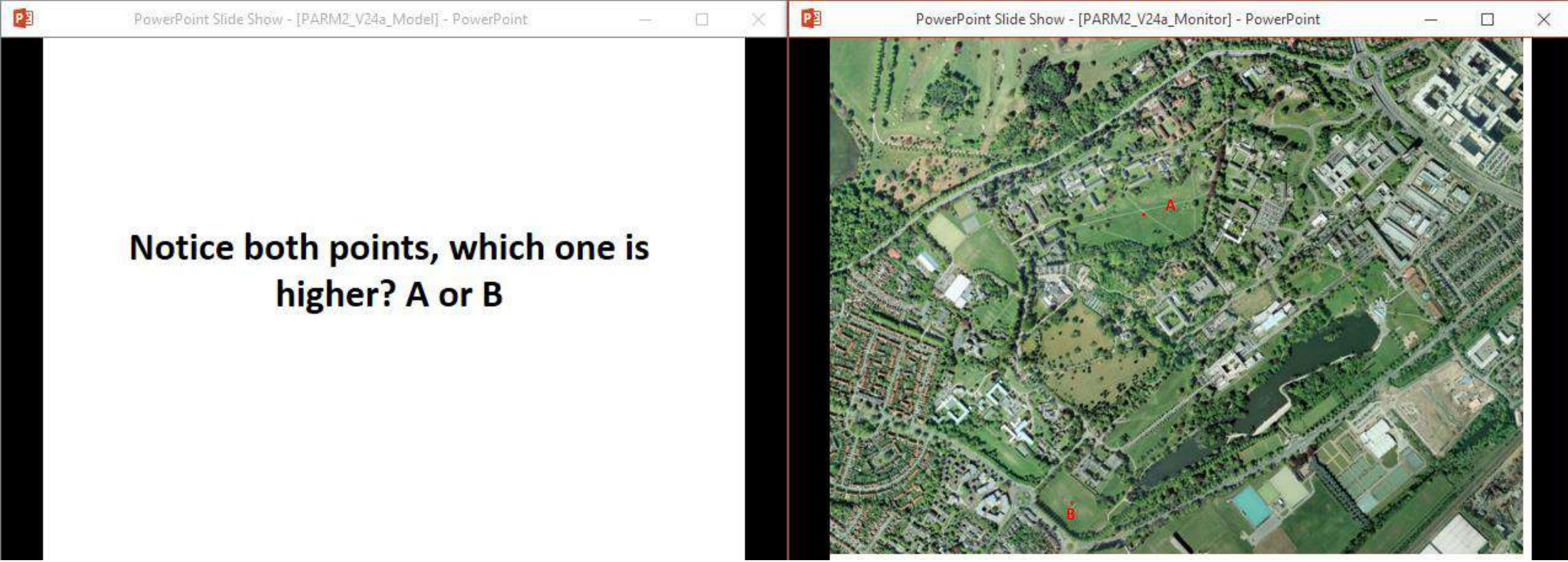
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint



No 11


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Could you show the location of the bridge?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

No 12


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Notice both points, which one is higher? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

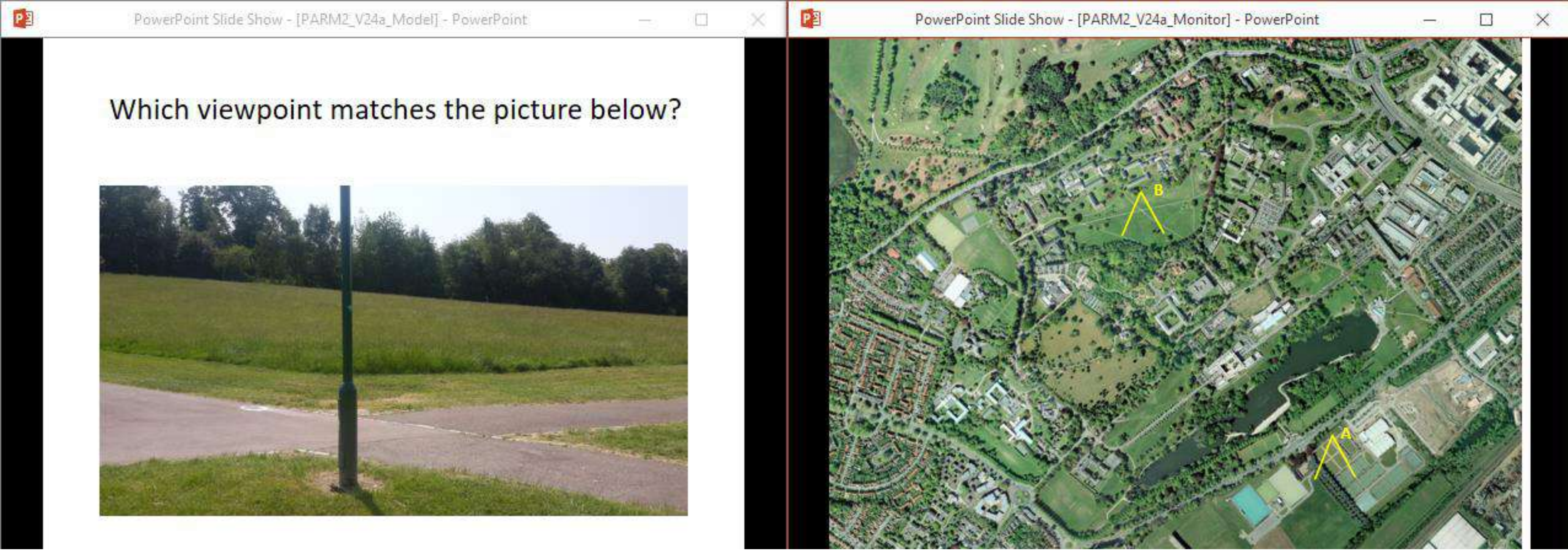
No 13

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

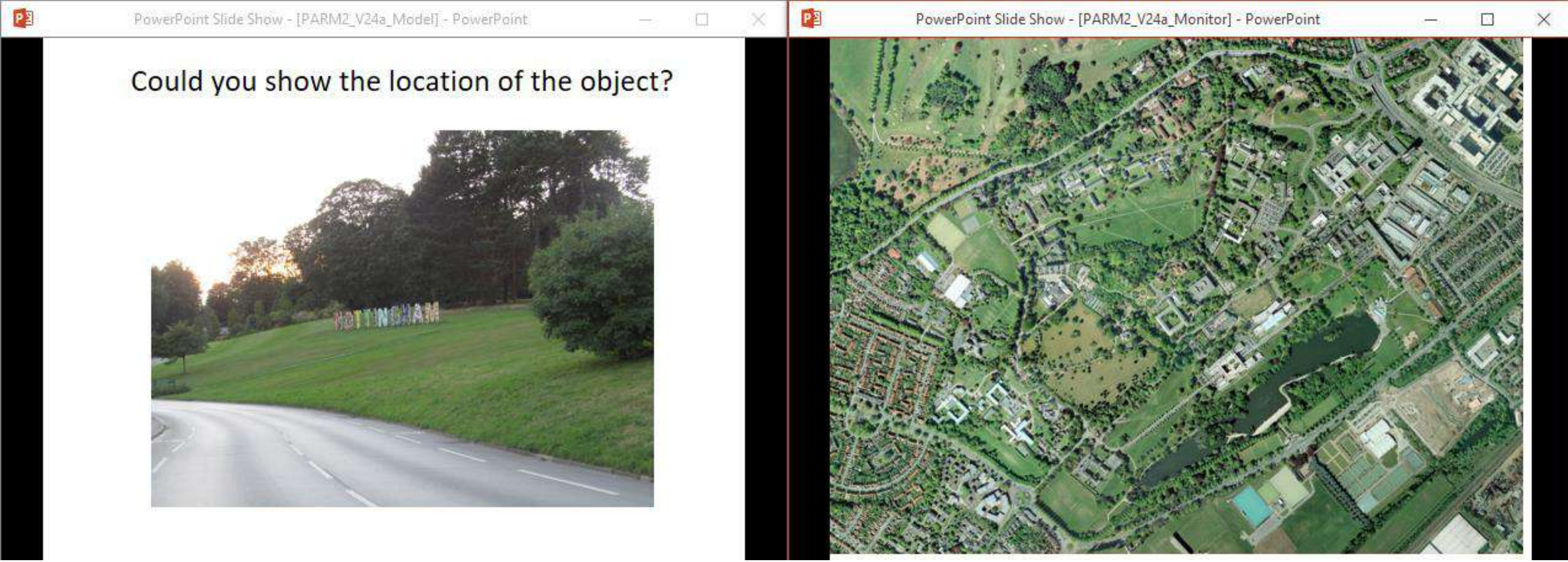
From which point is the yellow spot (building top) visible? A or B

PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

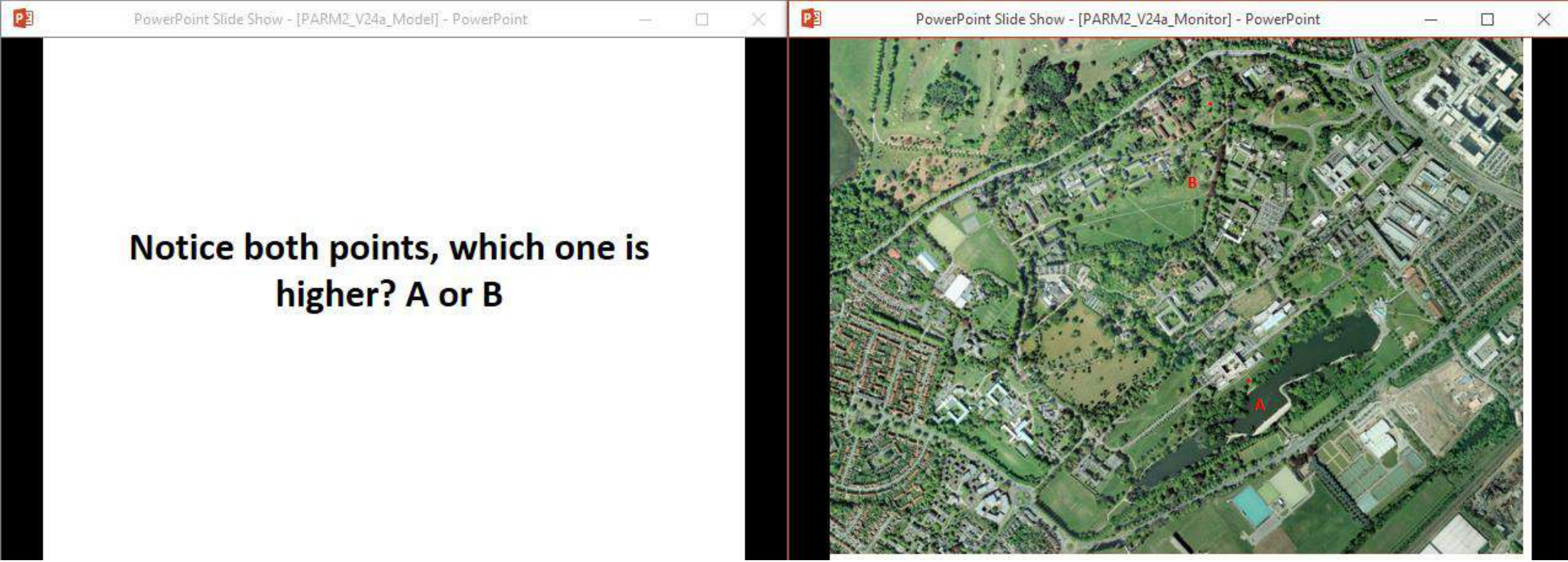
No 14


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Which viewpoint matches the picture below?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

No 15


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Could you show the location of the object?
NOTTINGHAM
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

No 16


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Notice both points, which one is higher? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

No 17

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

From which point is the yellow spot (building top) visible? A or B

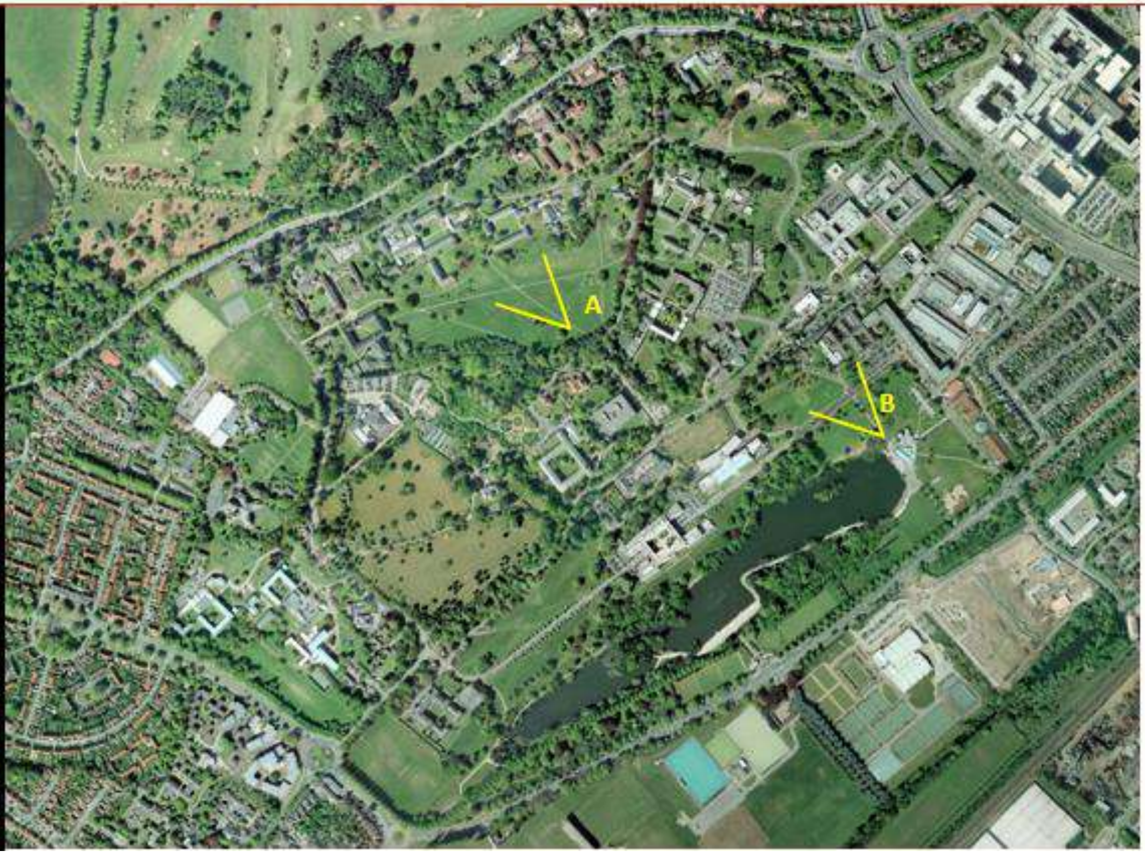
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

No 18

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

Which viewpoint matches the picture below?

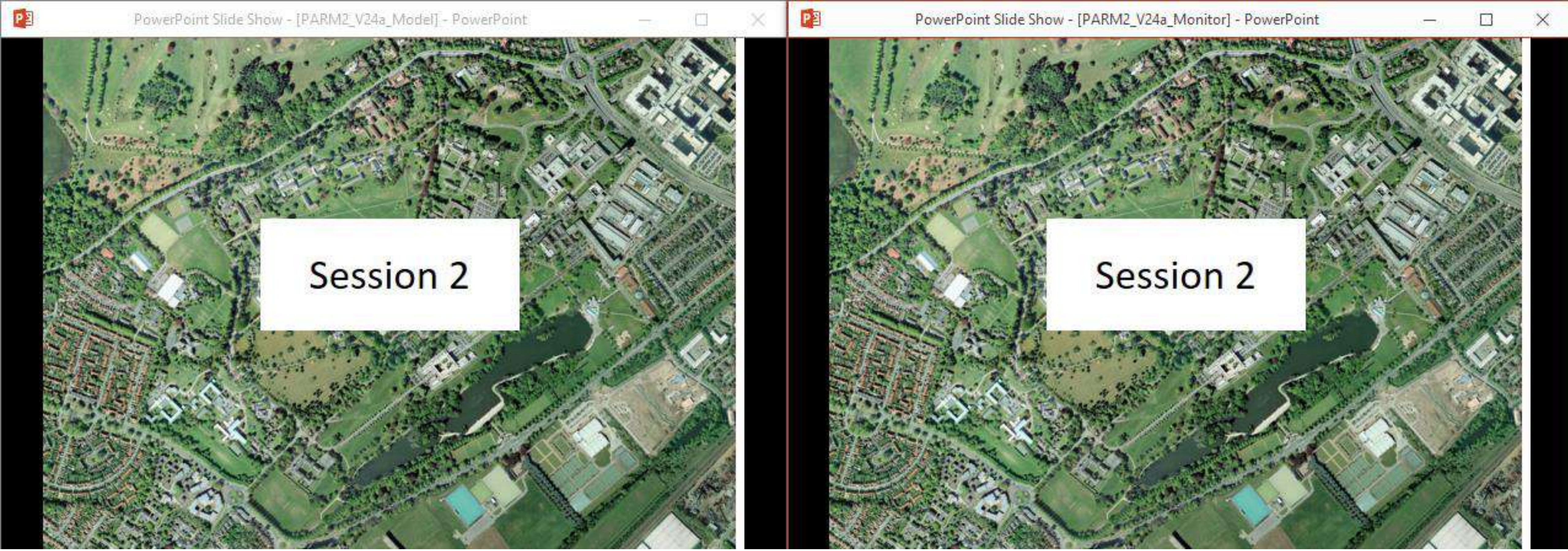
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

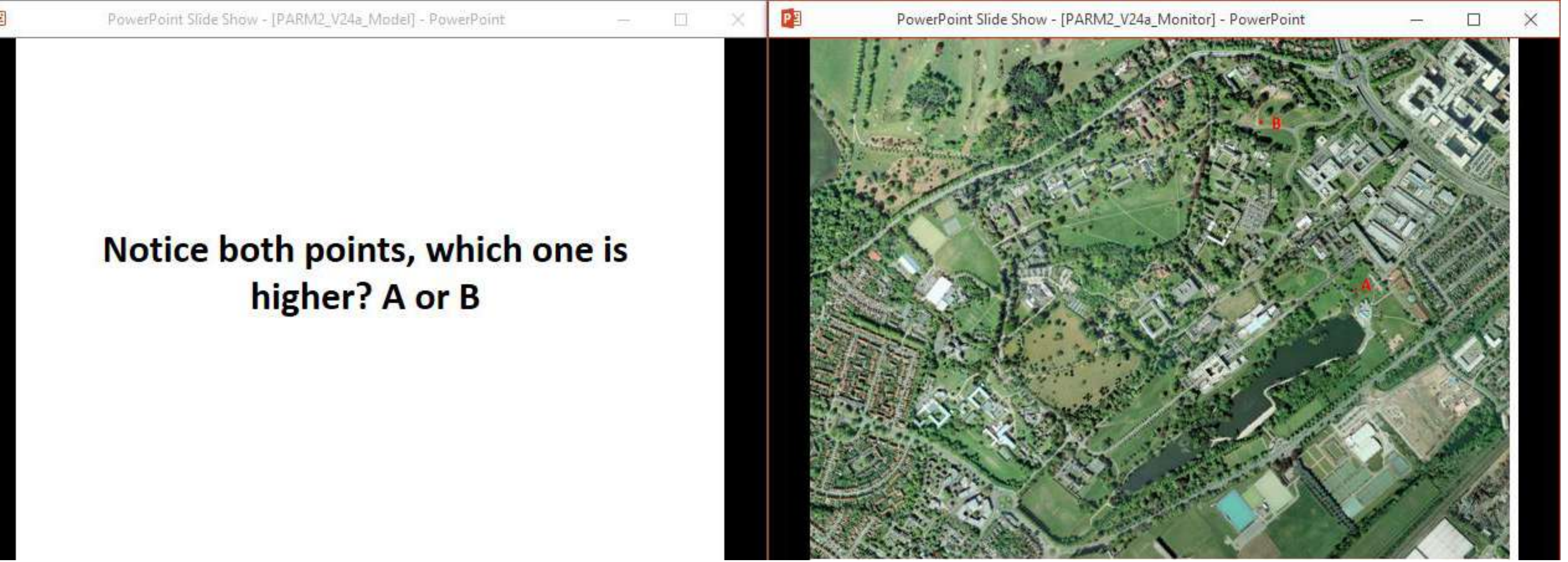


No 19

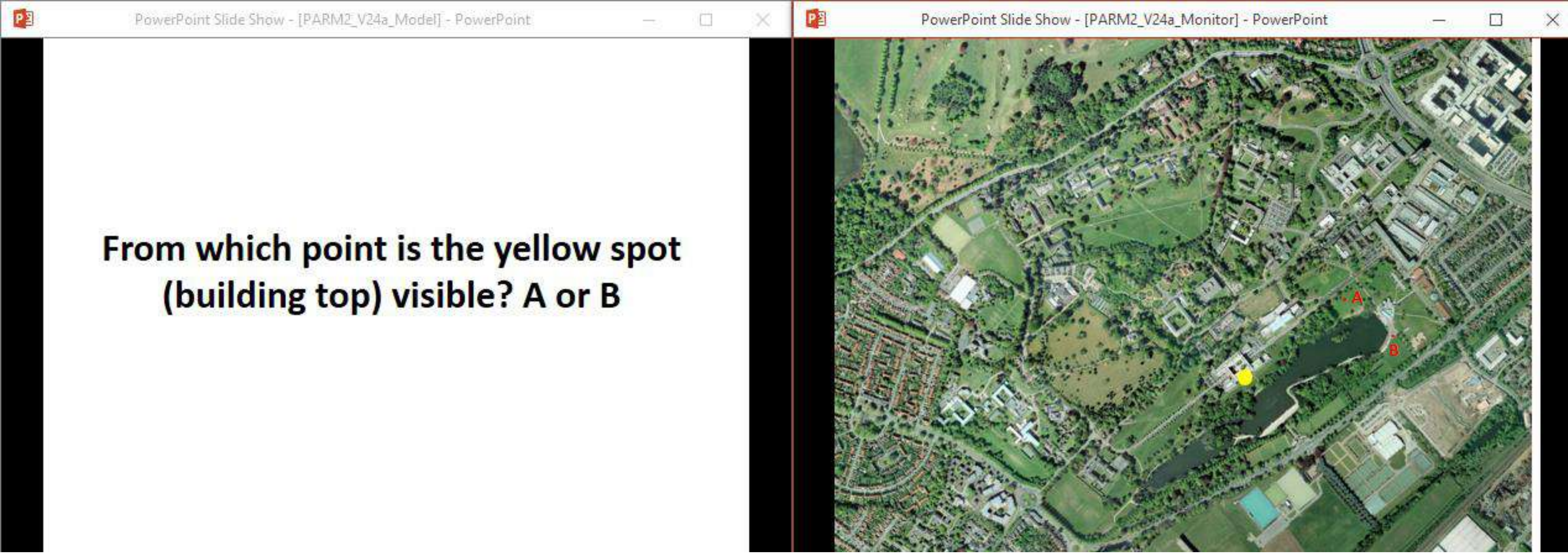

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Could you show the location of the road on the left?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

No 20

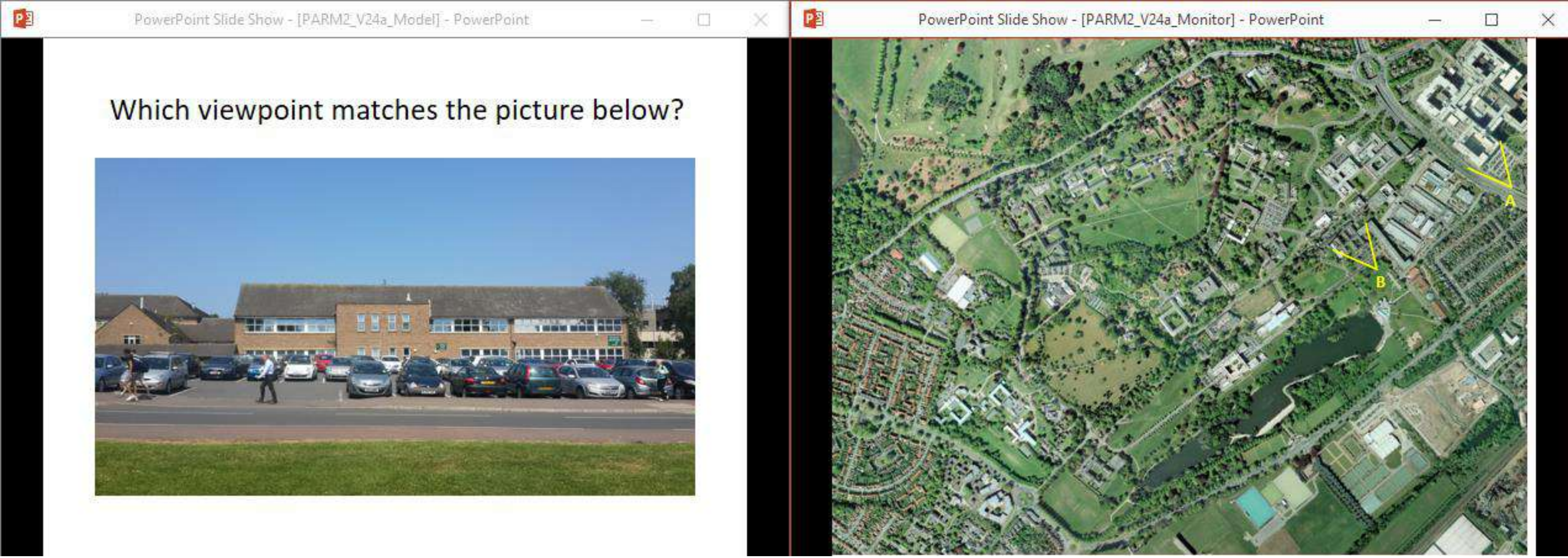

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Session 2
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
Session 2


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Notice both points, which one is higher? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

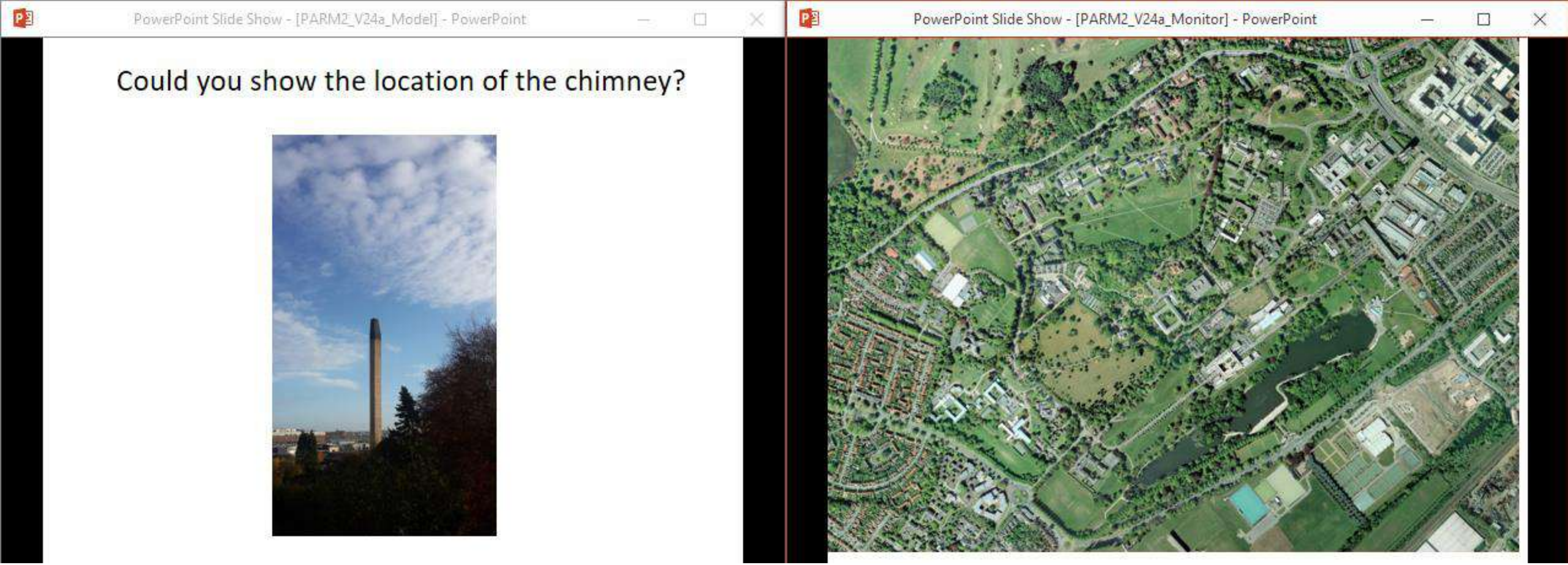
No 21


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
From which point is the yellow spot (building top) visible? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

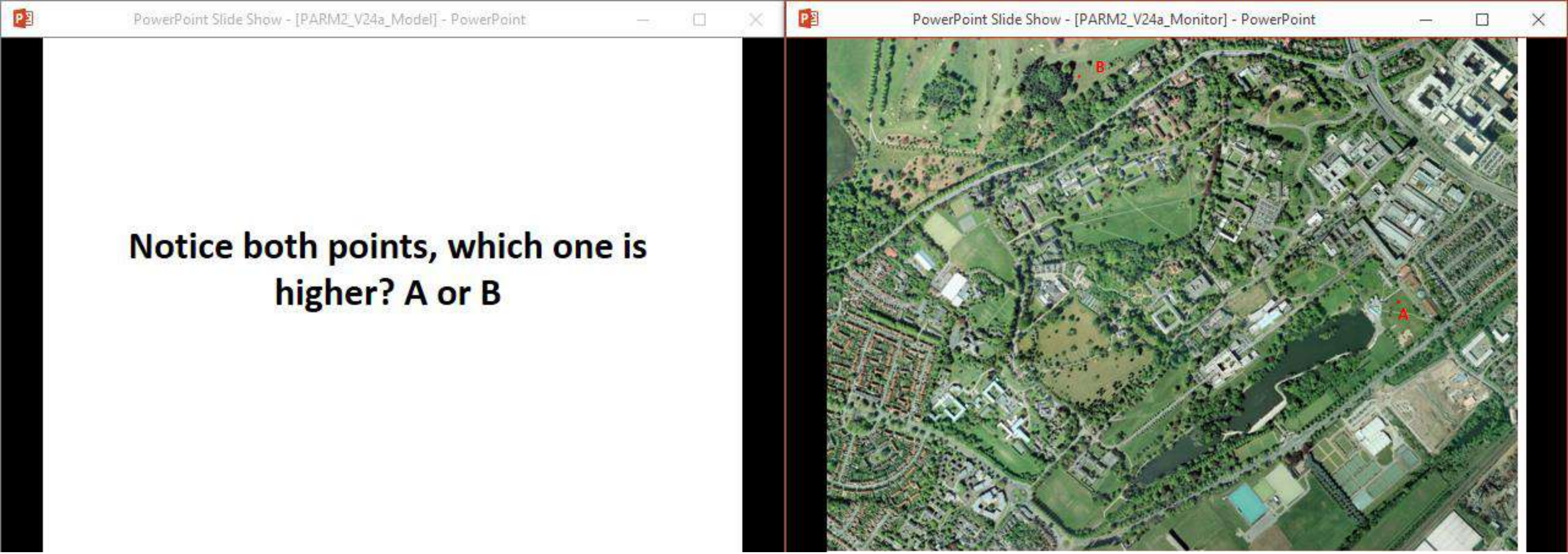
No 22


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Which viewpoint matches the picture below?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

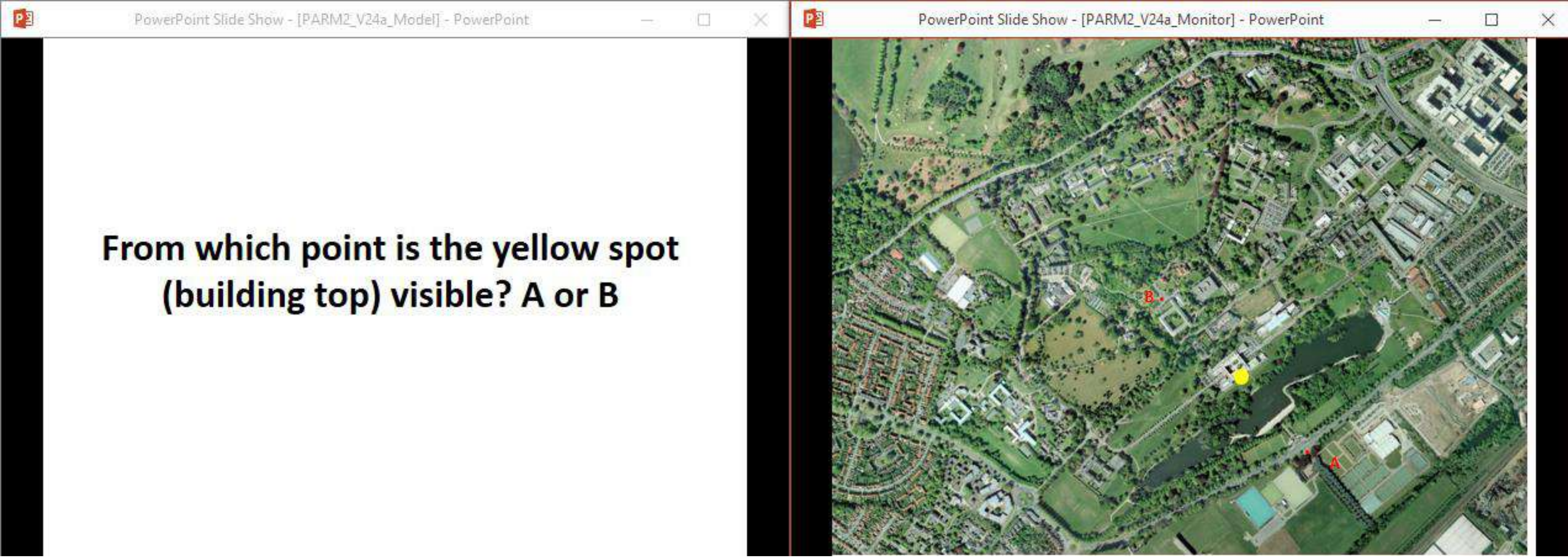
No 23


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Could you show the location of the chimney?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

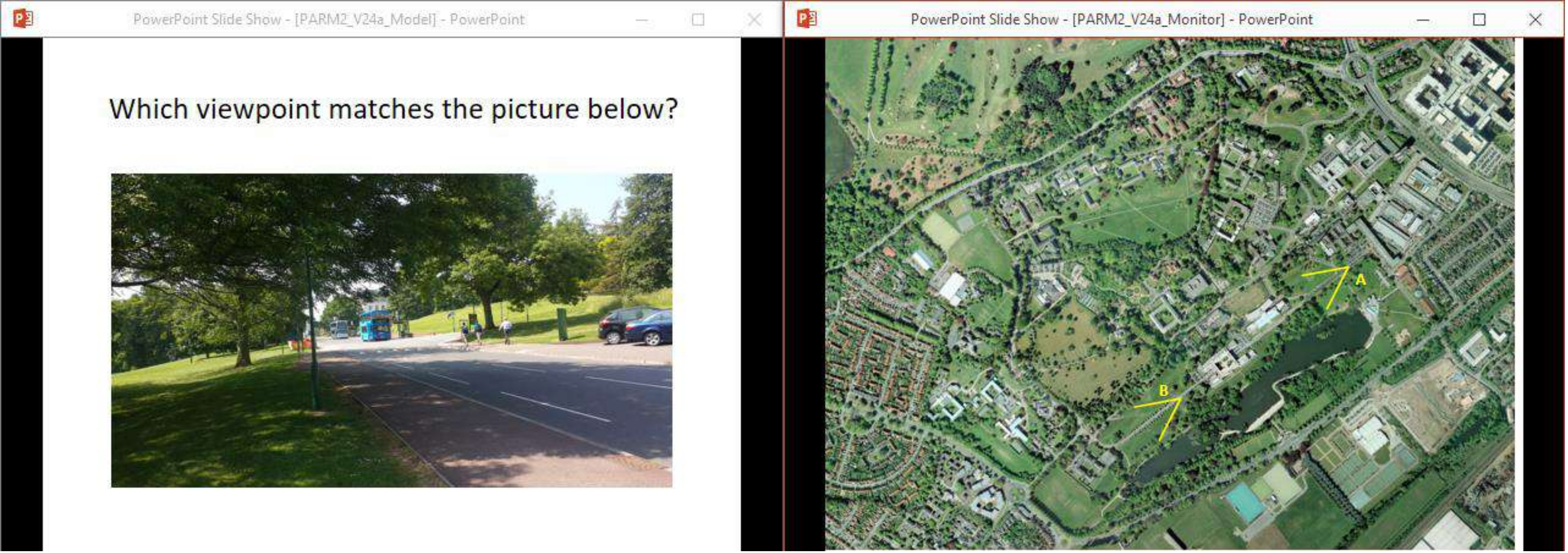
No 24


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Notice both points, which one is higher? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

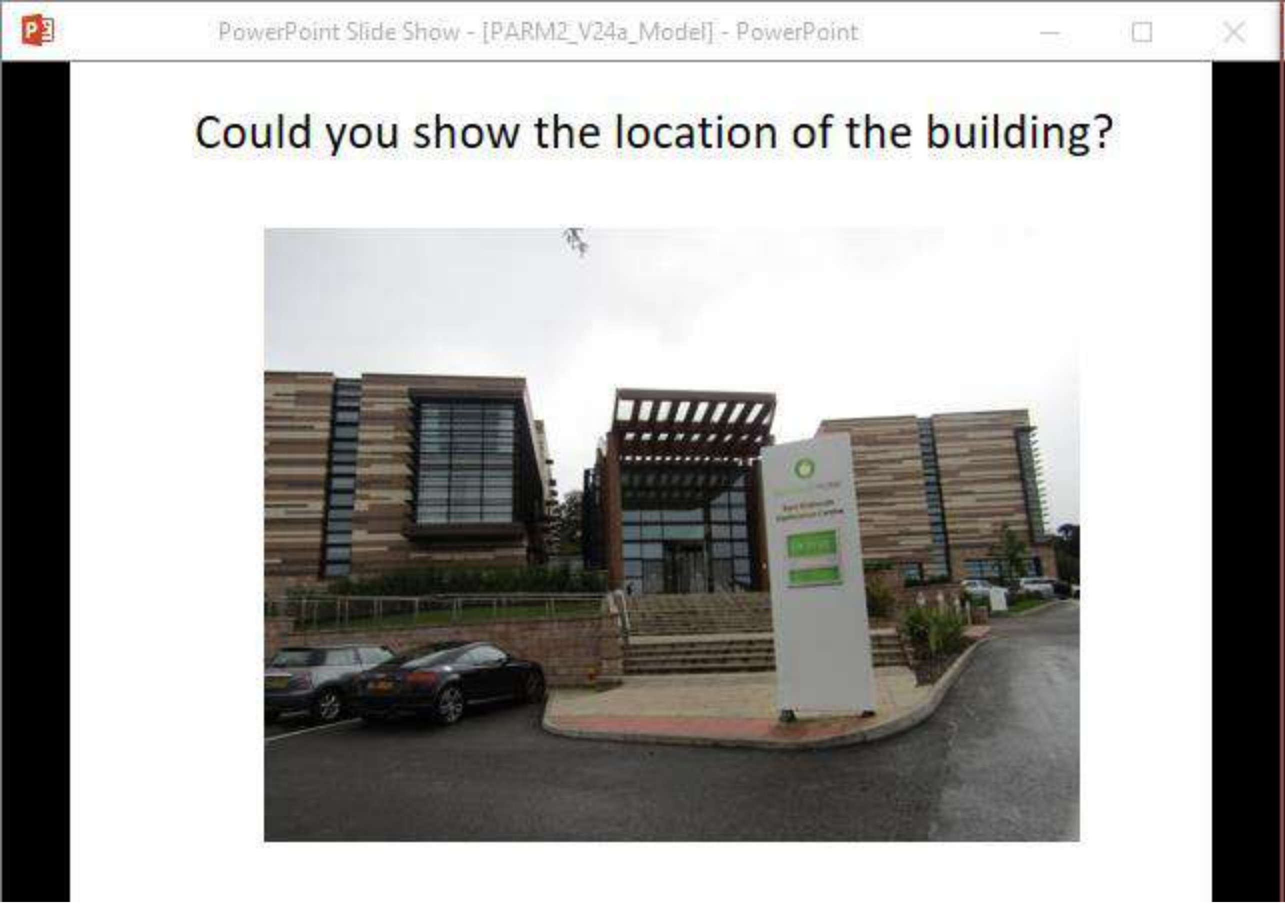
No 25


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
From which point is the yellow spot (building top) visible? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

No 26


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Which viewpoint matches the picture below?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

No 27


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Could you show the location of the building?

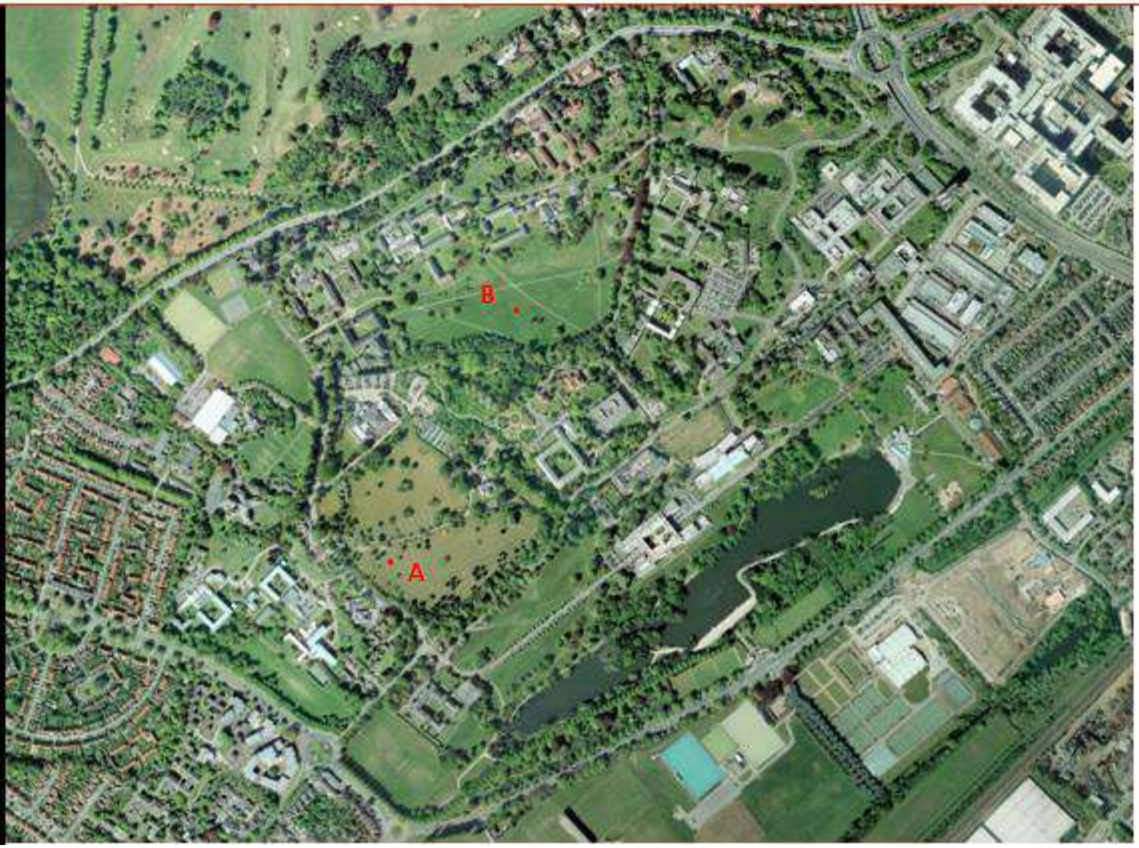

PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

No 28

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

Notice both points, which one is higher? A or B

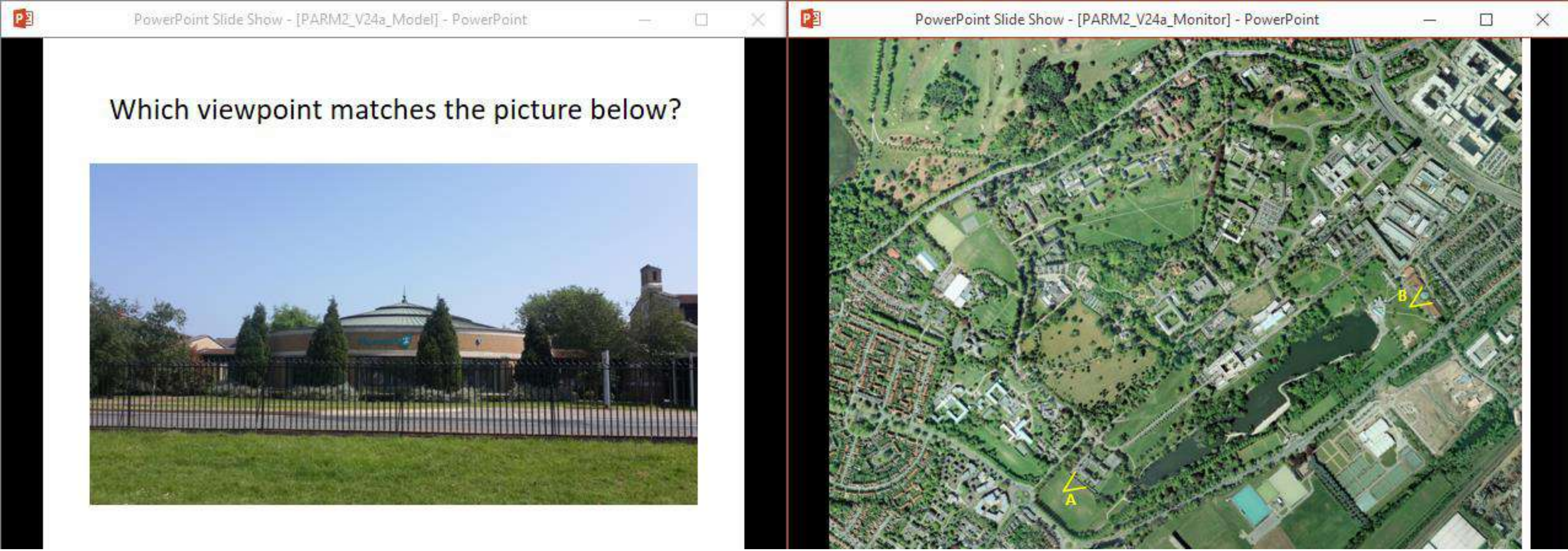
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint



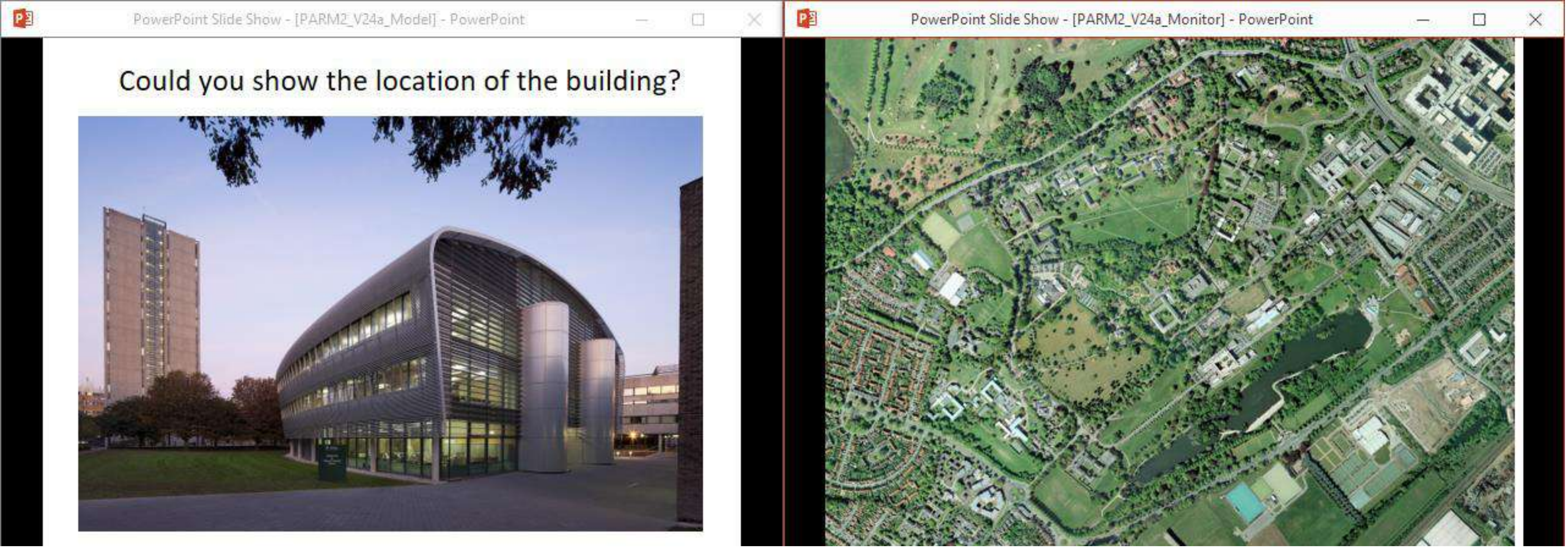
No 29

The picture can't be displayed.

No 30


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Which viewpoint matches the picture below?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

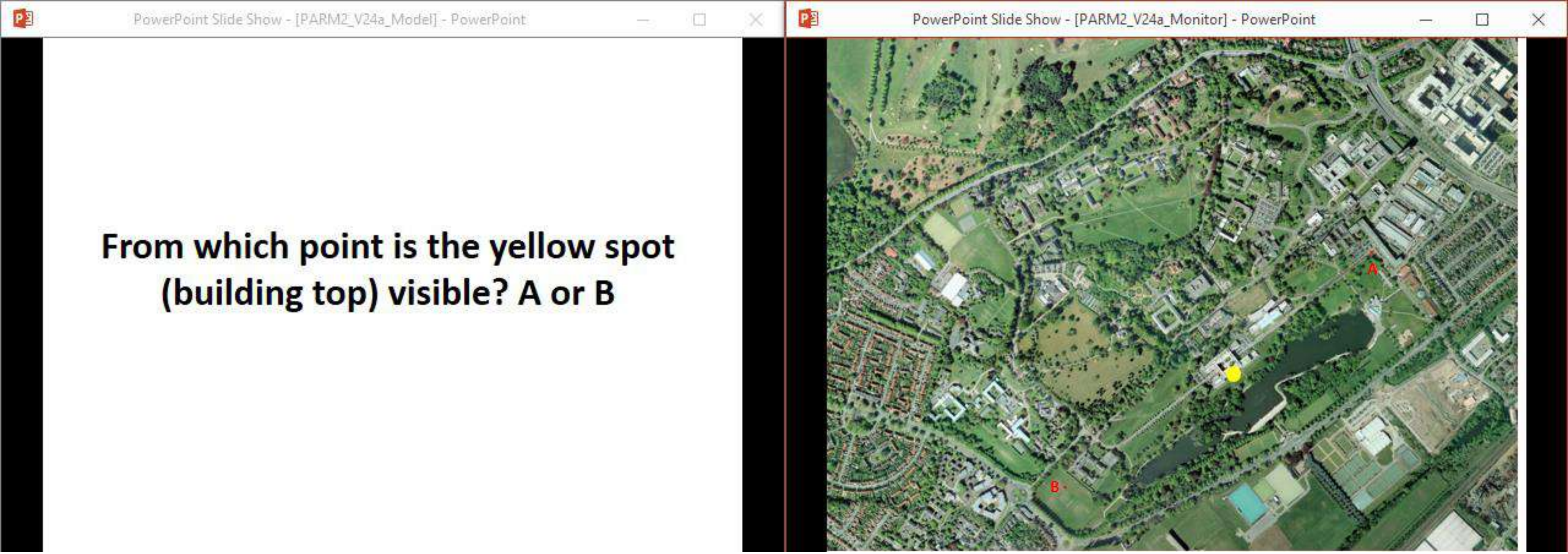
No 31


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Could you show the location of the building?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

No 32

The picture can't be displayed.

No 33

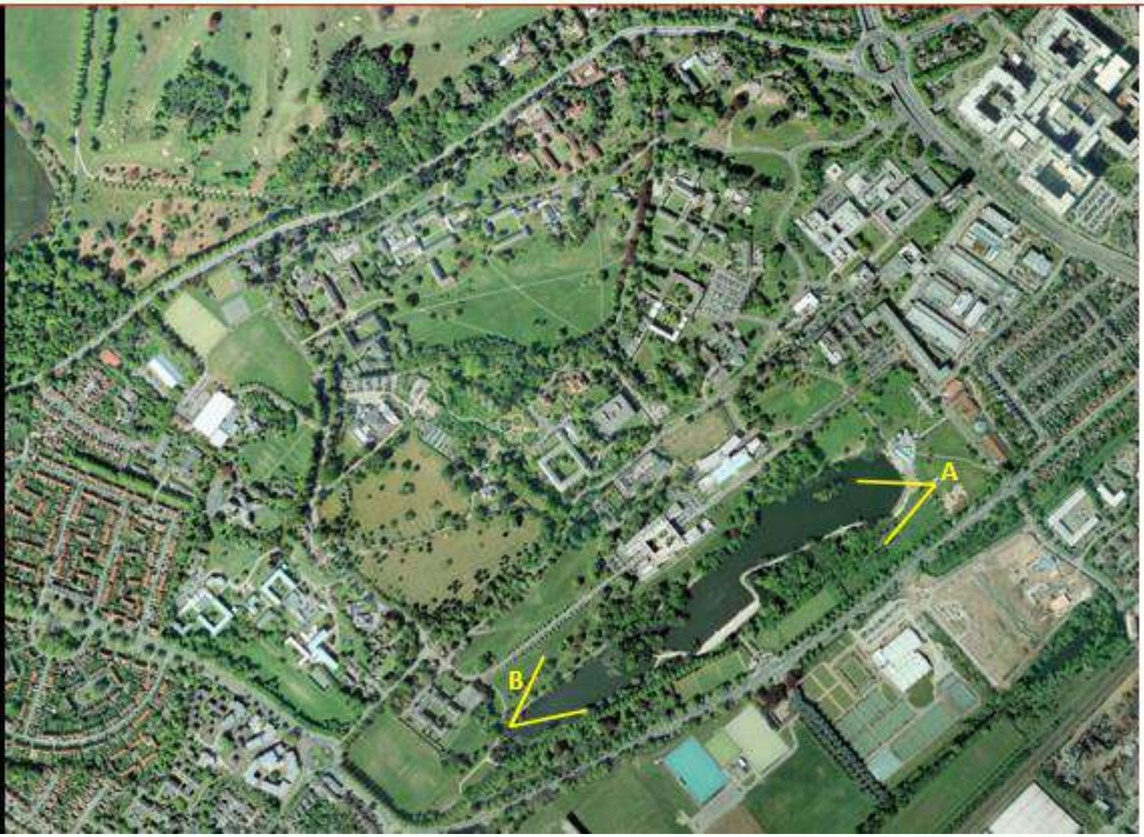

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
From which point is the yellow spot (building top) visible? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

No 34

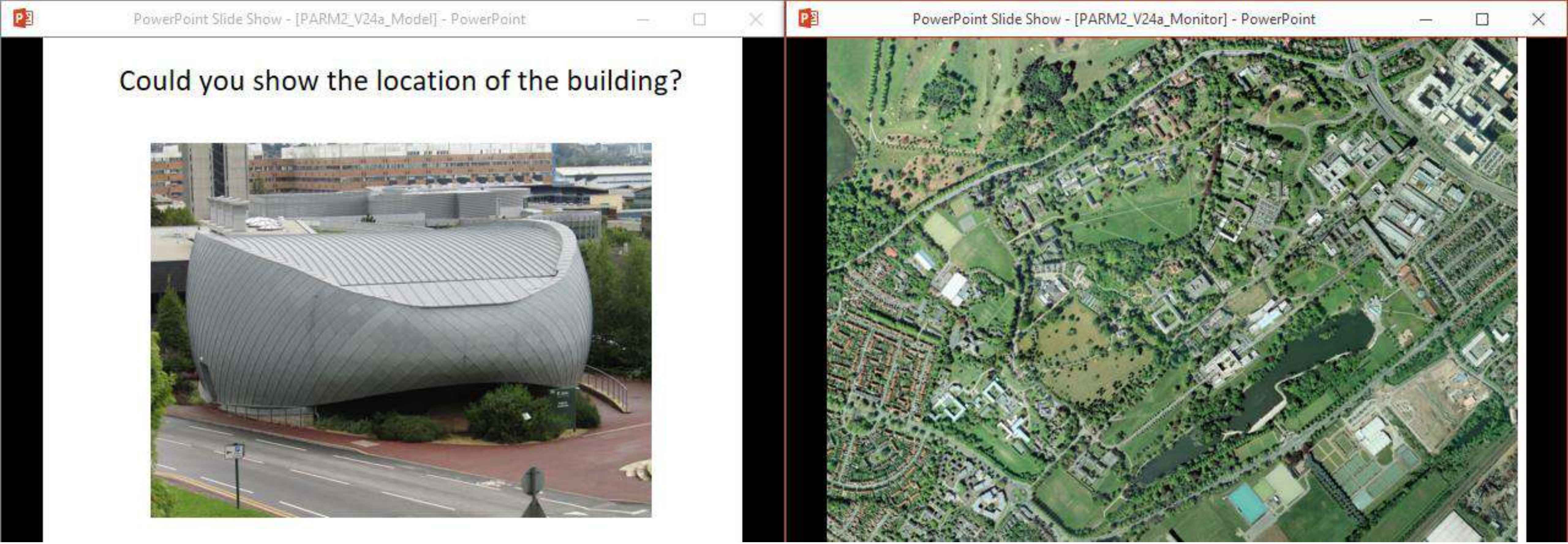
PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

Which viewpoint matches the picture below?

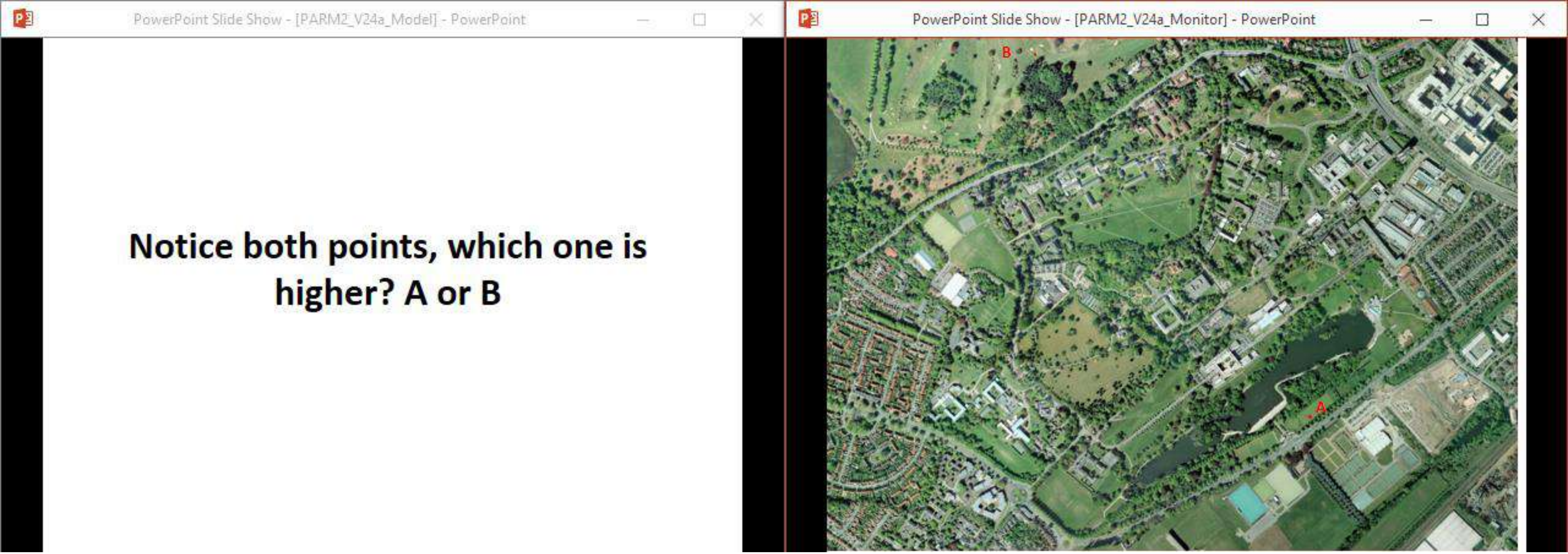
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint



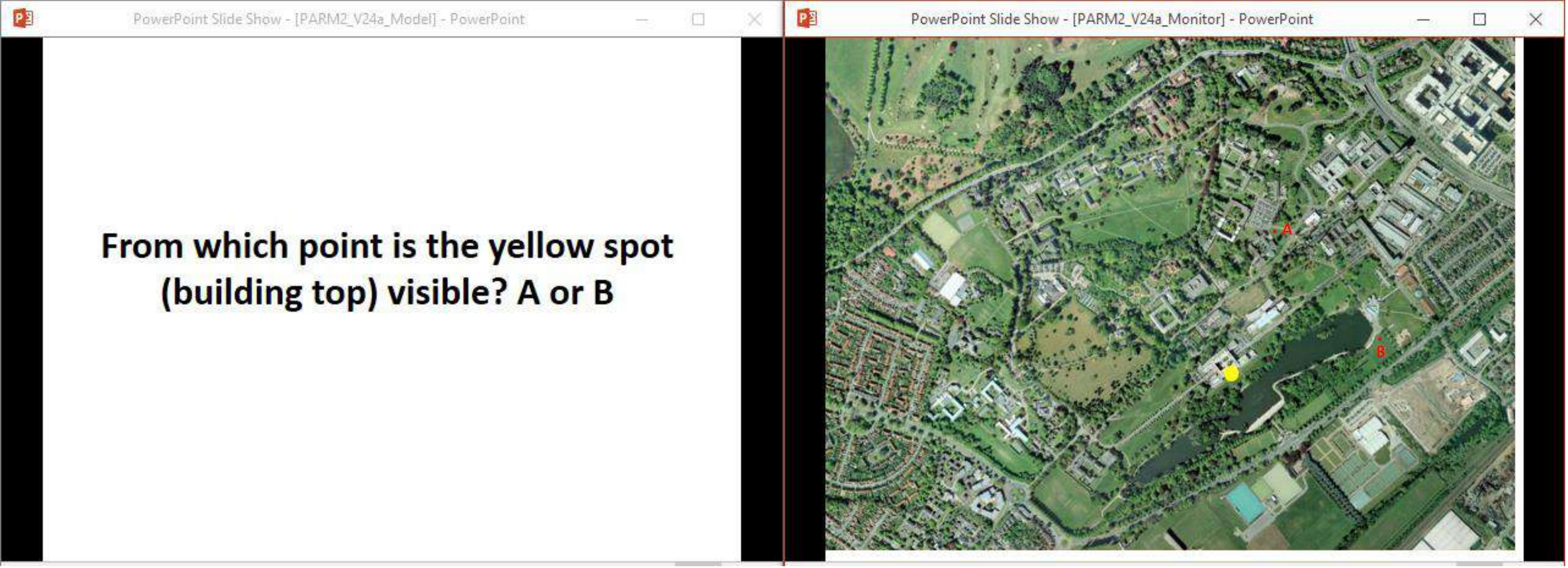
No 35


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Could you show the location of the building?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint

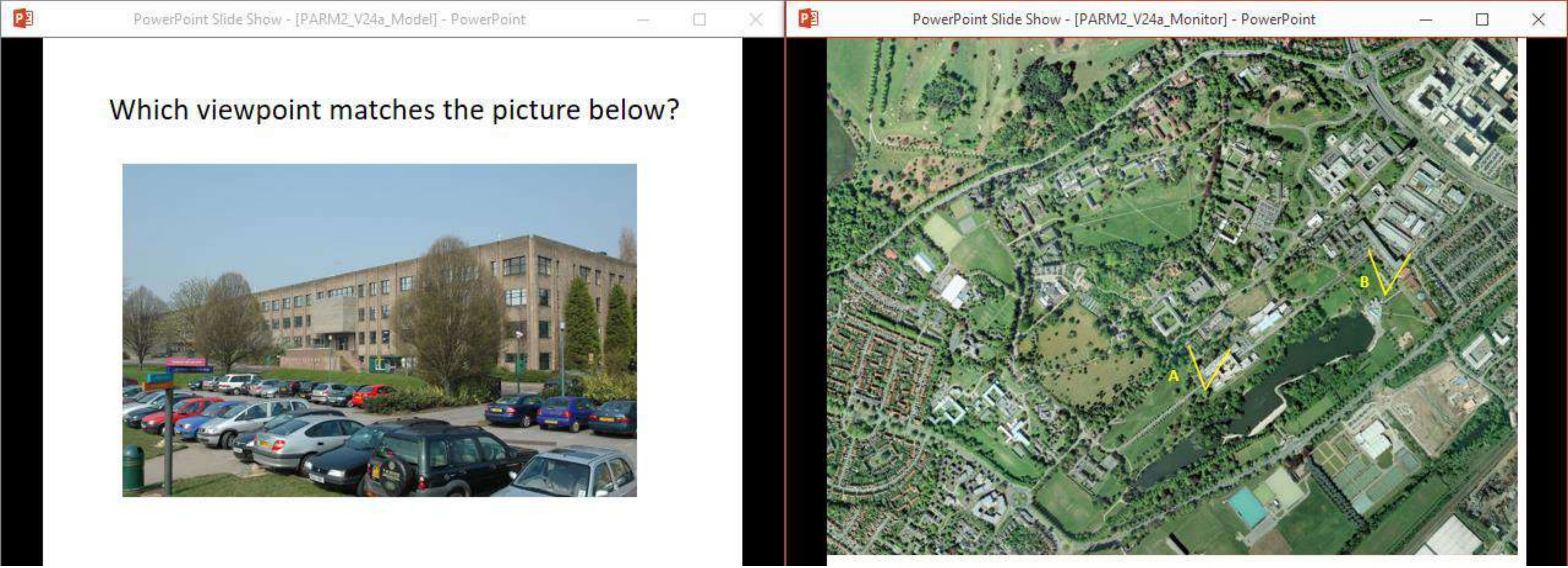
No 36


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Notice both points, which one is higher? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
B
A

No 37


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
From which point is the yellow spot (building top) visible? A or B
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

No 38

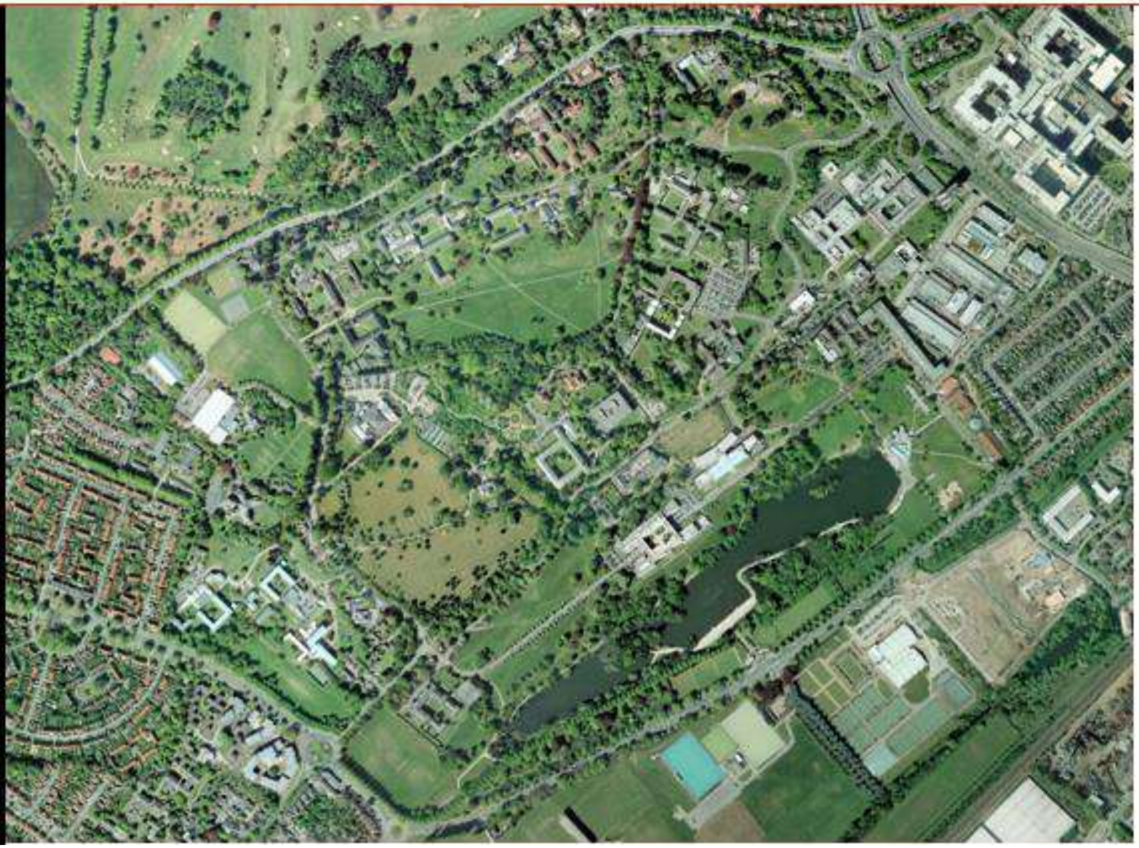

PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
Which viewpoint matches the picture below?
PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
A
B

No 39

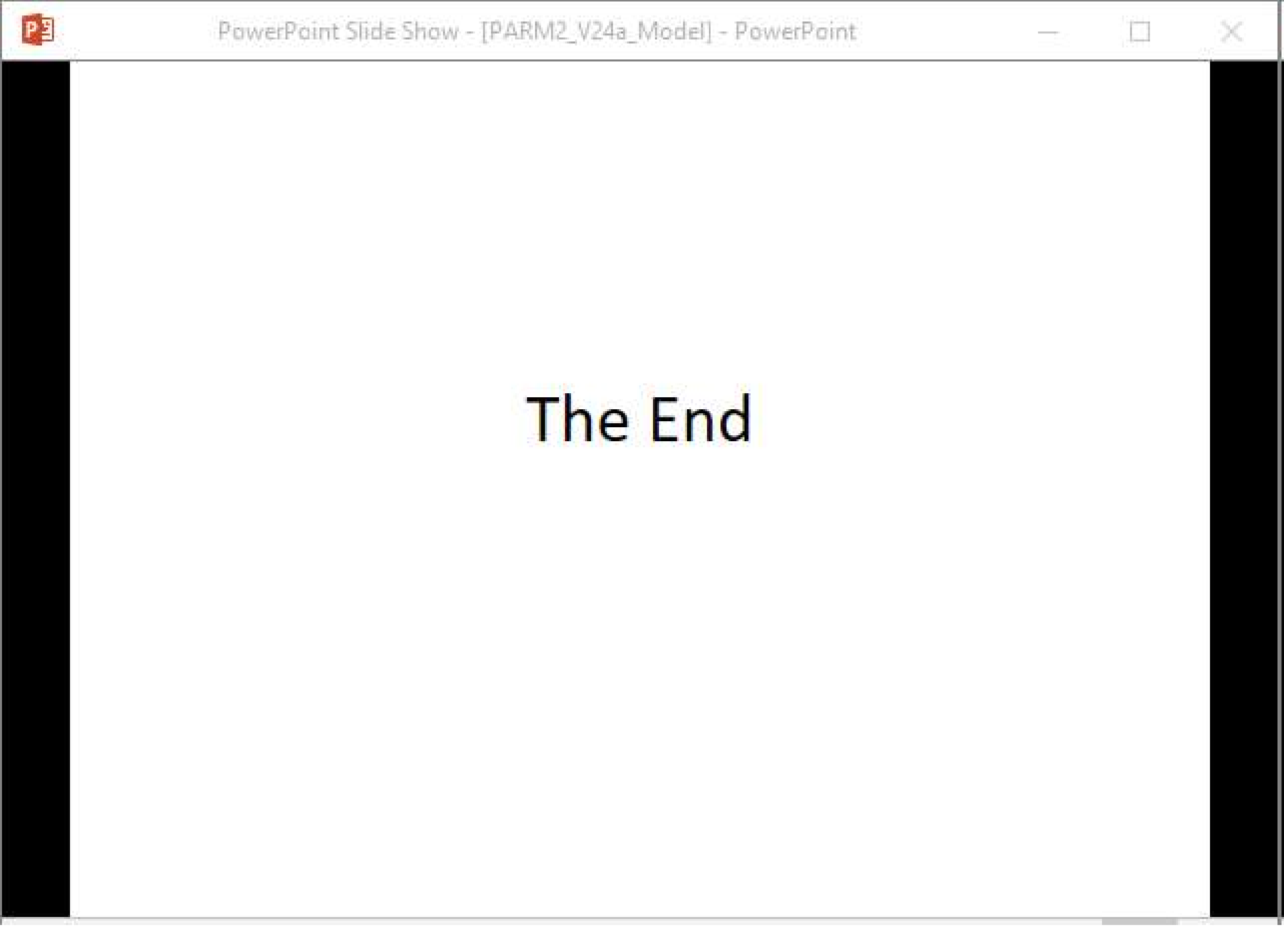
PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint

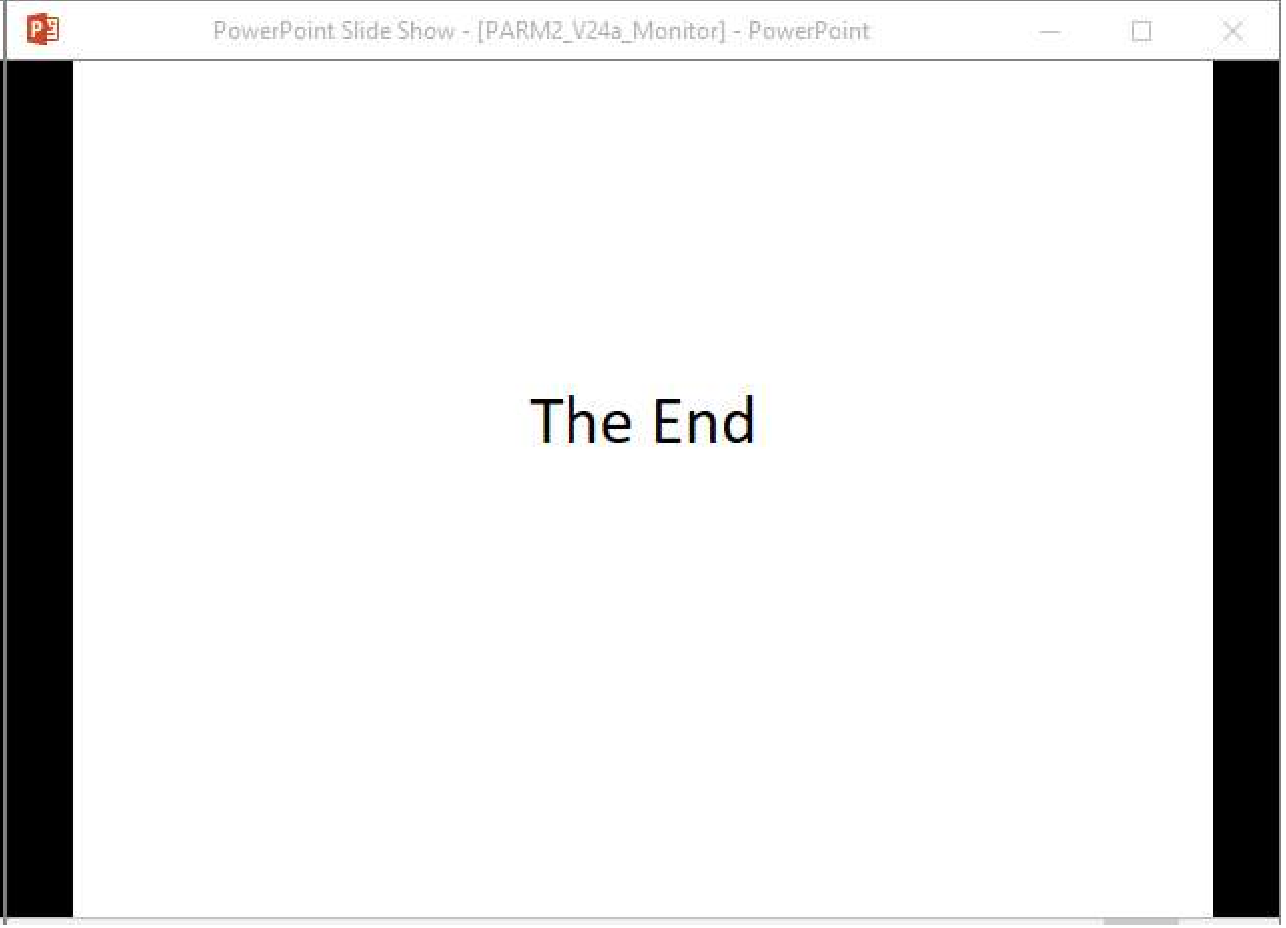
Could you show the location of the place?

PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint



No 40


PowerPoint Slide Show - [PARM2_V24a_Model] - PowerPoint
The End


PowerPoint Slide Show - [PARM2_V24a_Monitor] - PowerPoint
The End

Appendix 6. Finger Tracking program: Modification of Algorithm

Main window Algorithm

```
namespace FingerTracking
{
   partial class MainWindow
   {
      /// <summary>
      /// Required designer variable.
      /// </summary>
      private System.ComponentModel.IContainer components = null;

      /// <summary>
      /// Clean up any resources being used.
      /// </summary>
      /// <param name="disposing">true if managed resources should be disposed; otherwise, false.</param>
      protected override void Dispose(bool disposing)
      {
         if (disposing && (components != null))
         {
            components.Dispose();
         }
         base.Dispose(disposing);
      }

      #region Windows Form Designer generated code

      /// <summary>
      /// Required method for Designer support - do not modify
      /// the contents of this method with the code editor.
      /// </summary>
      private void InitializeComponent()
      {
         this.trackingImage = new System.Windows.Forms.PictureBox();
         this.colorButton = new System.Windows.Forms.Button();
         this.depthButton = new System.Windows.Forms.Button();
         this.thetaTrackBar = new System.Windows.Forms.TrackBar();
         this.kTrackBar = new System.Windows.Forms.TrackBar();
         this.label3 = new System.Windows.Forms.Label();
         this.thetaTextBox = new System.Windows.Forms.TextBox();
         this.kTextBox = new System.Windows.Forms.TextBox();
         this.label4 = new System.Windows.Forms.Label();
         this.fingersTextBox1 = new System.Windows.Forms.TextBox();
         this.NearSpaceTextBox = new System.Windows.Forms.TextBox();
         this.NearSpaceTrackBar = new System.Windows.Forms.TrackBar();
         this.AbsoluteCheckBox = new System.Windows.Forms.CheckBox();
         this.colorImage = new System.Windows.Forms.PictureBox();
         this.label6 = new System.Windows.Forms.Label();
         this.groupBox1 = new System.Windows.Forms.GroupBox();
         this.groupBox2 = new System.Windows.Forms.GroupBox();
```

```
this.groupBox8 = new System.Windows.Forms.GroupBox();
this.boxReductionTextBox = new System.Windows.Forms.TextBox();
this.boxReductionTrackBar = new System.Windows.Forms.TrackBar();
this.groupBox6 = new System.Windows.Forms.GroupBox();
this.smoothTextBox = new System.Windows.Forms.TextBox();
this.smoothTrackBar = new System.Windows.Forms.TrackBar();
this.groupBox7 = new System.Windows.Forms.GroupBox();
this.checkSameMargins = new System.Windows.Forms.CheckBox();
this.label8 = new System.Windows.Forms.Label();
this.textMarginBot = new System.Windows.Forms.TextBox();
this.label7 = new System.Windows.Forms.Label();
this.textMarginTop = new System.Windows.Forms.TextBox();
this.label2 = new System.Windows.Forms.Label();
this.textMarginRight = new System.Windows.Forms.TextBox();
this.textMarginLeft = new System.Windows.Forms.TextBox();
this.label5 = new System.Windows.Forms.Label();
this.groupBox5 = new System.Windows.Forms.GroupBox();
this.groupBox3 = new System.Windows.Forms.GroupBox();
this.groupBox4 = new System.Windows.Forms.GroupBox();
this.textBoxCoordinate = new System.Windows.Forms.TextBox();
this.listBox1 = new System.Windows.Forms.ListBox();
this.label1 = new System.Windows.Forms.Label();
this.fingersTextBox2 = new System.Windows.Forms.TextBox();
this.textBoxNames = new System.Windows.Forms.TextBox();
this.depthImage = new System.Windows.Forms.PictureBox();
this.pictureBox1 = new System.Windows.Forms.PictureBox();
this.buttonA1 = new System.Windows.Forms.Button();
this.buttonA2 = new System.Windows.Forms.Button();
this.buttonA3 = new System.Windows.Forms.Button();
this.buttonA4 = new System.Windows.Forms.Button();
this.buttonA5 = new System.Windows.Forms.Button();
this.buttonA6 = new System.Windows.Forms.Button();
this.buttonA8 = new System.Windows.Forms.Button();
this.buttonA7 = new System.Windows.Forms.Button();
this.buttonB8 = new System.Windows.Forms.Button();
this.buttonB7 = new System.Windows.Forms.Button();
this.buttonB6 = new System.Windows.Forms.Button();
this.buttonB5 = new System.Windows.Forms.Button();
this.buttonB4 = new System.Windows.Forms.Button();
this.buttonB3 = new System.Windows.Forms.Button();
this.buttonB2 = new System.Windows.Forms.Button();
this.buttonB1 = new System.Windows.Forms.Button();
((System.ComponentModel.ISupportInitialize)(this.trackingImage)).BeginInit();
((System.ComponentModel.ISupportInitialize)(this.thetaTrackBar)).BeginInit();
((System.ComponentModel.ISupportInitialize)(this.kTrackBar)).BeginInit();
((System.ComponentModel.ISupportInitialize)(this.NearSpaceTrackBar)).BeginInit();
((System.ComponentModel.ISupportInitialize)(this.colorImage)).BeginInit();
this.groupBox1.SuspendLayout();
this.groupBox2.SuspendLayout();
this.groupBox8.SuspendLayout();
((System.ComponentModel.ISupportInitialize)(this.boxReductionTrackBar)).BeginInit();
this.groupBox6.SuspendLayout();
((System.ComponentModel.ISupportInitialize)(this.smoothTrackBar)).BeginInit();
```

```
this.groupBox7.SuspendLayout();
this.groupBox5.SuspendLayout();
this.groupBox3.SuspendLayout();
this.groupBox4.SuspendLayout();
((System.ComponentModel.ISupportInitialize)(this.depthImage)).BeginInit();
((System.ComponentModel.ISupportInitialize)(this.pictureBox1)).BeginInit();
this.SuspendLayout();
//
// trackingImage
//
this.trackingImage.BackColor = System.Drawing.SystemColors.InactiveCaption;
this.trackingImage.BorderStyle = System.Windows.Forms.BorderStyle.FixedSingle;
this.trackingImage.Location = new System.Drawing.Point(371, 129);
this.trackingImage.Name = "trackingImage";
this.trackingImage.Size = new System.Drawing.Size(600, 488);
this.trackingImage.SizeMode = System.Windows.Forms.PictureBoxSizeMode.Zoom;
this.trackingImage.TabIndex = 0;
this.trackingImage.TabStop = false;
//
// colorButton
//
this.colorButton.AutoSize = true;
this.colorButton.Location = new System.Drawing.Point(792, 623);
this.colorButton.Name = "colorButton";
this.colorButton.Size = new System.Drawing.Size(75, 23);
this.colorButton.TabIndex = 1;
this.colorButton.Text = "Color";
this.colorButton.UseVisualStyleBackColor = true;
this.colorButton.Click += new System.EventHandler(this.colorButton_Click);
//
// depthButton
//
this.depthButton.Location = new System.Drawing.Point(896, 623);
this.depthButton.Name = "depthButton";
this.depthButton.Size = new System.Drawing.Size(75, 23);
this.depthButton.TabIndex = 2;
this.depthButton.Text = "Depth";
this.depthButton.UseVisualStyleBackColor = true;
this.depthButton.Click += new System.EventHandler(this.depthButton_Click);
//
// thetaTrackBar
//
this.thetaTrackBar.Location = new System.Drawing.Point(5, 18);
this.thetaTrackBar.Maximum = 50;
this.thetaTrackBar.Minimum = 10;
this.thetaTrackBar.Name = "thetaTrackBar";
this.thetaTrackBar.Size = new System.Drawing.Size(98, 45);
this.thetaTrackBar.TabIndex = 3;
this.thetaTrackBar.Value = 35;
this.thetaTrackBar.Scroll += new System.EventHandler(this.thetaTrackBar_Scroll);
//
// kTrackBar
//
```

```
this.kTrackBar.Location = new System.Drawing.Point(5, 18);
this.kTrackBar.Maximum = 80;
this.kTrackBar.Minimum = 2;
this.kTrackBar.Name = "kTrackBar";
this.kTrackBar.Size = new System.Drawing.Size(98, 45);
this.kTrackBar.TabIndex = 4;
this.kTrackBar.Value = 15;
this.kTrackBar.Scroll += new System.EventHandler(this.kTrackBar_Scroll);
//
// label3
//
this.label3.AutoSize = true;
this.label3.Location = new System.Drawing.Point(705, 628);
this.label3.Name = "label3";
this.label3.Size = new System.Drawing.Size(65, 13);
this.label3.TabIndex = 7;
this.label3.Text = "Image mode";
//
// thetaTextBox
//
this.thetaTextBox.BackColor = System.Drawing.SystemColors.ControlLightLight;
this.thetaTextBox.Location = new System.Drawing.Point(110, 18);
this.thetaTextBox.Name = "thetaTextBox";
this.thetaTextBox.ReadOnly = true;
this.thetaTextBox.Size = new System.Drawing.Size(42, 20);
this.thetaTextBox.TabIndex = 8;
this.thetaTextBox.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
//
// kTextBox
//
this.kTextBox.BackColor = System.Drawing.SystemColors.ControlLightLight;
this.kTextBox.Location = new System.Drawing.Point(110, 18);
this.kTextBox.Name = "kTextBox";
this.kTextBox.ReadOnly = true;
this.kTextBox.Size = new System.Drawing.Size(42, 20);
this.kTextBox.TabIndex = 9;
this.kTextBox.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
//
// label4
//
this.label4.AutoSize = true;
this.label4.Font = new System.Drawing.Font("Microsoft Sans Serif", 6F,
System.Drawing.FontStyle.Regular, System.Drawing.GraphicsUnit.Point, ((byte)(0)));
this.label4.Location = new System.Drawing.Point(2, 18);
this.label4.Name = "label4";
this.label4.Size = new System.Drawing.Size(58, 9);
this.label4.TabIndex = 10;
this.label4.Text = "Coordinate X, Y";
this.label4.Click += new System.EventHandler(this.label4_Click);
//
// fingersTextBox1
//
this.fingersTextBox1.BackColor = System.Drawing.SystemColors.ControlLightLight;
```

```
this.fingersTextBox1.Location = new System.Drawing.Point(66, 15);
this.fingersTextBox1.Name = "fingersTextBox1";
this.fingersTextBox1.ReadOnly = true;
this.fingersTextBox1.Size = new System.Drawing.Size(42, 20);
this.fingersTextBox1.TabIndex = 11;
this.fingersTextBox1.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
//
// NearSpaceTextBox
//
this.NearSpaceTextBox.BackColor = System.Drawing.SystemColors.ControlLightLight;
this.NearSpaceTextBox.Location = new System.Drawing.Point(110, 18);
this.NearSpaceTextBox.Name = "NearSpaceTextBox";
this.NearSpaceTextBox.ReadOnly = true;
this.NearSpaceTextBox.Size = new System.Drawing.Size(42, 20);
this.NearSpaceTextBox.TabIndex = 13;
this.NearSpaceTextBox.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
//
// NearSpaceTrackBar
//
this.NearSpaceTrackBar.Location = new System.Drawing.Point(5, 18);
this.NearSpaceTrackBar.Maximum = 100;
this.NearSpaceTrackBar.Name = "NearSpaceTrackBar";
this.NearSpaceTrackBar.Size = new System.Drawing.Size(98, 45);
this.NearSpaceTrackBar.TabIndex = 14;
this.NearSpaceTrackBar.Value = 10;
this.NearSpaceTrackBar.Scroll += new System.EventHandler(this.NearSpaceTrackBar_Scroll);
//
// AbsoluteCheckBox
//
this.AbsoluteCheckBox.AutoSize = true;
this.AbsoluteCheckBox.Location = new System.Drawing.Point(50, 63);
this.AbsoluteCheckBox.Name = "AbsoluteCheckBox";
this.AbsoluteCheckBox.Size = new System.Drawing.Size(67, 17);
this.AbsoluteCheckBox.TabIndex = 15;
this.AbsoluteCheckBox.Text = "Absolute";
this.AbsoluteCheckBox.UseVisualStyleBackColor = true;
//
// colorImage
//
this.colorImage.BackColor = System.Drawing.SystemColors.ControlText;
this.colorImage.Location = new System.Drawing.Point(10, 49);
this.colorImage.Name = "colorImage";
this.colorImage.Size = new System.Drawing.Size(165, 134);
this.colorImage.SizeMode = System.Windows.Forms.PictureBoxSizeMode.Zoom;
this.colorImage.TabIndex = 16;
this.colorImage.TabStop = false;
//
// label6
//
this.label6.AutoSize = true;
this.label6.Font = new System.Drawing.Font("Microsoft Sans Serif", 16.2F,
System.Drawing.FontStyle.Bold, System.Drawing.GraphicsUnit.Point, ((byte)(0)));
this.label6.Location = new System.Drawing.Point(366, 19);
```

```
this.label6.Name = "label6";
this.label6.Size = new System.Drawing.Size(630, 26);
this.label6.TabIndex = 17;
this.label6.Text = "Interaction of Projected Augmented Relief Models (PARM)";
this.label6.Click += new System.EventHandler(this.label6_Click);
//
// groupBox1
//
this.groupBox1.Controls.Add(this.thetaTrackBar);
this.groupBox1.Controls.Add(this.thetaTextBox);
this.groupBox1.Location = new System.Drawing.Point(10, 22);
this.groupBox1.Margin = new System.Windows.Forms.Padding(8, 2, 8, 2);
this.groupBox1.Name = "groupBox1";
this.groupBox1.Padding = new System.Windows.Forms.Padding(2);
this.groupBox1.Size = new System.Drawing.Size(158, 70);
this.groupBox1.TabIndex = 18;
this.groupBox1.TabStop = false;
this.groupBox1.Text = "Theta";
//
// groupBox2
//
this.groupBox2.Controls.Add(this.groupBox8);
this.groupBox2.Controls.Add(this.groupBox6);
this.groupBox2.Controls.Add(this.groupBox7);
this.groupBox2.Controls.Add(this.groupBox5);
this.groupBox2.Controls.Add(this.groupBox1);
this.groupBox2.Controls.Add(this.groupBox3);
this.groupBox2.Controls.Add(this.groupBox4);
this.groupBox2.Location = new System.Drawing.Point(9, 188);
this.groupBox2.Margin = new System.Windows.Forms.Padding(2);
this.groupBox2.Name = "groupBox2";
this.groupBox2.Padding = new System.Windows.Forms.Padding(2);
this.groupBox2.Size = new System.Drawing.Size(351, 564);
this.groupBox2.TabIndex = 19;
this.groupBox2.TabStop = false;
this.groupBox2.Text = "Parameters";
//
// groupBox8
//
this.groupBox8.Controls.Add(this.boxReductionTextBox);
this.groupBox8.Controls.Add(this.boxReductionTrackBar);
this.groupBox8.Location = new System.Drawing.Point(10, 337);
this.groupBox8.Margin = new System.Windows.Forms.Padding(8, 2, 8, 2);
this.groupBox8.Name = "groupBox8";
this.groupBox8.Padding = new System.Windows.Forms.Padding(2);
this.groupBox8.Size = new System.Drawing.Size(158, 70);
this.groupBox8.TabIndex = 21;
this.groupBox8.TabStop = false;
this.groupBox8.Text = "Container Box Reduction";
//
// boxReductionTextBox
//
this.boxReductionTextBox.BackColor = System.Drawing.SystemColors.ControlLightLight;
```

```
this.boxReductionTextBox.Location = new System.Drawing.Point(110, 18);
this.boxReductionTextBox.Name = "boxReductionTextBox";
this.boxReductionTextBox.ReadOnly = true;
this.boxReductionTextBox.Size = new System.Drawing.Size(42, 20);
this.boxReductionTextBox.TabIndex = 9;
this.boxReductionTextBox.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
//
// boxReductionTrackBar
//
this.boxReductionTrackBar.Location = new System.Drawing.Point(5, 18);
this.boxReductionTrackBar.Maximum = 99;
this.boxReductionTrackBar.Name = "boxReductionTrackBar";
this.boxReductionTrackBar.Size = new System.Drawing.Size(98, 45);
this.boxReductionTrackBar.TabIndex = 4;
//
// groupBox6
//
this.groupBox6.Controls.Add(this.smoothTextBox);
this.groupBox6.Controls.Add(this.smoothTrackBar);
this.groupBox6.Location = new System.Drawing.Point(15, 262);
this.groupBox6.Margin = new System.Windows.Forms.Padding(8, 2, 8, 2);
this.groupBox6.Name = "groupBox6";
this.groupBox6.Padding = new System.Windows.Forms.Padding(2);
this.groupBox6.Size = new System.Drawing.Size(158, 70);
this.groupBox6.TabIndex = 20;
this.groupBox6.TabStop = false;
this.groupBox6.Text = "Smooth";
//
// smoothTextBox
//
this.smoothTextBox.BackColor = System.Drawing.SystemColors.ControlLightLight;
this.smoothTextBox.Location = new System.Drawing.Point(110, 18);
this.smoothTextBox.Name = "smoothTextBox";
this.smoothTextBox.ReadOnly = true;
this.smoothTextBox.Size = new System.Drawing.Size(42, 20);
this.smoothTextBox.TabIndex = 9;
this.smoothTextBox.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
//
// smoothTrackBar
//
this.smoothTrackBar.Location = new System.Drawing.Point(5, 18);
this.smoothTrackBar.Maximum = 5;
this.smoothTrackBar.Name = "smoothTrackBar";
this.smoothTrackBar.Size = new System.Drawing.Size(98, 45);
this.smoothTrackBar.TabIndex = 4;
this.smoothTrackBar.Scroll += new System.EventHandler(this.Smooth_Scroll);
//
// groupBox7
//
this.groupBox7.Controls.Add(this.checkSameMargins);
this.groupBox7.Controls.Add(this.label8);
this.groupBox7.Controls.Add(this.textMarginBot);
this.groupBox7.Controls.Add(this.label7);
```

```
this.groupBox7.Controls.Add(this.textMarginTop);
this.groupBox7.Controls.Add(this.label2);
this.groupBox7.Controls.Add(this.textMarginRight);
this.groupBox7.Controls.Add(this.textMarginLeft);
this.groupBox7.Controls.Add(this.label5);
this.groupBox7.Location = new System.Drawing.Point(4, 415);
this.groupBox7.Margin = new System.Windows.Forms.Padding(8, 2, 8, 2);
this.groupBox7.Name = "groupBox7";
this.groupBox7.Padding = new System.Windows.Forms.Padding(2);
this.groupBox7.Size = new System.Drawing.Size(158, 145);
this.groupBox7.TabIndex = 21;
this.groupBox7.TabStop = false;
this.groupBox7.Text = "Margins";
//
// checkSameMargins
//
this.checkSameMargins.AutoSize = true;
this.checkSameMargins.Location = new System.Drawing.Point(34, 116);
this.checkSameMargins.Margin = new System.Windows.Forms.Padding(2);
this.checkSameMargins.Name = "checkSameMargins";
this.checkSameMargins.Size = new System.Drawing.Size(93, 17);
this.checkSameMargins.TabIndex = 18;
this.checkSameMargins.Text = "Same Margins";
this.checkSameMargins.UseVisualStyleBackColor = true;
//
// label8
//
this.label8.AutoSize = true;
this.label8.Location = new System.Drawing.Point(22, 92);
this.label8.Name = "label8";
this.label8.Size = new System.Drawing.Size(58, 13);
this.label8.TabIndex = 17;
this.label8.Text = "Margin Bot";
//
// textMarginBot
//
this.textMarginBot.Location = new System.Drawing.Point(106, 92);
this.textMarginBot.Name = "textMarginBot";
this.textMarginBot.Size = new System.Drawing.Size(42, 20);
this.textMarginBot.TabIndex = 16;
this.textMarginBot.TextChanged += new System.EventHandler(this.marginsChanged);
//
// label7
//
this.label7.AutoSize = true;
this.label7.Location = new System.Drawing.Point(22, 67);
this.label7.Name = "label7";
this.label7.Size = new System.Drawing.Size(61, 13);
this.label7.TabIndex = 15;
this.label7.Text = "Margin Top";
//
// textMarginTop
//
```

```
this.textMarginTop.Location = new System.Drawing.Point(106, 67);
this.textMarginTop.Name = "textMarginTop";
this.textMarginTop.Size = new System.Drawing.Size(42, 20);
this.textMarginTop.TabIndex = 14;
this.textMarginTop.TextChanged += new System.EventHandler(this.marginsChanged);
//
// label2
//
this.label2.AutoSize = true;
this.label2.Location = new System.Drawing.Point(22, 42);
this.label2.Name = "label2";
this.label2.Size = new System.Drawing.Size(67, 13);
this.label2.TabIndex = 13;
this.label2.Text = "Margin Right";
//
// textMarginRight
//
this.textMarginRight.Location = new System.Drawing.Point(106, 42);
this.textMarginRight.Name = "textMarginRight";
this.textMarginRight.Size = new System.Drawing.Size(42, 20);
this.textMarginRight.TabIndex = 12;
this.textMarginRight.TextChanged += new System.EventHandler(this.marginsChanged);
//
// textMarginLeft
//
this.textMarginLeft.Location = new System.Drawing.Point(106, 18);
this.textMarginLeft.Name = "textMarginLeft";
this.textMarginLeft.Size = new System.Drawing.Size(42, 20);
this.textMarginLeft.TabIndex = 11;
this.textMarginLeft.TextChanged += new System.EventHandler(this.marginsChanged);
//
// label5
//
this.label5.AutoSize = true;
this.label5.Location = new System.Drawing.Point(22, 18);
this.label5.Name = "label5";
this.label5.Size = new System.Drawing.Size(60, 13);
this.label5.TabIndex = 10;
this.label5.Text = "Margin Left";
//
// groupBox5
//
this.groupBox5.Controls.Add(this.AbsoluteCheckBox);
this.groupBox5.Controls.Add(this.NearSpaceTrackBar);
this.groupBox5.Controls.Add(this.NearSpaceTextBox);
this.groupBox5.Location = new System.Drawing.Point(10, 171);
this.groupBox5.Margin = new System.Windows.Forms.Padding(8, 2, 8, 2);
this.groupBox5.Name = "groupBox5";
this.groupBox5.Padding = new System.Windows.Forms.Padding(2);
this.groupBox5.Size = new System.Drawing.Size(158, 85);
this.groupBox5.TabIndex = 20;
this.groupBox5.TabStop = false;
this.groupBox5.Text = "Near Space";
```

```
//
// groupBox3
//
this.groupBox3.Controls.Add(this.kTextBox);
this.groupBox3.Controls.Add(this.kTrackBar);
this.groupBox3.Location = new System.Drawing.Point(10, 97);
this.groupBox3.Margin = new System.Windows.Forms.Padding(8, 2, 8, 2);
this.groupBox3.Name = "groupBox3";
this.groupBox3.Padding = new System.Windows.Forms.Padding(2);
this.groupBox3.Size = new System.Drawing.Size(158, 70);
this.groupBox3.TabIndex = 19;
this.groupBox3.TabStop = false;
this.groupBox3.Text = "K";
//
// groupBox4
//
this.groupBox4.Controls.Add(this.textBoxCoordinate);
this.groupBox4.Controls.Add(this.listBox1);
this.groupBox4.Controls.Add(this.label1);
this.groupBox4.Controls.Add(this.fingersTextBox2);
this.groupBox4.Controls.Add(this.fingersTextBox1);
this.groupBox4.Controls.Add(this.label4);
this.groupBox4.Location = new System.Drawing.Point(184, 22);
this.groupBox4.Margin = new System.Windows.Forms.Padding(8, 2, 8, 2);
this.groupBox4.Name = "groupBox4";
this.groupBox4.Padding = new System.Windows.Forms.Padding(2);
this.groupBox4.Size = new System.Drawing.Size(167, 538);
this.groupBox4.TabIndex = 20;
this.groupBox4.TabStop = false;
this.groupBox4.Text = "Index Finger Coordinate";
//
// textBoxCoordinate
//
this.textBoxCoordinate.BackColor = System.Drawing.SystemColors.ControlLightLight;
this.textBoxCoordinate.Location = new System.Drawing.Point(5, 41);
this.textBoxCoordinate.Name = "textBoxCoordinate";
this.textBoxCoordinate.ReadOnly = true;
this.textBoxCoordinate.Size = new System.Drawing.Size(55, 20);
this.textBoxCoordinate.TabIndex = 22;
this.textBoxCoordinate.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
this.textBoxCoordinate.TextChanged += new
System.EventHandler(this.textBoxCoordinate_TextChanged);
//
// listBox1
//
this.listBox1.FormattingEnabled = true;
this.listBox1.Location = new System.Drawing.Point(8, 93);
this.listBox1.Name = "listBox1";
this.listBox1.Size = new System.Drawing.Size(144, 433);
this.listBox1.TabIndex = 10;
this.listBox1.SelectedIndexChanged += new
System.EventHandler(this.listBox1_SelectedIndexChanged);
//
```

```
// label1
//
this.label1.AutoSize = true;
this.label1.Location = new System.Drawing.Point(5, 75);
this.label1.Name = "label1";
this.label1.Size = new System.Drawing.Size(94, 13);
this.label1.TabIndex = 13;
this.label1.Text = "List of Coordinates";
//
// fingersTextBox2
//
this.fingersTextBox2.BackColor = System.Drawing.SystemColors.ControlLightLight;
this.fingersTextBox2.Location = new System.Drawing.Point(110, 15);
this.fingersTextBox2.Name = "fingersTextBox2";
this.fingersTextBox2.ReadOnly = true;
this.fingersTextBox2.Size = new System.Drawing.Size(42, 20);
this.fingersTextBox2.TabIndex = 12;
this.fingersTextBox2.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
//
// textBoxNames
//
this.textBoxNames.BackColor = System.Drawing.SystemColors.ControlLightLight;
this.textBoxNames.Font = new System.Drawing.Font("Trebuchet MS", 40F,
System.Drawing.FontStyle.Regular, System.Drawing.GraphicsUnit.Point, ((byte)(0)));
this.textBoxNames.ForeColor = System.Drawing.SystemColors.MenuHighlight;
this.textBoxNames.Location = new System.Drawing.Point(997, 49);
this.textBoxNames.Name = "textBoxNames";
this.textBoxNames.ReadOnly = true;
this.textBoxNames.Size = new System.Drawing.Size(575, 69);
this.textBoxNames.TabIndex = 23;
this.textBoxNames.TextAlign = System.Windows.Forms.HorizontalAlignment.Center;
this.textBoxNames.TextChanged += new System.EventHandler(this.textBoxNames_TextChanged);
//
// depthImage
//
this.depthImage.BackColor = System.Drawing.SystemColors.ControlText;
this.depthImage.Location = new System.Drawing.Point(195, 49);
this.depthImage.Name = "depthImage";
this.depthImage.Size = new System.Drawing.Size(165, 134);
this.depthImage.SizeMode = System.Windows.Forms.PictureBoxSizeMode.Zoom;
this.depthImage.TabIndex = 20;
this.depthImage.TabStop = false;
//
// pictureBox1
//
this.pictureBox1.Location = new System.Drawing.Point(997, 129);
this.pictureBox1.Name = "pictureBox1";
this.pictureBox1.Size = new System.Drawing.Size(575, 488);
this.pictureBox1.TabIndex = 24;
this.pictureBox1.TabStop = false;
//
// buttonA1
//
```

```
this.buttonA1.AutoSize = true;
this.buttonA1.Location = new System.Drawing.Point(384, 49);
this.buttonA1.Name = "buttonA1";
this.buttonA1.Size = new System.Drawing.Size(44, 23);
this.buttonA1.TabIndex = 23;
this.buttonA1.Text = "A1";
this.buttonA1.UseVisualStyleBackColor = true;
this.buttonA1.Click += new System.EventHandler(this.button1_Click);
//
// buttonA2
//
this.buttonA2.AutoSize = true;
this.buttonA2.Location = new System.Drawing.Point(434, 49);
this.buttonA2.Name = "buttonA2";
this.buttonA2.Size = new System.Drawing.Size(44, 23);
this.buttonA2.TabIndex = 26;
this.buttonA2.Text = "A2";
this.buttonA2.UseVisualStyleBackColor = true;
this.buttonA2.Click += new System.EventHandler(this.buttonA2_Click);
//
// buttonA3
//
this.buttonA3.AutoSize = true;
this.buttonA3.Location = new System.Drawing.Point(484, 49);
this.buttonA3.Name = "buttonA3";
this.buttonA3.Size = new System.Drawing.Size(44, 23);
this.buttonA3.TabIndex = 28;
this.buttonA3.Text = "A3";
this.buttonA3.UseVisualStyleBackColor = true;
this.buttonA3.Click += new System.EventHandler(this.buttonA3_Click);
//
// buttonA4
//
this.buttonA4.AutoSize = true;
this.buttonA4.Location = new System.Drawing.Point(534, 49);
this.buttonA4.Name = "buttonA4";
this.buttonA4.Size = new System.Drawing.Size(44, 23);
this.buttonA4.TabIndex = 30;
this.buttonA4.Text = "A4";
this.buttonA4.UseVisualStyleBackColor = true;
this.buttonA4.Click += new System.EventHandler(this.buttonA4_Click);
//
// buttonA5
//
this.buttonA5.AutoSize = true;
this.buttonA5.Location = new System.Drawing.Point(584, 49);
this.buttonA5.Name = "buttonA5";
this.buttonA5.Size = new System.Drawing.Size(44, 23);
this.buttonA5.TabIndex = 32;
this.buttonA5.Text = "A5";
this.buttonA5.UseVisualStyleBackColor = true;
this.buttonA5.Click += new System.EventHandler(this.buttonA5_Click);
//
```

```
// buttonA6
//
this.buttonA6.AutoSize = true;
this.buttonA6.Location = new System.Drawing.Point(634, 49);
this.buttonA6.Name = "buttonA6";
this.buttonA6.Size = new System.Drawing.Size(44, 23);
this.buttonA6.TabIndex = 34;
this.buttonA6.Text = "A6";
this.buttonA6.UseVisualStyleBackColor = true;
this.buttonA6.Click += new System.EventHandler(this.buttonA6_Click);
//
// buttonA8
//
this.buttonA8.AutoSize = true;
this.buttonA8.Location = new System.Drawing.Point(734, 48);
this.buttonA8.Name = "buttonA8";
this.buttonA8.Size = new System.Drawing.Size(44, 23);
this.buttonA8.TabIndex = 38;
this.buttonA8.Text = "A8";
this.buttonA8.UseVisualStyleBackColor = true;
this.buttonA8.Click += new System.EventHandler(this.buttonA8_Click);
//
// buttonA7
//
this.buttonA7.AutoSize = true;
this.buttonA7.Location = new System.Drawing.Point(684, 48);
this.buttonA7.Name = "buttonA7";
this.buttonA7.Size = new System.Drawing.Size(44, 23);
this.buttonA7.TabIndex = 36;
this.buttonA7.Text = "A7";
this.buttonA7.UseVisualStyleBackColor = true;
this.buttonA7.Click += new System.EventHandler(this.buttonA7_Click);
//
// buttonB8
//
this.buttonB8.AutoSize = true;
this.buttonB8.Location = new System.Drawing.Point(734, 94);
this.buttonB8.Name = "buttonB8";
this.buttonB8.Size = new System.Drawing.Size(44, 23);
this.buttonB8.TabIndex = 46;
this.buttonB8.Text = "B8";
this.buttonB8.UseVisualStyleBackColor = true;
this.buttonB8.Click += new System.EventHandler(this.buttonB8_Click);
//
// buttonB7
//
this.buttonB7.AutoSize = true;
this.buttonB7.Location = new System.Drawing.Point(684, 94);
this.buttonB7.Name = "buttonB7";
this.buttonB7.Size = new System.Drawing.Size(44, 23);
this.buttonB7.TabIndex = 45;
this.buttonB7.Text = "B7";
this.buttonB7.UseVisualStyleBackColor = true;
```

```
this.buttonB7.Click += new System.EventHandler(this.buttonB7_Click);
//
// buttonB6
//
this.buttonB6.AutoSize = true;
this.buttonB6.Location = new System.Drawing.Point(634, 95);
this.buttonB6.Name = "buttonB6";
this.buttonB6.Size = new System.Drawing.Size(44, 23);
this.buttonB6.TabIndex = 44;
this.buttonB6.Text = "B6";
this.buttonB6.UseVisualStyleBackColor = true;
this.buttonB6.Click += new System.EventHandler(this.buttonB6_Click);
//
// buttonB5
//
this.buttonB5.AutoSize = true;
this.buttonB5.Location = new System.Drawing.Point(584, 95);
this.buttonB5.Name = "buttonB5";
this.buttonB5.Size = new System.Drawing.Size(44, 23);
this.buttonB5.TabIndex = 43;
this.buttonB5.Text = "B5";
this.buttonB5.UseVisualStyleBackColor = true;
this.buttonB5.Click += new System.EventHandler(this.buttonB5_Click);
//
// buttonB4
//
this.buttonB4.AutoSize = true;
this.buttonB4.Location = new System.Drawing.Point(534, 95);
this.buttonB4.Name = "buttonB4";
this.buttonB4.Size = new System.Drawing.Size(44, 23);
this.buttonB4.TabIndex = 42;
this.buttonB4.Text = "B4";
this.buttonB4.UseVisualStyleBackColor = true;
this.buttonB4.Click += new System.EventHandler(this.buttonB4_Click);
//
// buttonB3
//
this.buttonB3.AutoSize = true;
this.buttonB3.Location = new System.Drawing.Point(484, 95);
this.buttonB3.Name = "buttonB3";
this.buttonB3.Size = new System.Drawing.Size(44, 23);
this.buttonB3.TabIndex = 41;
this.buttonB3.Text = "B3";
this.buttonB3.UseVisualStyleBackColor = true;
this.buttonB3.Click += new System.EventHandler(this.buttonB3_Click);
//
// buttonB2
//
this.buttonB2.AutoSize = true;
this.buttonB2.Location = new System.Drawing.Point(434, 95);
this.buttonB2.Name = "buttonB2";
this.buttonB2.Size = new System.Drawing.Size(44, 23);
this.buttonB2.TabIndex = 40;
```

```
this.buttonB2.Text = "B2";
this.buttonB2.UseVisualStyleBackColor = true;
this.buttonB2.Click += new System.EventHandler(this.buttonB2_Click);
//
// buttonB1
//
this.buttonB1.AutoSize = true;
this.buttonB1.Location = new System.Drawing.Point(384, 95);
this.buttonB1.Name = "buttonB1";
this.buttonB1.Size = new System.Drawing.Size(44, 23);
this.buttonB1.TabIndex = 39;
this.buttonB1.Text = "B1";
this.buttonB1.UseVisualStyleBackColor = true;
this.buttonB1.Click += new System.EventHandler(this.buttonB1_Click);
//
// MainWindow
//
this.AutoScaleDimensions = new System.Drawing.SizeF(6F, 13F);
this.AutoScaleMode = System.Windows.Forms.AutoScaleMode.Font;
this.ClientSize = new System.Drawing.Size(1284, 763);
this.Controls.Add(this.buttonB8);
this.Controls.Add(this.buttonB7);
this.Controls.Add(this.buttonB6);
this.Controls.Add(this.buttonB5);
this.Controls.Add(this.buttonB4);
this.Controls.Add(this.buttonB3);
this.Controls.Add(this.buttonB2);
this.Controls.Add(this.buttonB1);
this.Controls.Add(this.buttonA8);
this.Controls.Add(this.buttonA7);
this.Controls.Add(this.buttonA6);
this.Controls.Add(this.buttonA5);
this.Controls.Add(this.buttonA4);
this.Controls.Add(this.buttonA3);
this.Controls.Add(this.buttonA2);
this.Controls.Add(this.buttonA1);
this.Controls.Add(this.pictureBox1);
this.Controls.Add(this.depthImage);
this.Controls.Add(this.textBoxNames);
this.Controls.Add(this.groupBox2);
this.Controls.Add(this.label6);
this.Controls.Add(this.colorImage);
this.Controls.Add(this.label3);
this.Controls.Add(this.depthButton);
this.Controls.Add(this.colorButton);
this.Controls.Add(this.trackingImage);
this.FormBorderStyle = System.Windows.Forms.FormBorderStyle.FixedToolWindow;
this.Name = "MainWindow";
this.Text = "Fingertracking Test Panel";
((System.ComponentModel.ISupportInitialize)(this.trackingImage)).EndInit();
((System.ComponentModel.ISupportInitialize)(this.thetaTrackBar)).EndInit();
((System.ComponentModel.ISupportInitialize)(this.kTrackBar)).EndInit();
((System.ComponentModel.ISupportInitialize)(this.NearSpaceTrackBar)).EndInit();
```

```
    ((System.ComponentModel.ISupportInitialize)(this.colorImage)).EndInit();
    this.groupBox1.ResumeLayout(false);
    this.groupBox1.PerformLayout();
    this.groupBox2.ResumeLayout(false);
    this.groupBox8.ResumeLayout(false);
    this.groupBox8.PerformLayout();
    ((System.ComponentModel.ISupportInitialize)(this.boxReductionTrackBar)).EndInit();
    this.groupBox6.ResumeLayout(false);
    this.groupBox6.PerformLayout();
    ((System.ComponentModel.ISupportInitialize)(this.smoothTrackBar)).EndInit();
    this.groupBox7.ResumeLayout(false);
    this.groupBox7.PerformLayout();
    this.groupBox5.ResumeLayout(false);
    this.groupBox5.PerformLayout();
    this.groupBox3.ResumeLayout(false);
    this.groupBox3.PerformLayout();
    this.groupBox4.ResumeLayout(false);
    this.groupBox4.PerformLayout();
    ((System.ComponentModel.ISupportInitialize)(this.depthImage)).EndInit();
    ((System.ComponentModel.ISupportInitialize)(this.pictureBox1)).EndInit();
    this.ResumeLayout(false);
    this.PerformLayout();
}
#endregion

private System.Windows.Forms.Button colorButton;
private System.Windows.Forms.Button depthButton;
private System.Windows.Forms.TrackBar thetaTrackBar;
private System.Windows.Forms.TrackBar kTrackBar;
private System.Windows.Forms.Label label3;
private System.Windows.Forms.TextBox thetaTextBox;
private System.Windows.Forms.TextBox kTextBox;
private System.Windows.Forms.Label label4;
private System.Windows.Forms.TextBox fingersTextBox1;
private System.Windows.Forms.TextBox NearSpaceTextBox;
private System.Windows.Forms.TrackBar NearSpaceTrackBar;
private System.Windows.Forms.CheckBox AbsoluteCheckBox;
private System.Windows.Forms.PictureBox colorImage;
private System.Windows.Forms.Label label6;
private System.Windows.Forms.PictureBox trackingImage;
private System.Windows.Forms.GroupBox groupBox1;
private System.Windows.Forms.GroupBox groupBox2;
private System.Windows.Forms.GroupBox groupBox4;
private System.Windows.Forms.GroupBox groupBox5;
private System.Windows.Forms.GroupBox groupBox3;
private System.Windows.Forms.Label label1;
private System.Windows.Forms.TextBox fingersTextBox2;
private System.Windows.Forms.GroupBox groupBox7;
private System.Windows.Forms.Label label8;
private System.Windows.Forms.TextBox textMarginBot;
private System.Windows.Forms.Label label7;
private System.Windows.Forms.TextBox textMarginTop;
private System.Windows.Forms.Label label2;
```

```
        private System.Windows.Forms.TextBox textMarginRight;
        private System.Windows.Forms.TextBox textMarginLeft;
        private System.Windows.Forms.Label label5;
        private System.Windows.Forms.PictureBox depthImage;
        private System.Windows.Forms.CheckBox checkSameMargins;
        private System.Windows.Forms.GroupBox groupBox6;
        private System.Windows.Forms.TextBox smoothTextBox;
        private System.Windows.Forms.TrackBar smoothTrackBar;
        private System.Windows.Forms.GroupBox groupBox8;
        private System.Windows.Forms.TextBox boxReductionTextBox;
        private System.Windows.Forms.TrackBar boxReductionTrackBar;
        private System.Windows.Forms.TextBox textBoxCoordinate;
        private System.Windows.Forms.ListBox listBox1;
        private System.Windows.Forms.TextBox textBoxNames;
        private System.Windows.Forms.PictureBox pictureBox1;
        private System.Windows.Forms.Button buttonA1;
        private System.Windows.Forms.Button buttonA2;
        private System.Windows.Forms.Button buttonA3;
        private System.Windows.Forms.Button buttonA4;
        private System.Windows.Forms.Button buttonA5;
        private System.Windows.Forms.Button buttonA6;
        private System.Windows.Forms.Button buttonA8;
        private System.Windows.Forms.Button buttonA7;
        private System.Windows.Forms.Button buttonB8;
        private System.Windows.Forms.Button buttonB7;
        private System.Windows.Forms.Button buttonB6;
        private System.Windows.Forms.Button buttonB5;
        private System.Windows.Forms.Button buttonB4;
        private System.Windows.Forms.Button buttonB3;
        private System.Windows.Forms.Button buttonB2;
        private System.Windows.Forms.Button buttonB1;
    }
}
```

Finger Tracking program: Modification of Kinect Tracker algorithm

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
//using Microsoft.Kinect.dll;
using Microsoft.Kinect;
//using System.Te
using System.Drawing.Imaging;
using System.Drawing;
using System.Runtime.InteropServices;

namespace FingerTracking
{
  public class KinectTracker
  {
    KinectSensor sensor;
    private bool connected = false;

    public Bitmap depthImage;
    public Bitmap colorImage;
    public int tanganke;
    public int jarike;
    public int t2;
    public int j2;

    private IntPtr depthPtr;
    private IntPtr colorPtr;
    private void skip(){}
    public delegate void afterReady();
    private afterReady afterColorReady;
    private afterReady afterDepthReady;

    public KinectSettings settings{get; set;}
    public List<Hand> hands { get; set; }
    public KinectTracker()
    {
      afterColorReady = skip;
      afterDepthReady = skip;
      settings = new KinectSettings();
      hands = new List<Hand>();

      // Check if there is any Kinect device connected
      if (KinectSensor.KinectSensors.Count > 0)
      {
        connected = true;
        sensor = KinectSensor.KinectSensors.ElementAt(0);
         //sensor.DepthStream.Range = DepthRange.Near;
```

```
            sensor.DepthFrameReady += new
EventHandler<DepthImageFrameReadyEventArgs>(depthFrameReady);
            sensor.ColorFrameReady += new
EventHandler<ColorImageFrameReadyEventArgs>(colorFrameReady);

        }
        else // No device connected
        {
            connected = false;
        }
    }
    public void start()
    {
        sensor.DepthStream.Enable(settings.depthFormat);
        sensor.ColorStream.Enable();
        sensor.Start();
    }
    public void stop()
    {
        sensor.DepthStream.Disable();
        sensor.ColorStream.Disable();
        sensor.Stop();
    }
    public void setEventColorReady(afterReady del)
    {
        afterColorReady = del;
    }
    public void clearEventColorReady()
    {
        afterColorReady = skip;
    }
    public void setEventDepthReady(afterReady del)
    {
        afterDepthReady = del;
    }
    public void clearEventDepthReady()
    {
        afterDepthReady = skip;
    }
    public void colorFrameReady(object sender, ColorImageFrameReadyEventArgs e)
    {
        ColorImageFrame frame = e.OpenColorImageFrame();
        if (frame == null)
            return;
        byte[] pixels = new byte[frame.PixelDataLength];
        frame.CopyPixelDataTo(pixels);

        Marshal.FreeHGlobal(colorPtr);
        colorPtr = Marshal.AllocHGlobal(pixels.Length);
        Marshal.Copy(pixels, 0, colorPtr, pixels.Length);

        int stride = frame.Width * 4;
```

```
    colorImage = new Bitmap(
      frame.Width,
      frame.Height,
      stride,
      PixelFormat.Format32bppRgb,
      colorPtr);

    afterColorReady();
  }
  public void depthFrameReady(object sender, DepthImageFrameReadyEventArgs e)
  {
    // Get the depth frame from Kinect
    DepthImageFrame frame = e.OpenDepthImageFrame();
    // Check that the frame is not null
    if (frame == null)
      return;
    // Calculate the real distance for every pixel in the depth image
    int[] distances = generateDistances(frame);
    // Return a 0 or 1 matrix, which contains wich pixels are near enough
    bool[][] near = generateValidMatrix(frame, distances);
    // Return the tracked hands based on the near pixels
    hands = localizeHands(near);
    byte[] pixels = new byte[frame.PixelDataLength * 4];
    // Free last depth Matrix
    Marshal.FreeHGlobal(depthPtr);
    depthPtr = Marshal.AllocHGlobal(pixels.Length);
    Marshal.Copy(pixels, 0, depthPtr, pixels.Length);
    // Create the bitmap
    int height = near.Length;
    int width = 0;
    if (near.Length > 0)
    {
      width = near[0].Length;
    }
    int stride = width * 4;

    depthImage = new Bitmap(
      width,
      height,
      stride,
      PixelFormat.Format32bppRgb,
      depthPtr);

    // Calculate 3D points for the hands
    for (int i = 0; i < hands.Count; ++i)
    {
      hands[i].calculate3DPoints(settings.screenWidth, settings.screenHeight, distances);
    }
    // Call the rest of the functions
    afterDepthReady();

    drawFormat.Dispose();
  }        // Draw COORDINATES of fingertips
```

```
        Graphics gBmp = Graphics.FromImage(depthImage);
        Brush blueBrush = new SolidBrush(Color.Blue);
        Brush redBrush = new SolidBrush(Color.Red);
        System.Drawing.Font drawFont = new System.Drawing.Font("Arial", 15);
        System.Drawing.StringFormat drawFormat = new System.Drawing.StringFormat();
        System.Drawing.SolidBrush                    drawBrush                    =                    new
System.Drawing.SolidBrush(System.Drawing.Color.Yellow);
  //     int jari = new int();
  //     int tangan = new int();
  //     int tanganke = tangan;

        for (tanganke = 0; tanganke < hands.Count; ++tanganke)
        {
          gBmp.FillEllipse(redBrush, hands[tanganke].palm.Y - 5, hands[tanganke].palm.X - 5, 10, 10);

          for (jarike = 0; jarike < hands[tanganke].contour.Count; ++jarike)
          {
            PointFT p = hands[tanganke].contour[jarike];
            depthImage.SetPixel(p.Y, p.X, Color.Red);
          }
              for (jarike = 0; jarike < hands[tanganke].fingertips.Count; ++jarike)
          {
            if (hands[tanganke].fingertips[jarike].X != -1)
            {
              gBmp.FillEllipse(blueBrush,          hands[tanganke].fingertips[jarike].Y          -          5,
hands[tanganke].fingertips[jarike].X - 5, 10, 10);

gBmp.DrawString('('+hands[tanganke].fingertips[jarike].Y.ToString()+','+hands[tanganke].fingertips[jarike].X.T
oString()+')', drawFont, drawBrush, hands[tanganke].fingertips[jarike].Y, hands[tanganke].fingertips[jarike].X,
drawFormat);
              t2 = hands[tanganke].fingertips[jarike].X;
              j2 = hands[tanganke].fingertips[jarike].Y;

              return;
            }
          }
        }
        blueBrush.Dispose();
        redBrush.Dispose();
        gBmp.Dispose();
        drawBrush.Dispose();
        drawFont.Dispose();

      private int[] generateDistances(DepthImageFrame frame)
      {
        // Raw depth data form the Kinect
        short[] depth = new short[frame.PixelDataLength];
        frame.CopyPixelDataTo(depth);
        // Calculate the real distance
        int[] distance = new int[frame.PixelDataLength];
        for (int i = 0; i < distance.Length; ++i)
        {
          distance[i] = depth[i] >> DepthImageFrame.PlayerIndexBitmaskWidth;
```

```
    }
    return distance;
}
private bool[][] generateValidMatrix(DepthImageFrame frame, int[] distance)
{
    // Create the matrix. The size depends on the margins
    int x1 = (int) (frame.Width * settings.marginLeftPerc / 100.0f);
    int x2 = (int) (frame.Width * (1 - (settings.marginRightPerc / 100.0f)));
    int y1 = (int) (frame.Height * settings.marginTopPerc / 100.0f);
    int y2 = (int) (frame.Height * (1 - (settings.marginBotPerc / 100.0f)));
    bool[][] near = new bool[y2 - y1][];
    for (int i = 0; i < near.Length; ++i)
    {
        near[i] = new bool[x2 - x1];
    }
    // Calculate max and min distance
    int max = int.MinValue, min = int.MaxValue;
    for (int k = 0; k < distance.Length; ++k)
    {
        if (distance[k] > max) max = distance[k];
        if (distance[k] < min && distance[k] != -1) min = distance[k];
    }
    // Decide if it is near or not
    int margin = (int)(min + settings.nearSpacePerc * (max - min));
    int index = 0;
    if (settings.absoluteSpace != -1) margin = min + settings.absoluteSpace;
    for (int i = 0; i < near.Length; ++i)
    {
        for (int j = 0; j < near[i].Length; ++j)
        {
            index = frame.Width * (i + y1) + (j + x1);
            if (distance[index] <= margin && distance[index] != -1)
            {
                near[i][j] = true;
            }
            else
            {
                near[i][j] = false;
            }
        }
    }
    // Dilate and erode the image to get smoother figures
    if (settings.smoothingIterations > 0)
    {
        near = dilate(near, settings.smoothingIterations);
        near = erode(near, settings.smoothingIterations);
    }
    // Mark as not valid the borders of the matrix to improve the efficiency in some methods
    int m;
    // First row
    for (int j = 0; j < near[0].Length; ++j)
        near[0][j] = false;
    // Last row
```

```
        m = near.Length - 1;
        for (int j = 0; j < near[0].Length; ++j)
            near[m][j] = false;
        // First column
        for (int i = 0; i < near.Length; ++i)
            near[i][0] = false;
        // Last column
        m = near[0].Length - 1;
        for (int i = 0; i < near.Length; ++i)
            near[i][m] = false;
        return near;
    }
    private List<Hand> localizeHands(bool[][] valid)
    {
        int i, j, k;
        List<Hand> hands = new List<Hand>();
        List<PointFT> insidePoints = new List<PointFT>();
        List<PointFT> contourPoints = new List<PointFT>();

        bool[][] contour = new bool[valid.Length][];
        for (i = 0; i < valid.Length; ++i)
        {
            contour[i] = new bool[valid[0].Length];
        }
        // Divide points in contour and inside points
        int count = 0;
        for (i = 1; i < valid.Length - 1; ++i)
        {
            for (j = 1; j < valid[i].Length - 1; ++j)
            {
                if (valid[i][j])
                {
                    // Count the number of valid adjacent points
                    count = this.numValidPixelAdjacent(ref i, ref j, ref valid);
                    if (count == 4) // Inside
                    {
                        insidePoints.Add(new PointFT(i, j));
                    }
                    else // Contour
                    {
                        contour[i][j] = true;
                        contourPoints.Add(new PointFT(i, j));
                    }
                }
            }
        }
        // Create the sorted contour list, using the turtle algorithm
        for (i = 0; i < contourPoints.Count; ++i)
        {
            Hand hand = new Hand();
            // If it is a possible start point
            if(contour[contourPoints[i].X][contourPoints[i].Y]){
```

```
            // Calculate the contour
            hand.contour = CalculateFrontier(ref valid, contourPoints[i], ref contour);
            // Check if the contour is big enough to be a hand
            if (hand.contour.Count / (contourPoints.Count * 1.0f) > 0.20f
               && hand.contour.Count > settings.k)
            {
               // Calculate the container box
               hand.calculateContainerBox(settings.containerBoxReduction);
               // Add the hand to the list
               hands.Add(hand);
            }
            // Don't look for more hands, if we reach the limit
            if (hands.Count >= settings.maxTrackedHands)
            {
               break;
            }
         }
      }
      // Allocate the inside points to the correct hand using its container box
      //List<int> belongingHands = new List<int>();
      for (i = 0; i < insidePoints.Count; ++i)
      {
         for (j = 0; j < hands.Count; ++j)
         {
            if (hands[j].isPointInsideContainerBox(insidePoints[i]))
            {
               hands[j].inside.Add(insidePoints[i]);
               //belongingHands.Add(j);
            }
         }
         // A point can only belong to one hand, if not we don't take that point into account
         /*if (belongingHands.Count == 1)
         {
            hands[belongingHands.ElementAt(0)].inside.Add(insidePoints[i]);
         }
         belongingHands.Clear();*/
      }
      // Find the center of the palm
      float min, max, distance = 0;
      for (i = 0; i < hands.Count; ++i)
      {
         max = float.MinValue;
         for (j = 0; j < hands[i].inside.Count; j += settings.findCenterInsideJump)
         {
            min = float.MaxValue;
            for (k = 0; k < hands[i].contour.Count; k += settings.findCenterInsideJump)
            {
               distance = PointFT.distanceEuclidean(hands[i].inside[j], hands[i].contour[k]);
               if (!hands[i].isCircleInsideContainerBox(hands[i].inside[j], distance)) continue;
               if (distance < min) min = distance;
               if (min < max) break;
            }
            if (max < min && min != float.MaxValue)
```

```
            {
                max = min;
                hands[i].palm = hands[i].inside[j];
            }
        }
    }
    // Find the fingertips
    PointFT p1, p2, p3, pAux, r1, r2;
    int size;
    double angle;
    int jump;
    for (i = 0; i < hands.Count; ++i)
    {
        // Check if there is a point at the beginning to avoid checking the last ones of the list
        max = hands[i].contour.Count;
        size = hands[i].contour.Count;
        jump = (int) (size * settings.fingertipFindJumpPerc);
        for (j = 0; j < settings.k; j += 1)
        {
            p1 = hands[i].contour[(j - settings.k + size) % size];
            p2 = hands[i].contour[j];
            p3 = hands[i].contour[(j + settings.k) % size];
            r1 = p1 - p2;
            r2 = p3 - p2;

            angle = PointFT.angle(r1, r2);
            if (angle > 0 && angle < settings.theta)
            {
                pAux = p3 + ((p1 - p3) / 2);
                if (PointFT.distanceEuclideanSquared(pAux, hands[i].palm) >
                    PointFT.distanceEuclideanSquared(hands[i].contour[j], hands[i].palm))
                    continue;

                hands[i].fingertips.Add(hands[i].contour[j]);
                max = hands[i].contour.Count + j - jump;
                max = Math.Min(max, hands[i].contour.Count);
                j += jump;
                break;
            }
        }
        // Continue with the rest of the points
        for ( ; j < max; j += settings.findFingertipsJump)
        {
            p1 = hands[i].contour[(j - settings.k + size) % size];
            p2 = hands[i].contour[j];
            p3 = hands[i].contour[(j + settings.k) % size];
            r1 = p1 - p2;
            r2 = p3 - p2;

            angle = PointFT.angle(r1, r2);
            if (angle > 0 && angle < settings.theta)
            {
                pAux = p3 + ((p1 - p3) / 2);
```

```
            if (PointFT.distanceEuclideanSquared(pAux, hands[i].palm) >
               PointFT.distanceEuclideanSquared(hands[i].contour[j], hands[i].palm))
               continue;
            hands[i].fingertips.Add(hands[i].contour[j]);
            j += jump;
         }
      }
   }
   return hands;
}
/*
 * This function calcute the border of a closed figure starting in one of the contour points.
 * The turtle algorithm is used.
 */
private List<PointFT> CalculateFrontier(ref bool[][] valid, PointFT start, ref bool[][] contour)
{
   List<PointFT> list = new List<PointFT>();
   PointFT last = new PointFT(-1, -1);
   PointFT current = new PointFT(start);
   int dir = 0;
   do
   {
      if (valid[current.X][current.Y])
      {
         dir = (dir + 1) % 4;
         if (current != last)
         {
            list.Add(new PointFT(current.X, current.Y));
            last = new PointFT(current);
            contour[current.X][current.Y] = false;
         }
      }
      else
      {
         dir = (dir + 4 - 1) % 4;
      }
      switch (dir)
      {
         case 0: current.X += 1; break; // Down
         case 1: current.Y += 1; break; // Right
         case 2: current.X -= 1; break; // Up
         case 3: current.Y -= 1; break; // Left
      }
   } while (current != start);
   return list;
}
private bool[][] dilate(bool[][] image, int it)
{
   // Matrix to store the dilated image
   bool[][] dilateImage = new bool[image.Length][];
   for (int i = 0; i < image.Length; ++i)
   {
      dilateImage[i] = new bool[image[i].Length];
```

```
    }
    // Distances matrix
    int[][] distance = manhattanDistanceMatrix(image, true);
    // Dilate the image
    for (int i = 0; i < image.Length; i++)
    {
        for (int j = 0; j < image[i].Length; j++)
        {
            dilateImage[i][j] = ((distance[i][j] <= it) ? true : false);
        }
    }
    return dilateImage;
}
private bool[][] erode(bool[][] image, int it)
{
    // Matrix to store the dilated image
    bool[][] erodeImage = new bool[image.Length][];
    for (int i = 0; i < image.Length; ++i)
    {
        erodeImage[i] = new bool[image[i].Length];
    }
    // Distances matrix
    int[][] distance = manhattanDistanceMatrix(image, false);
    // Dilate the image
    for (int i = 0; i < image.Length; i++)
    {
        for (int j = 0; j < image[i].Length; j++)
        {
            erodeImage[i][j] = ((distance[i][j] > it) ? true : false);
        }
    }
    return erodeImage;
}
/// <summary>
///
/// </summary>
/// <param name="image"></param>
/// <param name="zeroDistanceValue"></param>
/// <returns></returns>
private int[][] manhattanDistanceMatrix(bool[][] image, bool zeroDistanceValue)
{
    int[][] distanceMatrix = new int[image.Length][];
    for (int i = 0; i < distanceMatrix.Length; ++i)
    {
        distanceMatrix[i] = new int[image[i].Length];
    }
    // traverse from top left to bottom right
    for (int i = 0; i < distanceMatrix.Length; i++)
    {
        for (int j = 0; j < distanceMatrix[i].Length; j++)
        {
            if ((image[i][j] && zeroDistanceValue) || (!image[i][j] && !zeroDistanceValue))
            {
```

```
                // first pass and pixel was on, it gets a zero
                distanceMatrix[i][j] = 0;
            }
            else
            {
                // pixel was off
                // It is at most the sum of the lengths of the array
                // away from a pixel that is on
                distanceMatrix[i][j] = image.Length + image[i].Length;
                // or one more than the pixel to the north
                if (i > 0) distanceMatrix[i][j] = Math.Min(distanceMatrix[i][j], distanceMatrix[i - 1][j] + 1);
                // or one more than the pixel to the west
                if (j > 0) distanceMatrix[i][j] = Math.Min(distanceMatrix[i][j], distanceMatrix[i][j - 1] + 1);
            }
        }
    }
    // traverse from bottom right to top left
    for (int i = distanceMatrix.Length - 1; i >= 0; i--)
    {
        for (int j = distanceMatrix[i].Length - 1; j >= 0; j--)
        {
            // either what we had on the first pass
            // or one more than the pixel to the south
            if (i + 1 < distanceMatrix.Length)
                distanceMatrix[i][j] = Math.Min(distanceMatrix[i][j], distanceMatrix[i + 1][j] + 1);
            // or one more than the pixel to the east
            if (j + 1 < distanceMatrix[i].Length)
                distanceMatrix[i][j] = Math.Min(distanceMatrix[i][j], distanceMatrix[i][j + 1] + 1);
        }
    }
    return distanceMatrix;
}
/*
 * Counts the number of adjacent valid points without taking into account the diagonals
 */
private int numValidPixelAdjacent(ref int i, ref int j, ref bool[][] valid)
{
    int count = 0;
    if (valid[i + 1][j]) ++count;
    if (valid[i - 1][j]) ++count;
    if (valid[i][j + 1]) ++count;
    if (valid[i][j - 1]) ++count;
    //if (valid[i + 1][j + 1]) ++count;
    //if (valid[i + 1][j - 1]) ++count;
    //if (valid[i - 1][j + 1]) ++count;
    //if (valid[i - 1][j - 1]) ++count;
    return count;
}
// Generate a representable image of the valid matrix
private byte[] generateDepthImage(bool[][] near)
{
    // Image pixels
    byte[] pixels = new byte[near.Length * near[0].Length * 4];
```

```
            int width = near[0].Length;

            for (int i = 1; i < near.Length - 1; ++i)
            {
                for (int j = 1; j < near[i].Length - 1; ++j)
                {
                    if (near[i][j]){

                        if (!near[i + 1][j] || !near[i - 1][j]
                        || !near[i][j + 1] || !near[i][j - 1]) // Is border
                        {
                            pixels[(i * width + j) * 4 + 0] = 255;
                            pixels[(i * width + j) * 4 + 1] = 0;
                            pixels[(i * width + j) * 4 + 2] = 0;
                            pixels[(i * width + j) * 4 + 3] = 0;
                        }
                        else
                        {
                            pixels[(i * width + j) * 4 + 0] = 255;
                            pixels[(i * width + j) * 4 + 1] = 255;
                            pixels[(i * width + j) * 4 + 2] = 255;
                            pixels[(i * width + j) * 4 + 3] = 0;
                        }
                    }
                }
            }
            return pixels;
        }
        public bool isConnected()
        {
            return connected;
        }
        public Bitmap getDepthImage()
        {
            return depthImage;
        }
        public Bitmap getColorImage()
        {
            return colorImage;
        }
    }
}
```

APPENDIX 6: Results of Finger Detection on PARM

For Lake District model, data of coordinates of each point from 50 participants are shown in **Table 1**. The distance data (**Table 2**) was calculated by substracting the attempted coordinate with the coordinate of the target points. It will show how far the coordinate of the finger touch deviated from the target points.

Data from the 50 participants on the UP Campus model is shown in **Table 3**, while data of distance were presented in **Table 4. Figure 1** to **Figure 8** presented the attempted finger-pointing coordinates and distance from target point from 50 participants on Lake District and Figure 9 to 5.32 for the UP Campus model.

Table 1. Coordinate data of finger detection on Lake District Model

No	A1		A2		A3		A4		B1		B2		B3		B4	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Attempt_1	205	58	149	52	134	81	52	126	226	46	178	92	120	46	68	118
Attempt_2	206	54	148	50	133	83	50	114	226	44	178	93	123	47	64	115
Attempt_3	206	48	148	51	132	79	48	115	223	43	178	91	123	48	64	117
Attempt_4	206	55	149	53	132	83	50	117	223	43	180	90	123	45	65	120
Attempt_5	203	55	149	53	133	79	49	121	225	43	177	91	120	45	67	114
Attempt_6	205	54	149	52	135	82	49	116	229	41	180	93	125	49	70	126
Attempt_7	206	52	149	51	136	84	57	123	226	45	179	91	120	46	73	121
Attempt_8	206	53	150	53	135	82	53	125	228	46	179	93	120	51	66	125
Attempt_9	206	63	151	63	134	93	51	130	229	51	179	103	122	56	67	132
Attempt_10	205	56	149	56	135	86	52	123	229	44	181	96	121	49	65	124
Attempt_11	204	59	151	56	135	83	50	122	231	46	182	94	121	51	60	119
Attempt_12	206	58	149	53	135	85	51	126	227	44	181	95	121	48	65	124
Attempt_13	208	60	151	56	136	87	50	126	228	46	182	94	121	51	67	126
Attempt_14	204	56	151	55	134	89	50	130	228	46	182	99	122	53	64	127
Attempt_15	206	57	144	55	134	86	52	129	230	46	181	97	122	53	62	122
Attempt_16	209	58	149	53	136	86	49	124	231	47	182	97	126	52	63	125
Attempt_17	209	57	150	58	136	86	48	120	230	46	183	97	122	52	66	126
Attempt_18	209	57	150	58	134	88	52	128	232	47	182	93	122	51	68	126
Attempt_19	208	57	148	56	136	87	54	126	230	44	182	97	121	50	65	125
Attempt_20	211	58	150	56	135	85	54	128	229	44	177	93	120	49	65	122
Attempt_21	206	53	147	56	133	85	310	223	228	47	181	98	122	51	70	124
Attempt_22	210	58	148	56	135	87	53	127	232	46	182	99	121	55	52	129
Attempt_23	209	60	152	56	135	85	54	128	228	46	181	96	119	50	63	123
Attempt_24	210	57	148	57	130	87	52	125	226	42	179	95	121	51	66	126
Attempt_25	210	56	151	56	134	86	53	122	231	44	178	92	120	49	63	119
Attempt_26	211	56	149	56	132	87	55	127	229	44	176	94	117	48	66	121
Attempt_27	210	55	151	52	134	87	54	125	225	47	179	96	121	51	68	125
Attempt_28	210	56	149	57	132	88	57	128	230	43	180	96	121	50	65	124
Attempt_29	210	56	150	52	135	85	51	128	227	47	179	89	121	49	62	119
Attempt_30	207	52	149	54	135	84	47	120	229	44	180	94	121	49	66	122
Attempt_31	203	42	149	54	135	84	49	122	227	45	180	92	117	48	68	123
Attempt_32	206	54	148	56	136	86	49	119	225	45	183	93	120	49	65	126
Attempt_33	210	59	151	54	135	86	54	127	230	45	182	96	119	48	66	126
Attempt_34	212	56	148	55	136	87	52	124	229	43	183	95	123	48	67	122
Attempt_35	207	56	148	53	133	86	52	126	227	40	182	96	120	49	68	122
Attempt_36	205	64	149	54	134	84	50	111	224	41	176	94	123	46	67	123
Attempt_37	211	58	149	55	133	81	52	122	229	42	181	95	123	49	64	119
Attempt_38	210	55	149	53	134	86	49	118	226	44	182	98	124	49	67	128
Attempt_39	198	53	147	57	135	85	53	130	232	44	182	97	123	48	67	124
Attempt_40	210	55	147	53	133	83	49	122	224	42	176	92	123	43	58	109
Attempt_41	206	51	152	52	136	83	55	121	227	47	180	96	123	48	66	121
Attempt_42	209	53	149	54	135	85	57	123	231	46	182	96	122	47	66	122
Attempt_43	208	57	147	55	134	86	316	223	229	43	180	97	123	49	61	119
Attempt_44	206	56	149	53	132	86	48	123	228	44	228	44	121	48	65	124
Attempt_45	210	52	149	55	136	87	53	124	229	45	174	96	120	51	63	124
Attempt_46	207	57	148	57	131	87	52	127	229	44	181	98	123	50	67	126
Attempt_47	207	56	151	53	134	85	52	125	229	44	178	95	120	49	62	118
Attempt_48	214	8	145	48	132	86	50	121	225	38	180	93	122	47	67	117
Attempt_49	220	182	148	51	133	86	50	122	229	42	180	96	121	50	65	124
Attempt_50	200	59	146	54	129	87	62	127	222	46	179	89	115	96	69	126

Table 2. Distance of finger detection from target point on Lake District Model. Point A represent the high surfaces/objects and point B represent the low surfaces

No	Point A1	Point A2	Point A3	Point A4	Point B1	Point B2	Point B3	Point B4
Attempt_1	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
Attempt_2	2.56	1.38	2.46	1.46	1.36	2.17	2.32	1.54
Attempt_3	2.50	1.65	1.46	1.54	1.36	1.63	2.58	1.96
Attempt_4	1.21	2.17	2.50	0.77	1.36	1.46	1.82	2.58
Attempt_5	1.38	2.17	1.38	0.98	1.12	1.65	1.63	0.86
Attempt_6	2.19	1.90	2.19	1.15	0.98	2.24	3.04	4.11
Attempt_7	0.81	1.63	2.77	1.74	1.63	1.65	1.90	3.04
Attempt_8	1.36	2.19	2.19	1.65	1.98	2.19	3.26	3.84
Attempt_9	3.53	4.92	5.16	3.00	3.36	4.89	4.65	5.71
Attempt_10	0.86	2.99	3.27	1.09	1.58	3.10	2.73	3.62
Attempt_11	0.27	3.04	2.46	0.98	2.34	2.67	3.27	3.07
Attempt_12	0.38	2.17	3.00	1.92	1.38	2.83	2.46	3.62
Attempt_13	0.61	3.04	3.57	1.98	1.98	2.67	3.27	4.08
Attempt_14	0.61	2.77	4.07	3.04	1.98	3.95	3.84	4.48
Attempt_15	0.86	3.04	3.26	2.72	2.19	3.36	3.84	3.40
Attempt_16	0.86	2.17	3.30	1.58	2.56	3.43	3.89	4.04
Attempt_17	1.12	3.54	3.30	1.12	2.19	3.53	3.57	4.11
Attempt_18	1.38	3.54	3.80	2.44	2.72	2.43	3.30	4.07
Attempt_19	1.65	3.00	3.57	1.98	1.74	3.43	3.00	3.89
Attempt_20	1.92	3.00	3.00	2.50	1.58	2.19	2.72	3.10
Attempt_21	3.27	3.04	3.00	2.19	2.24	3.62	3.30	3.57
Attempt_22	3.27	3.00	3.54	2.19	2.50	3.95	4.35	6.54
Attempt_23	0.61	3.10	3.00	2.50	1.98	3.10	3.00	3.53
Attempt_24	1.46	3.27	3.69	1.63	0.81	2.73	3.27	4.11
Attempt_25	1.46	3.04	3.26	0.86	1.92	1.90	2.72	2.56
Attempt_26	1.72	2.99	3.57	2.32	1.58	2.50	2.58	2.77
Attempt_27	1.82	1.98	3.53	1.72	2.19	3.00	3.27	3.80
Attempt_28	1.82	3.26	3.84	2.80	1.54	3.04	3.00	3.62
Attempt_29	2.58	1.92	3.00	2.46	2.19	1.12	2.73	2.72
Attempt_30	2.58	2.44	2.73	1.38	1.58	2.50	2.73	3.04
Attempt_31	1.21	2.44	2.73	1.15	1.65	1.98	2.58	3.26
Attempt_32	1.96	3.00	3.30	0.81	1.65	2.56	2.72	4.15
Attempt_33	1.96	2.50	3.27	2.24	1.96	3.18	2.46	4.11
Attempt_34	2.19	2.73	3.57	1.36	1.36	3.04	2.58	3.00
Attempt_35	2.67	2.19	3.27	1.90	0.38	3.18	2.72	2.99
Attempt_36	1.38	2.44	2.72	2.24	0.77	2.50	2.07	3.27
Attempt_37	1.74	2.72	1.92	0.81	1.15	2.83	2.83	2.43
Attempt_38	1.74	2.17	3.26	0.86	1.36	3.69	2.92	4.62
Attempt_39	1.74	3.30	3.00	3.00	2.12	3.43	2.58	3.54
Attempt_40	1.92	2.24	2.46	1.15	0.98	1.98	1.36	2.77
Attempt_41	1.92	2.07	2.50	0.98	2.19	3.04	2.58	2.77
Attempt_42	1.92	2.44	3.00	1.74	2.34	3.18	2.24	3.04
Attempt_43	2.12	2.77	3.26	1.54	1.36	3.30	2.83	2.89
Attempt_44	2.34	2.17	3.30	1.54	1.46	3.30	2.46	3.62
Attempt_45	2.56	2.72	3.57	1.38	1.82	3.18	3.26	3.78
Attempt_46	2.12	3.27	3.62	2.17	1.58	3.62	3.10	4.08
Attempt_47	2.50	2.24	2.99	1.63	1.58	2.72	2.72	2.50
Attempt_48	2.50	1.36	3.30	0.77	0.38	2.24	2.24	1.65
Attempt_49	0.00	1.65	3.27	0.98	1.15	3.04	3.00	3.62
Attempt_50	2.34	2.58	3.78	3.48	2.19	1.12	3.00	4.08
Average Distance	1.75	2.58	3.08	1.75	1.70	2.76	2.84	3.39

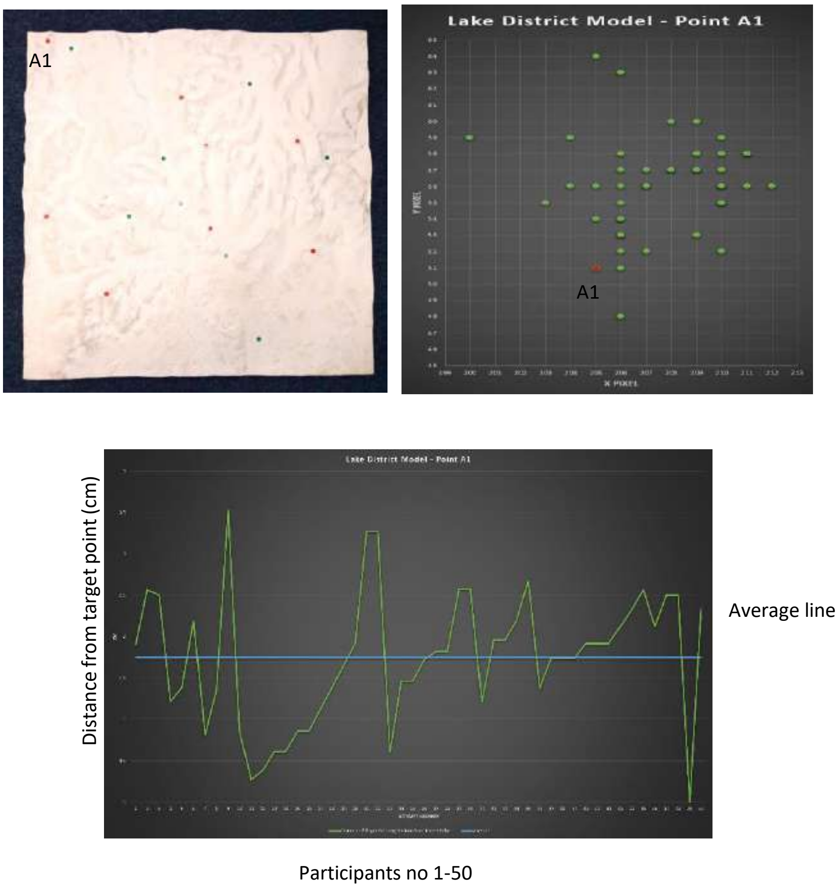


Figure 1. A1 point finger-touch experiment on Lake District model. The A1 target point location on the model (top-left). The top-right picture shows the A1 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted points of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance of 1.75 cm. It can be seen that most of the attempted points are located on the top-right position of the target point because the Kinect sensor was positioned above the centre of the model.

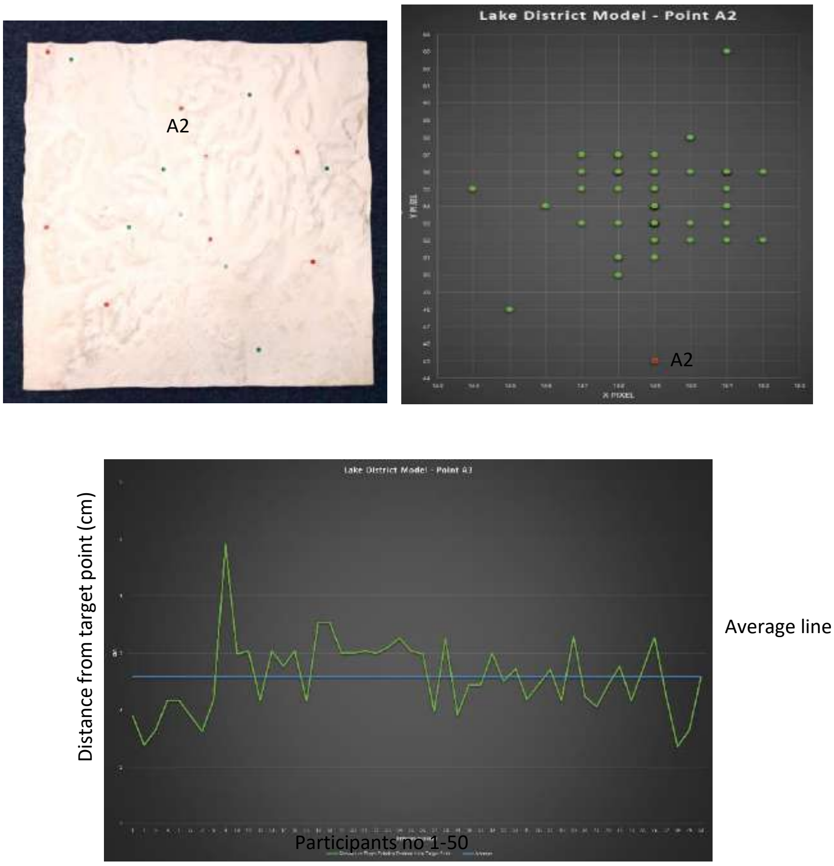


Figure 2. A2 point finger-touch experiment on Lake District model. The A2 target point location on the model (top-left). The top-right picture shows the A2 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted point of 50 participants and the y-axis is the distance from target point in centimetres. The blue line shows the average distance 2.58 cm. It can be seen that most of the attempted points are located on the top position of the target point because the Kinect sensor was positioned above the centre of the model.

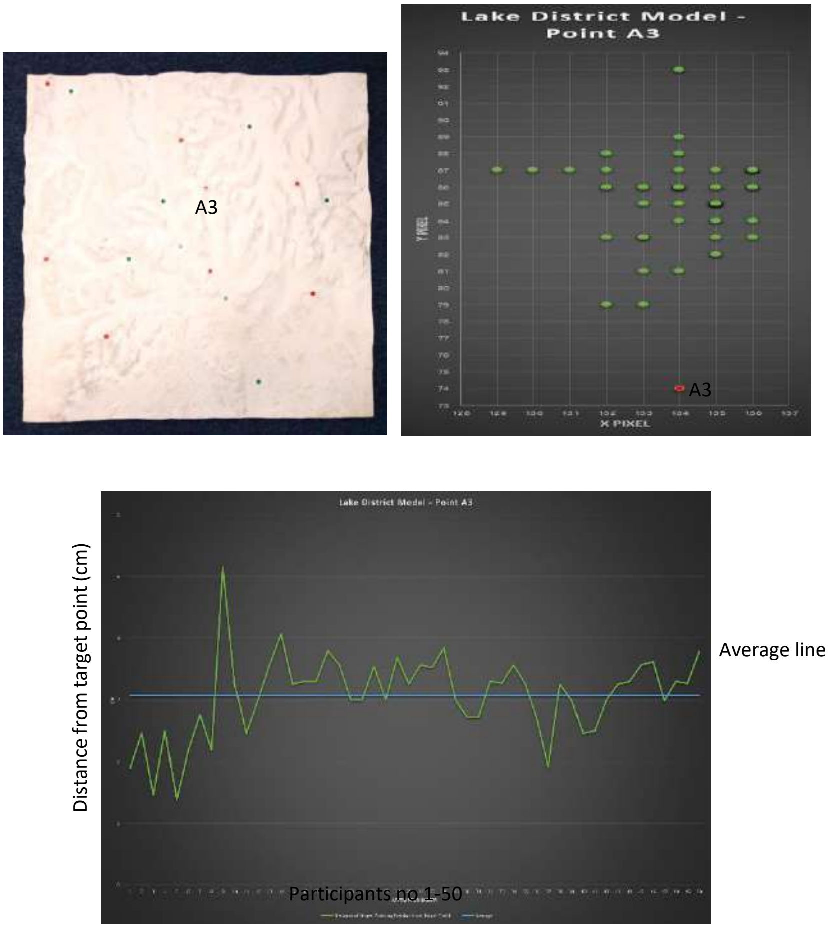


Figure 3. A3 point finger-touch experiment on Lake District model. The A3 target point location on the model (top-left). The top-right picture shows the A3 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted point of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 3.08 cm. It can be seen that most of the attempted points are located at the top position of the target point because the Kinect sensor was positioned above the centre of the model.

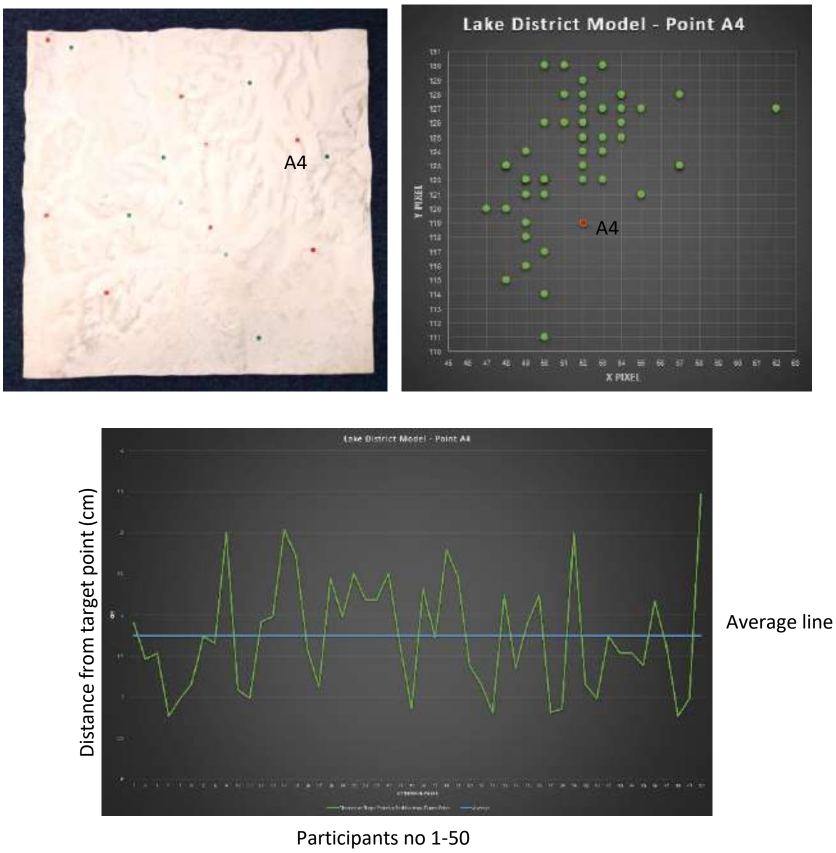


Figure 4. A4 point finger-touch experiment on Lake District . The A4 target point location on the model (top-left). The top-right picture shows the A4 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted point of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 1.75 cm. It can be seen that most of the attempted points were located on the top-left position of the target point because the Kinect sensor was positioned above the centre of the model.

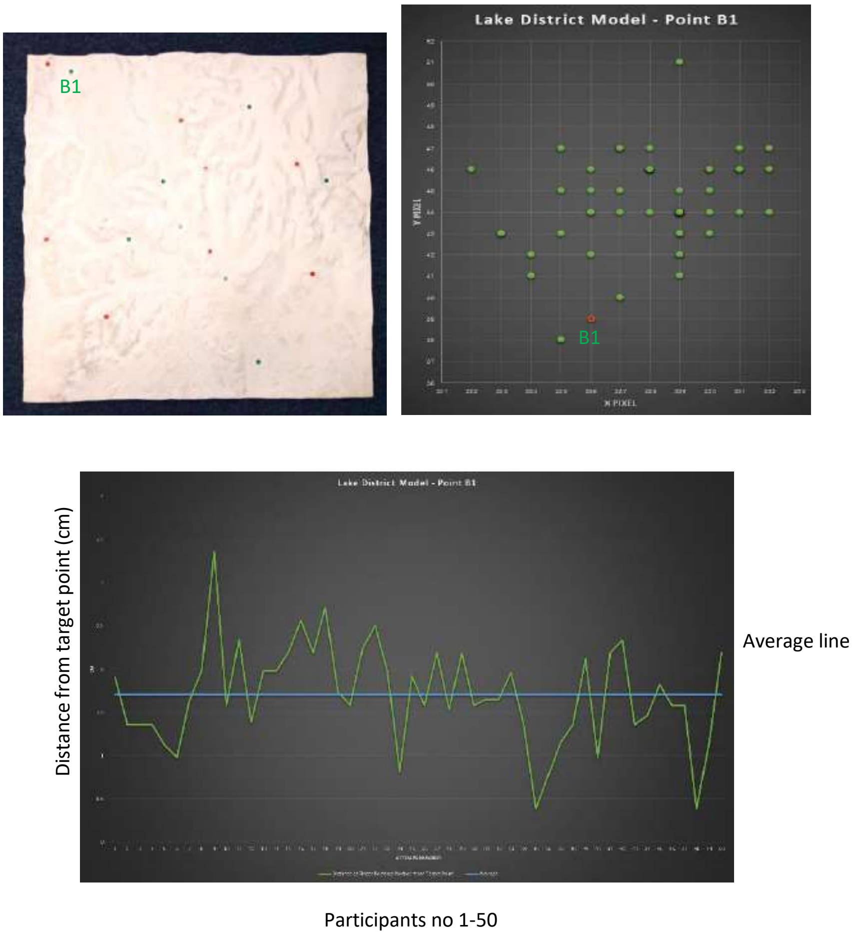
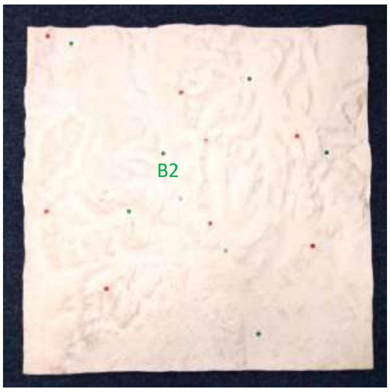
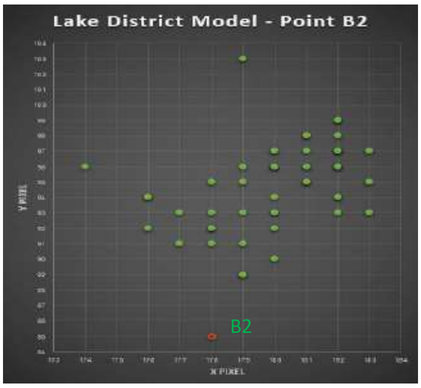
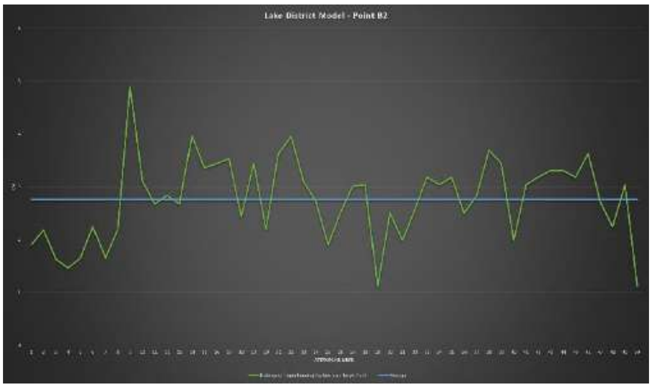


Figure 5. B1 point finger-touch experiment on Lake District model. The B1 target point location on the model (top-left). The top-right picture shows the B1 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted point of 50 participants and the y-axis as the distance from the target point in centimetres. The blue line shows the average distance 1.70 cm. It can be seen that most of the attempted points were located to the top-right of the target point because the Kinect sensor was positioned above the centre of the model.





Distance from target point (cm)



Average line

Participants no 1-50

Figure 6. B2 point finger-touch experiment on Lake District model**. T**he B2 target point location on the model (top-left). The top-right picture shows the B2 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted points of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 1.70 cm. It can be seen that most of the attempted points are located at the top position of the target point because the Kinect sensor position is located above the centre of the model.

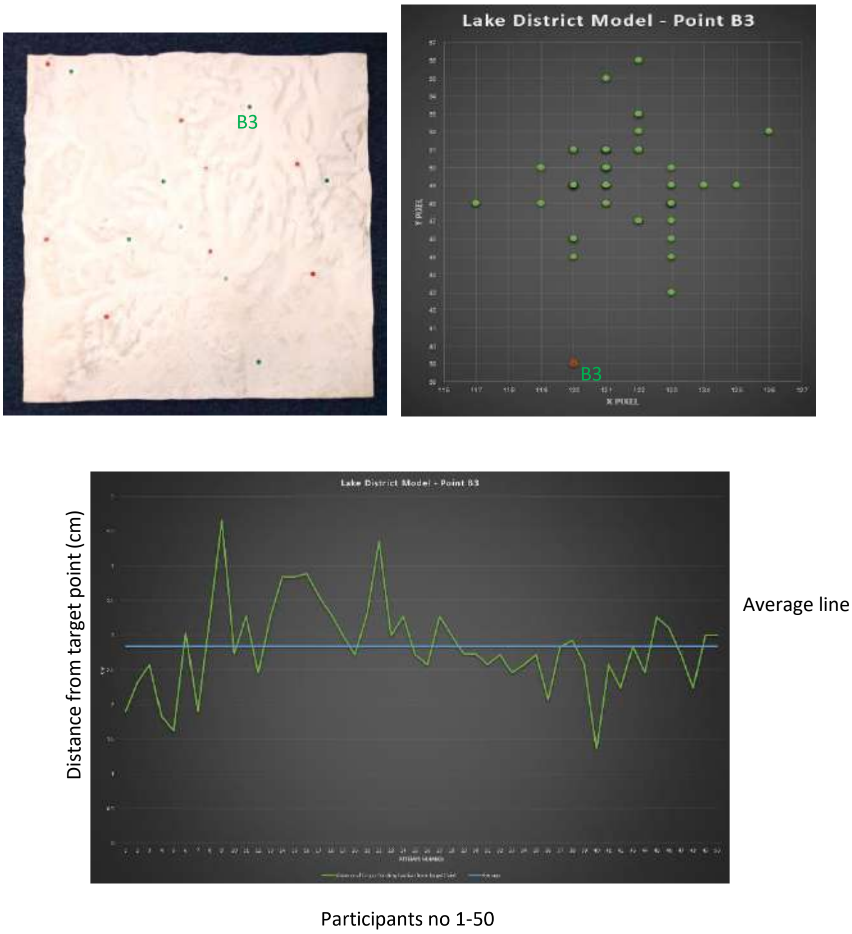


Figure 7. B3 point finger-touch experiment on Lake District model**. T**he B3 target point of finger detection on the Lake District model. The B3 target point location on the model (top-left). The top-right picture shows the B3 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The X-axis represents the attempted point of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 2.84 cm. It can be seen that most of the attempted points are located at the top position of the target point because the Kinect sensor position is located above the centre of the model.

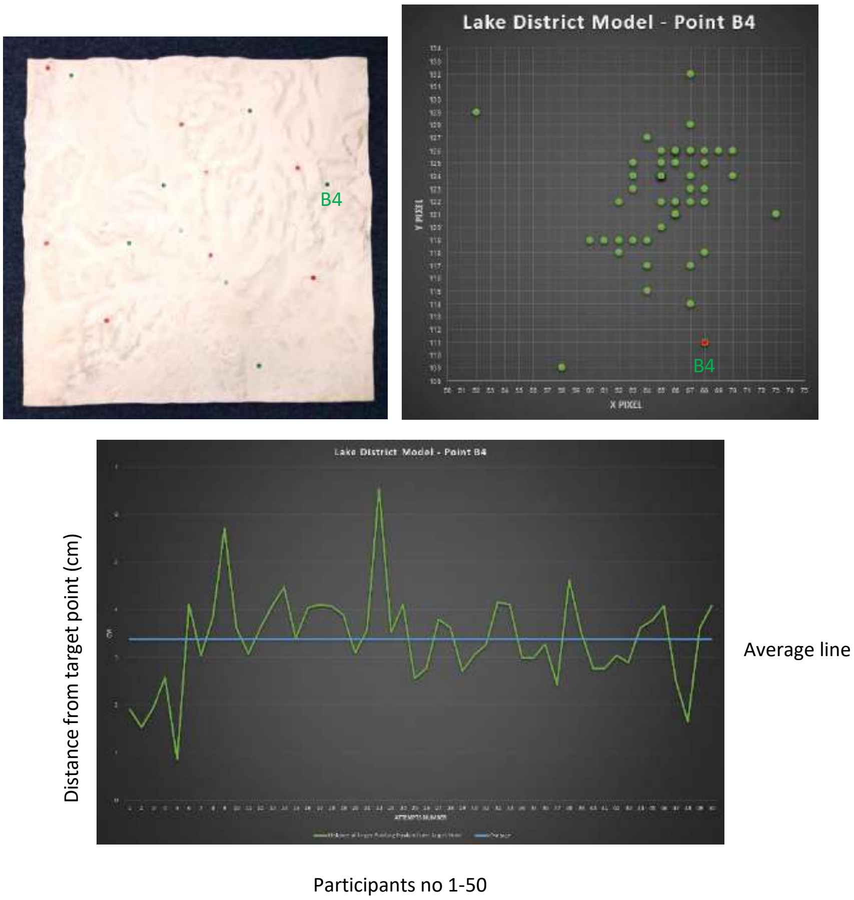


Figure 8. B4 point finger-touch experiment on Lake District model. The B4 target point location on the Lake District model (top-left). The top-right picture shows the B4 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted points of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 3.39 cm. It can be seen that most of the attempted points are located in the top-left position of the target point because the Kinect sensor was positioned above the centre of the model.

Table 3. Coordinate data of finger detection on UP Campus Model

No	Point A1		Point A2		Point A3		Point A4		Point B1		Point B2		Point B3		Point B4	
	x2	y2	x2	y2	x2	y2	x2	y2	x2	y2	x2	y2	x2	y2	x2	y2
attempt_1	220	182	210	162	182	134	87	179	183	111	156	174	140	131	83	140
attempt_2	223	185	207	163	179	137	87	179	180	111	157	174	138	131	83	140
attempt_3	222	186	206	161	180	135	87	178	184	111	156	178	137	133	82	142
attempt_4	219	185	207	162	181	135	84	171	182	111	151	181	137	131	82	139
attempt_5	222	189	211	160	181	137	87	176	178	113	158	177	138	133	81	142
attempt_6	208	188	203	157	184	136	82	181	181	106	158	181	141	132	83	137
attempt_7	220	185	213	164	181	138	85	182	187	116	159	181	138	129	82	141
attempt_8	223	185	208	161	181	139	85	181	187	117	161	180	139	133	83	143
attempt_9	203	210	209	162	209	162	84	179	182	140	160	179	140	128	85	142
attempt_10	175	239	209	160	180	136	83	179	187	113	159	178	136	130	83	140
attempt_11	194	202	209	159	182	137	79	178	184	113	159	178	135	129	80	139
attempt_12	222	187	207	169	138	131	83	177	187	112	158	178	137	130	80	136
attempt_13	222	188	213	162	186	139	82	179	185	122	155	179	137	127	81	138
attempt_14	223	185	207	162	181	136	71	207	184	111	157	179	138	129	80	141
attempt_15	216	186	206	159	185	139	85	178	184	115	155	181	137	130	82	136
attempt_16	199	207	209	162	183	138	84	179	183	120	157	179	137	129	80	139
attempt_17	195	202	205	168	183	136	86	177	183	119	157	187	137	135	81	147
attempt_18	216	192	210	163	184	135	80	175	184	115	158	184	137	129	84	139
attempt_19	219	191	213	163	184	139	82	181	187	115	153	181	137	130	81	144
attempt_20	221	187	208	164	182	146	79	171	187	112	156	182	135	127	80	138
attempt_21	220	181	207	158	183	133	78	179	187	113	155	175	137	130	79	143
attempt_22	215	186	204	165	180	139	78	173	186	111	155	180	137	126	80	138
attempt_23	218	190	208	158	180	137	79	181	188	108	155	178	138	129	81	142
attempt_24	214	188	315	226	183	139	80	178	183	124	152	179	137	124	78	136
attempt_25	209	200	207	157	182	137	82	176	184	111	157	181	138	127	76	152
attempt_26	215	189	206	157	179	139	80	180	187	112	158	178	138	129	82	137
attempt_27	217	186	209	160	184	138	87	176	188	110	158	179	135	126	82	136
attempt_28	214	186	207	158	185	137	84	177	184	113	160	179	137	126	76	139
attempt_29	216	188	206	164	181	132	78	178	187	110	157	178	138	128	78	140
attempt_30	222	186	209	158	187	135	80	179	181	113	155	180	138	123	76	134
attempt_31	224	183	209	156	185	125	76	164	183	111	160	170	135	123	74	134
attempt_32	225	184	210	161	179	141	85	167	182	134	157	186	137	132	85	142
attempt_33	224	187	211	165	179	136	80	184	186	115	152	181	138	127	80	134
attempt_34	221	189	209	159	182	138	79	175	191	112	157	178	137	128	84	138
attempt_35	218	190	208	158	180	138	77	182	185	108	157	178	136	125	77	136
attempt_36	219	184	209	159	184	133	81	175	185	111	156	181	134	124	80	137
attempt_37	207	197	209	159	183	141	83	171	185	108	158	183	137	128	80	137
attempt_38	214	186	209	159	183	142	81	175	177	116	160	179	135	124	79	140
attempt_39	219	185	209	159	181	138	80	175	185	113	156	178	138	126	81	138
attempt_40	225	185	210	158	179	137	77	179	184	107	155	182	135	123	79	135
attempt_41	226	182	209	159	182	139	78	172	185	118	159	182	134	121	76	135
attempt_42	222	185	215	157	183	136	85	171	185	109	156	174	134	126	78	134
attempt_43	222	185	210	158	182	136	79	175	188	112	160	177	83	137	85	136
attempt_44	221	192	209	163	179	134	78	177	189	112	157	176	136	125	82	143
attempt_45	219	191	212	159	182	134	83	178	187	110	159	178	137	125	83	138
attempt_46	220	193	215	162	183	134	83	183	186	110	155	179	131	129	77	140
attempt_47	217	193	217	162	181	137	86	181	188	110	155	182	138	126	83	138
attempt_48	220	192	210	160	183	135	80	186	185	111	157	181	139	128	81	137
attempt_49	218	191	212	160	183	133	81	177	181	123	158	175	137	124	81	148
attempt_50	226	189	211	161	184	136	83	177	187	110	158	178	138	126	80	142

Table 4. Distance of finger detection from target point on UP Campus Model

No	Point A1	Point A2	Point A3	Point A4	Point B1	Point B2	Point B3	Point B4
Attempt_1	1.90	1.90	1.90	1.90	1.90	1.90	1.90	2.17
Attempt_2	2.83	2.32	2.83	1.90	2.07	1.92	1.98	2.17
Attempt_3	3.04	1.96	2.24	1.63	1.92	2.99	2.58	2.73
Attempt_4	2.73	2.07	2.19	0.86	1.92	4.04	2.07	1.92
Attempt_5	3.84	1.38	2.73	1.09	2.80	2.77	2.50	2.77
Attempt_6	4.80	1.98	2.50	2.80	0.77	3.84	2.19	1.36
Attempt_7	2.72	2.58	3.00	2.77	3.43	3.89	1.46	2.46
Attempt_8	2.83	1.72	3.27	2.50	3.69	3.78	2.46	2.99
Attempt_9	10.56	1.92	3.27	2.07	3.54	3.43	1.09	2.77
Attempt_10	10.56	1.38	2.50	2.19	2.67	3.10	1.96	2.17
Attempt_11	10.18	1.12	2.72	2.72	2.46	3.10	1.92	2.07
Attempt_12	3.30	3.89	2.72	1.74	2.43	3.04	1.82	1.36
Attempt_13	3.57	2.07	3.43	2.34	4.92	3.27	1.15	1.72
Attempt_14	2.83	2.07	2.46	2.34	1.92	3.27	1.46	2.58
Attempt_15	3.18	1.54	3.36	1.72	3.00	3.81	1.82	1.12
Attempt_16	10.39	1.92	3.00	2.07	4.34	3.27	1.58	2.07
Attempt_17	9.99	3.78	2.46	1.38	4.07	5.44	3.10	4.11
Attempt_18	4.74	2.17	2.24	2.07	3.00	4.65	1.58	1.92
Attempt_19	4.35	2.32	3.30	2.80	3.18	3.89	1.82	3.30
Attempt_20	3.27	2.50	5.16	2.19	2.43	4.07	1.58	1.82
Attempt_21	1.63	1.15	1.65	3.10	2.67	2.19	1.82	3.18
Attempt_22	3.28	3.17	3.30	2.46	2.07	3.54	0.98	1.82
Attempt_23	4.11	0.98	2.77	3.27	1.74	3.00	1.46	2.77
Attempt_24	3.89	0.98	3.27	2.50	5.43	3.43	0.81	1.74
Attempt_25	7.42	0.98	2.72	1.74	1.92	3.81	0.98	2.19
Attempt_26	4.04	1.21	3.36	2.89	2.43	3.04	1.46	1.38
Attempt_27	3.10	1.38	3.04	1.09	2.12	3.30	1.46	1.12
Attempt_28	3.40	1.15	2.83	1.58	2.46	3.43	0.98	2.69
Attempt_29	3.69	2.67	1.38	2.94	1.96	3.00	1.21	2.56
Attempt_30	3.04	0.86	2.56	2.69	2.50	3.54	0.61	1.98
Attempt_31	2.43	0.38	0.98	3.69	1.90	1.36	1.38	2.50
Attempt_32	2.80	1.63	3.89	1.46	1.92	5.17	2.32	2.77
Attempt_33	3.43	2.73	2.58	3.77	3.10	3.95	0.98	0.98
Attempt_34	3.81	1.12	2.99	2.32	3.07	3.00	1.36	1.65
Attempt_35	4.11	0.98	3.04	3.84	1.21	3.00	1.12	1.96
Attempt_36	2.46	1.12	1.72	1.82	1.98	3.80	1.63	1.58
Attempt_37	6.94	1.12	3.81	1.12	1.21	4.38	1.36	1.58
Attempt_38	3.40	1.12	4.08	1.82	3.64	3.43	1.36	2.43
Attempt_39	2.73	1.12	3.00	2.07	2.50	2.99	0.77	1.72
Attempt_40	3.04	0.81	2.83	3.31	0.86	4.08	1.38	1.36
Attempt_41	2.50	1.12	3.26	2.44	3.84	4.15	1.82	2.07
Attempt_42	2.77	1.46	2.46	0.61	1.46	1.90	1.72	1.46
Attempt_43	2.77	0.81	2.44	2.32	2.56	2.92	1.72	1.21
Attempt_44	4.62	2.19	2.07	2.80	2.72	2.46	1.12	3.00
Attempt_45	4.35	1.21	1.90	1.96	1.96	3.10	0.86	1.63
Attempt_46	4.89	2.34	1.92	3.18	1.82	3.27	2.80	2.72
Attempt_47	4.95	2.69	2.73	2.46	2.12	4.08	0.77	1.63
Attempt_48	4.62	1.36	2.19	4.25	1.98	3.81	1.12	1.46
Attempt_49	4.38	1.46	1.65	2.12	5.19	2.24	0.81	4.38
Attempt_50	4.14	1.65	2.50	1.74	1.96	3.04	0.77	2.83
Average Distance	4.29	1.71	2.72	2.29	2.58	3.36	1.54	2.16

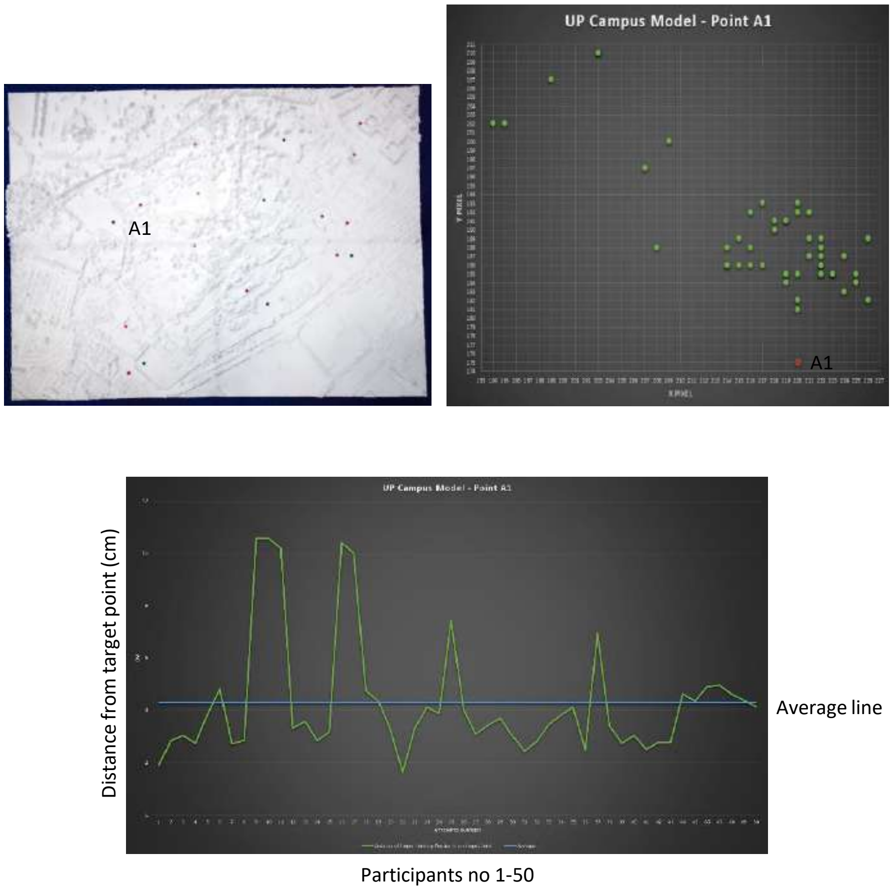


Figure 9. A1 point finger-touch experiment on UP Campus model. The A1 target point location on the UP Campus model (top-left). The top-right picture shows the A1 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. x-axis represent the attempted point of 50 participants and the y-axis is the distance from target point in centimetres. The blue line shows the average distance 4.29 cm. It can be seen that most of the attempted points are located in the top-left position of the target point because the Kinect sensor was positioned above the centre of the model.

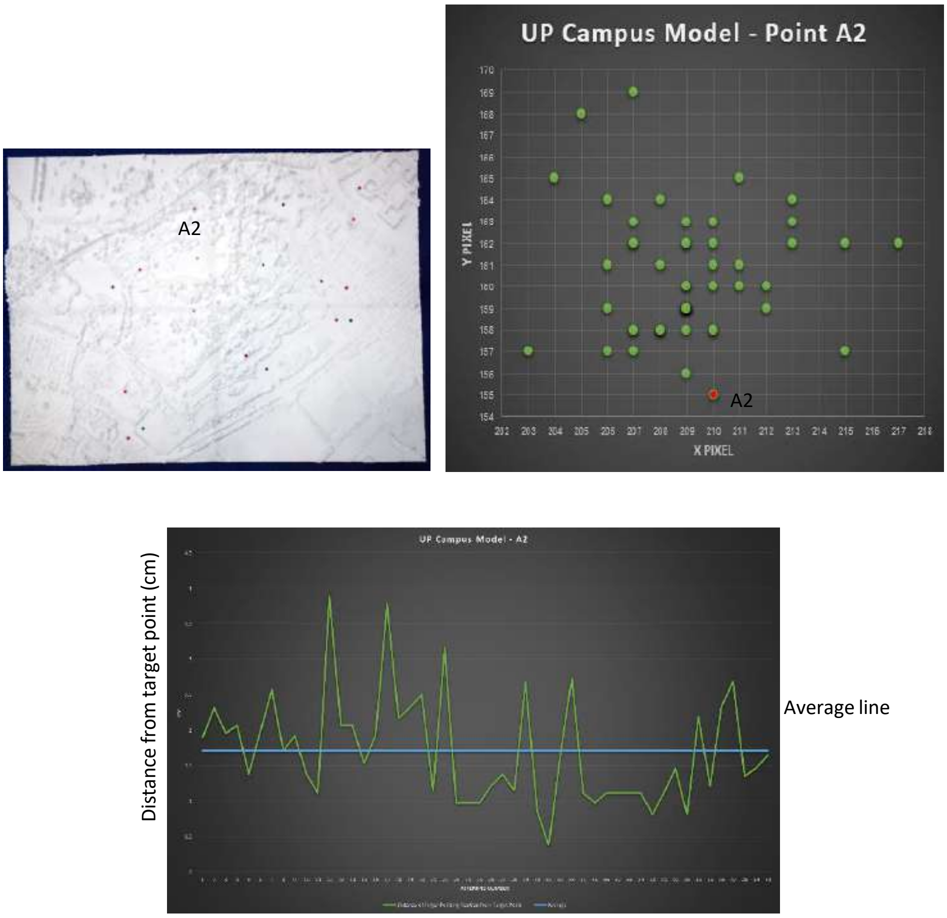


Figure 10. A2 point finger-touch experiment on UP Campus model. The A2 target point location on the UP Campus model (top-left). The top-right picture shows the A2 (red dot) target point and the location of the attempted target points by the 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted points of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 1.71 cm. It can be seen that most of the attempted points were located on the top position of the target point because the Kinect sensor was positioned above the centre of the model.

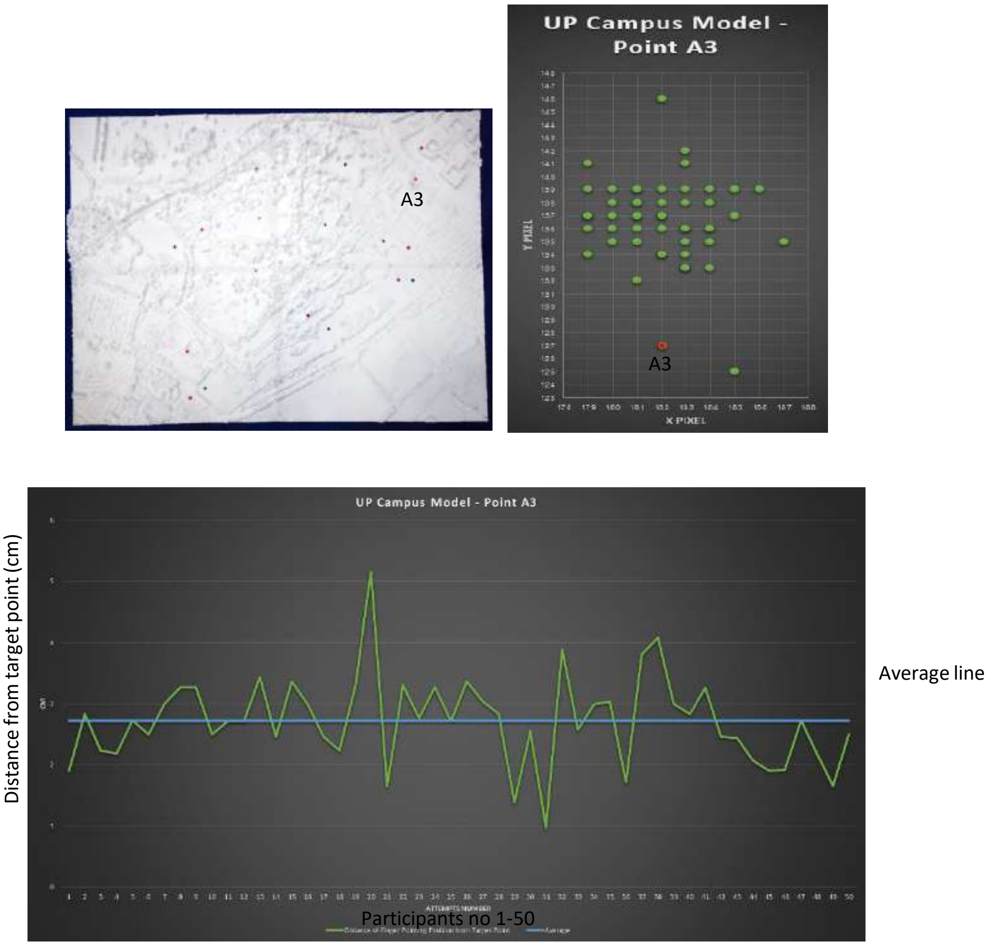


Figure 11. A3 point finger-touch experiment on UP Campus model**. T**he A3 target point location on the UP Campus model (top-left). The top-right picture shows the A3 (red dot) target point and the location of the attempted target points by the 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted points of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 2.72 cm. It can be seen that most of the attempted points were located on the top left position of the target point because the Kinect sensor was positioned above the centre of the model.

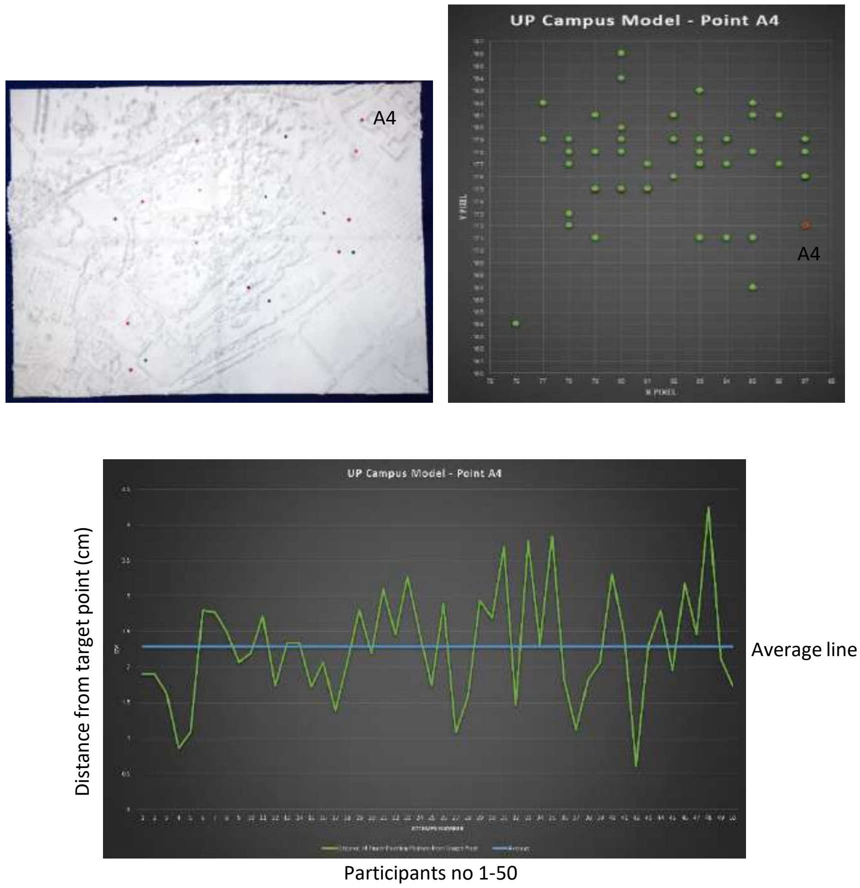
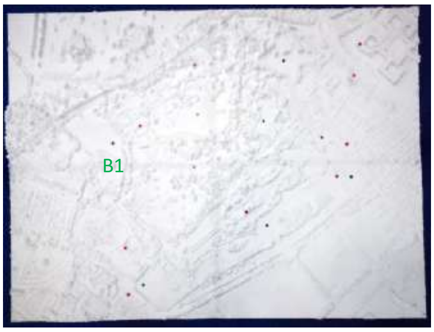
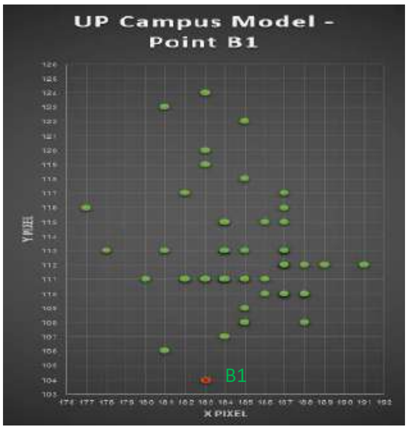


Figure 12. A4 point finger-touch experiment on UP Campus model**. T**he A4 target point location on the UP Campus model (top-left). The top-right picture shows the A4 (red dot) target point and the location of attempted target points by the 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted points of 50 participants and the y-axis is the distance from target points in centimetres. The blue line shows the average distance 2.29 cm. It can be seen that most of the attempted points were located on the top-left position of the target point because the Kinect sensor was positioned above the centre of the model.





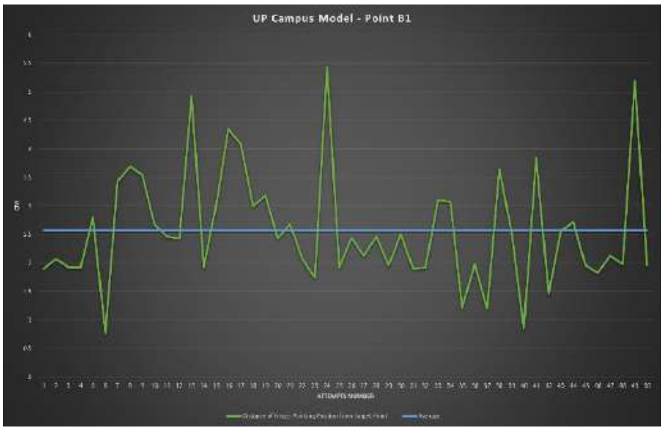


Figure 13. B1 point finger-touch experiment on UP Campus model. The B1 target point location on the UP Campus model (top-left). The top-right picture shows the B1 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted point of 50 participants and y-axis is the distance from the target point in centimetres. The blue line shows the average distance 2.58 cm. It can be seen that most of the attempted points are located in the top-left position of the target point because the Kinect sensor was positioned above the centre of the model.

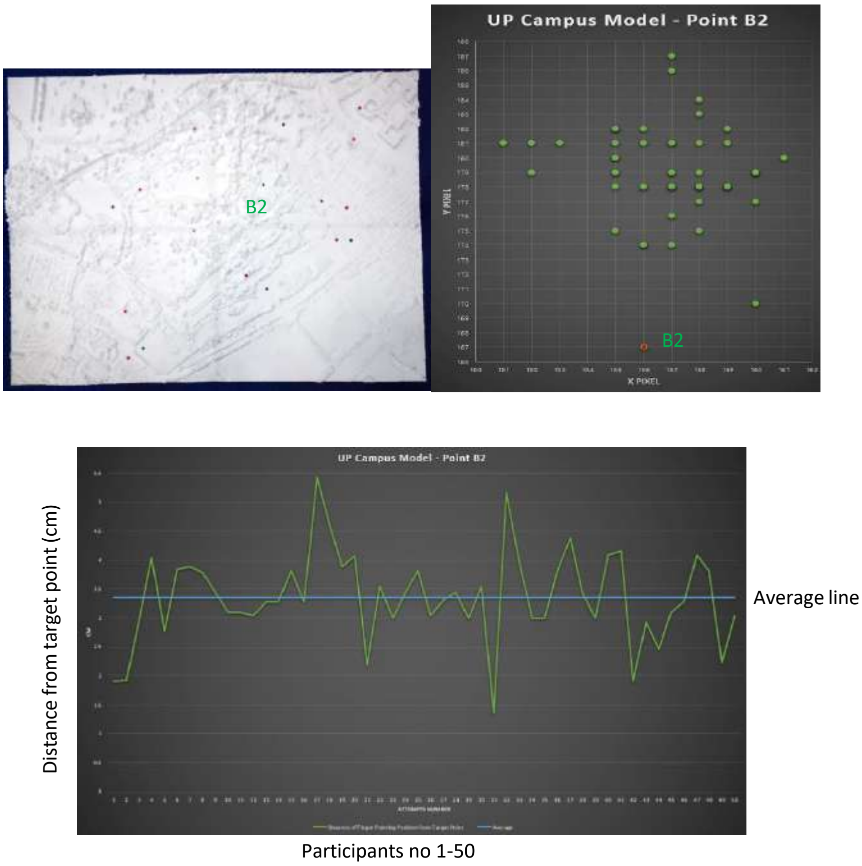


Figure 14. B2 point finger-touch experiment on UP Campus model**. T**he B2 target point location on the UP Campus model (top-left). The top-right picture shows the B2 (red dot) target point and the location of attempted target points by 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted points of 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average 3.36 cm. It can be seen that most of the attempted points were located on the top position of the target point because the Kinect sensor was positioned above the centre of the model.

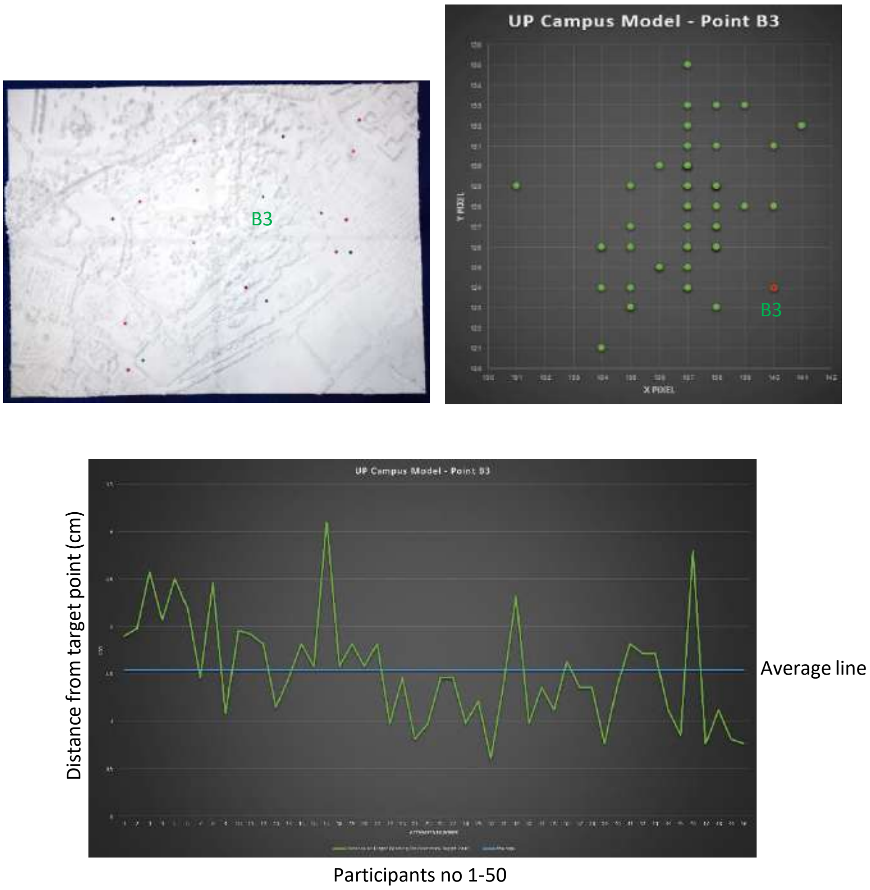


Figure 15. B3 point finger-touch experiment on UP Campus model. The B3 target point location on the UP Campus model (top-left). The top-right picture shows the B3 (red dot) target point and the location of the attempted target points by the 50 participants (green dots). The picture on the bottom shows the distance of attempted points from the target point. The x-axis represents the attempted points of the 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 1.54 cm. It can be seen that most of the attempted points were located on the top-left position of the target point because the Kinect sensor was positioned above the centre of the model.

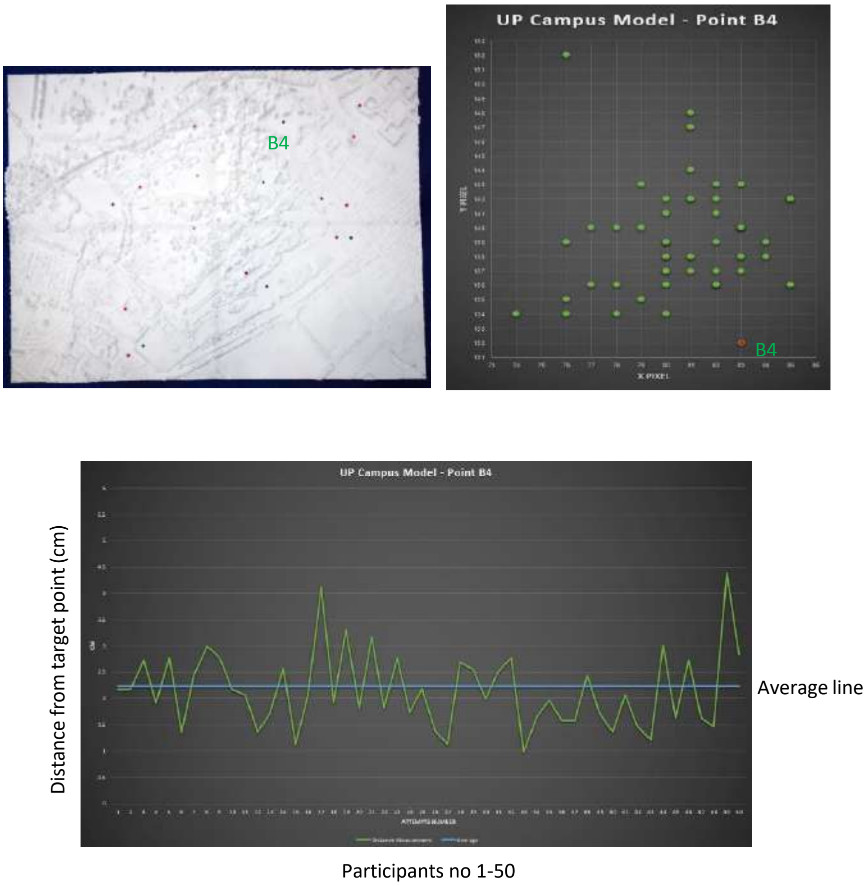


Figure 16. B4 point finger-touch experiment on UP Campus mode. The B4 target point location on the UP Campus model (top-left). The top-right picture shows the B4 (red dot) target point and the location of the attempted target points by the 50 participants (green dots). The picture on the bottom shows the distance of the attempted points from the target point. The x-axis represents the attempted points of the 50 participants and the y-axis is the distance from the target point in centimetres. The blue line shows the average distance 2.16 cm. It can be seen that most of the attempted points were located on the top-left position of the target point because the Kinect sensor was positioned above the centre of the model.

Appendix 8: The libraries of the Frantracerkinectft

BuildProcessTemplates/DefaultTemplate.11.1.xaml

BuildProcessTemplates/LabDefaultTemplate.11.xaml

BuildProcessTemplates/UpgradeTemplate.xaml

FingerTracking/FingerTracking.sln

FingerTracking/FingerTracking.vssscc

FingerTracking/FingerTracking/ClassDiagram1.cd

FingerTracking/FingerTracking/FingerTracking.csproj

FingerTracking/FingerTracking/FingerTracking.csproj.vspscc

FingerTracking/FingerTracking/Hand.cs

FingerTracking/FingerTracking/KinectSettings.cs

FingerTracking/FingerTracking/KinectTracker.cs

FingerTracking/FingerTracking/MainWindow.Designer.cs

FingerTracking/FingerTracking/MainWindow.cs

FingerTracking/FingerTracking/MainWindow.resx

FingerTracking/FingerTracking/PointFT.cs

FingerTracking/FingerTracking/Program.cs

FingerTracking/FingerTracking/Properties/AssemblyInfo.cs

FingerTracking/FingerTracking/Properties/Resources.Designer.cs

FingerTracking/FingerTracking/Properties/Resources.resx

FingerTracking/FingerTracking/Properties/Settings.Designer.cs

FingerTracking/FingerTracking/Properties/Settings.settings

FingerTracking/FingerTracking/Vector3FT.cs

FingerTracki2.9 ng/FingerTracking/Win32.cs